User Manual

Flowel 4 Development and Marketing

Emerson Process Management

Emerson Project 3007536
Rev 0
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1 Introduction

1.1 Typographic Conventions

The information we have provided in this manual will be easier to understand if you familiarize yourself with the following conventions:

1. Menu names, commands, and functions generally begin with capital letters and are bolded. For example, **File** menu, **Open Tag**, and **Help**.
2. Information you are to type in is usually in `Courier` font.

For example, if the instruction in the material name field says to type in “`Steel`“, you would enter only the letters between the quotation marks, not the quotation marks themselves.

1.2 Customer Service

For customer service on Flowel 4® and other Emerson products, please contact us at:

Emerson Process Management
Hydrocarbon and Energy Industry Center
7175 - 12th Street SE
Calgary, Alberta
Canada
T2H 2S6
e-mail: flowelsoftware@emersonprocess.com
T +1(403) 258-6234
F +1(403) 258-6201
Website: http://www.flowel.com/

When you call in for support, please be ready to provide the customer service representative with the name of the application and version you are calling about, as well as your **customer service number**. Your customer service number is located on the inside of the Flowel binder’s front cover. Other useful information to have handy includes the error message that appears, the type of computer you are using, the type of operating system, the hard disk drive space available, and the names of any other programs you may have running.

1.3 Version 4 Features

Flowel 4 is built on a new modern platform that is compatible with current versions of Microsoft Windows.

1.3.1 Network Installation

Flowel's new network installation provides several benefits to the purchaser.

First, the number of copies can be tailored to the number of simultaneous users. If a company or office has 10 Flowel users, but only three are using the program at any one time, then only three licenses are needed. The network version will keep track of the number of users and allow only the licensed maximum. If someone else needs to use the program, he/she will obtain a list of the logged-in users and then request that one of the users log out.

Second, the network version will provide a centralized database. This means that all members of a project team will be able to access all of the jobs and tags. Flowel 4 will allow administrators to use a variety of security settings depending on each user's job, tag, and/or group requirement.

Refer to Section 1.8 Network Server Installation for network installation instructions.

1.3.2 Standards and Calculations

New standards and calculations implemented include:

- ISO 5167 (2003) (orifice meters, nozzles, and venturi tubes)
- ASME MFC 14M (2003) (small bore precision orifice meters)
- AGA 10 (natural gas thermodynamic properties)
- expanded fluid database
- orifice plate thickness (AGA-3 2000)
- permanent pressure loss can be specified when sizing a restriction orifice
- support for all major flow calculation standards including:
  - AGA 3 (1985 and1992)
  - ISO 5167 (1981, 1991, and 2003)
  - ISO TR 15377
  - BS 1042
  - ASME MFC 3M, 7M, 14M
- flow rate uncertainty calculations as per ISO 5168
- basic fluid property options

1.3.3 Convenience Features

Flowel 4 convenience features include:

- easy migration of data in Flowel 3.0g to Flowel 4
- portable document format (PDF) of specification sheets for easy viewing, emailing and archiving; this provides several additional printing options, such as printing on A4 paper
- creation and archiving of specification sheets for pressure, differential pressure, and temperature elements is available
- enhanced job and tag management
- standard Microsoft Windows interface
- improved compatibility with new operating systems
- graphical user interface (GUI), which simplifies operation and limits user entry errors
- help system in PDF format

1.3.4 Optional Package

The Fluid Property Calculator is an optional package that is available. It includes a more extensive set of fluids and methods for determining viscosity, isentropic exponent, vapor pressure, and bubblepoint as well as additional tools for density calculation. The features of these options are:

- Density Methods ─ Soave-Redlich-Kwong, Peng-Robinson, Lee-Kessler, and various NBS methods
- Viscosity Methods ─ IAPS (1975) Viscosity Eqn. (water/steam only) and Lucas Viscosity Eqn. (gases only)
- Isentropic Exponent Methods ─ Ideal Gas Heat Capacity Ratio, Real Gas with Redlich-Kwong Correction, Real Gas with Lee-Kessler Correction, and AGA 10
- Vapor Pressure Method ─ Antoine
- Bubblepoint Methods ─ Soave-Redlich-Kwong and Peng-Robinson

1.4 Design Philosophy

1.4.1 We Listen to Our Customers

All of our products are the result of a collaborative effort between us, the developers, and you, our customers. We present the following design notes as a statement of our objectives for Flowel. We welcome your feedback regarding our goals and/or our success in achieving these goals.

1.4.2 Include Visual Cues for all Actions

We include visual cues for all actions. For example, in the calculation dialog box, we could have automatically computed the result, but feedback from our users indicates that most prefer to actually tell the program to calculate; otherwise, users have to contend with frequent delays whenever an auto calculation occurs.

1.4.3 Only Show Applicable Options

Flowel can handle thousands of different combinations of devices, fluids, and methods, but the program makes decisions easier by showing only applicable choices.

For example:

- Flowel supports over 600 pure fluids, plus any number of user-defined mixtures. To limit the number of fluids presented to the user, we categorize fluids by types.
- In the calculation dialog box, you are presented with a list of flow sizing methods. The content of that list depends upon your previous choices of fluid state, fluid type, and flow element.

1.4.4 Present Mandatory Choices First

In Flowel, each decision affects subsequent options, so Flowel presents choices in their proper sequence.

For example, instrument engineers do not generally choose the process fluid, so fluid-related choices are made first; then, the meter run is selected, and finally, the actual size is chosen.

1.5 Recommended Hardware/Software Requirements

The following configuration is the minimum recommended hardware/software required for Flowel 4:

- 266 MHz processor
- 32 MB RAM
- 120 MB free disk space
- Windows ME, NT, 2000, XP, or XP Pro
- CD-ROM drive (required only for installation from CD-ROM)

1.6 Basic Installation Procedure

Flowel 4 uses a standard Windows InstallShield to install the components of the program. Double-click the *Flowel_Setup.exe* program to initiate installation. There are four components to the installed program:

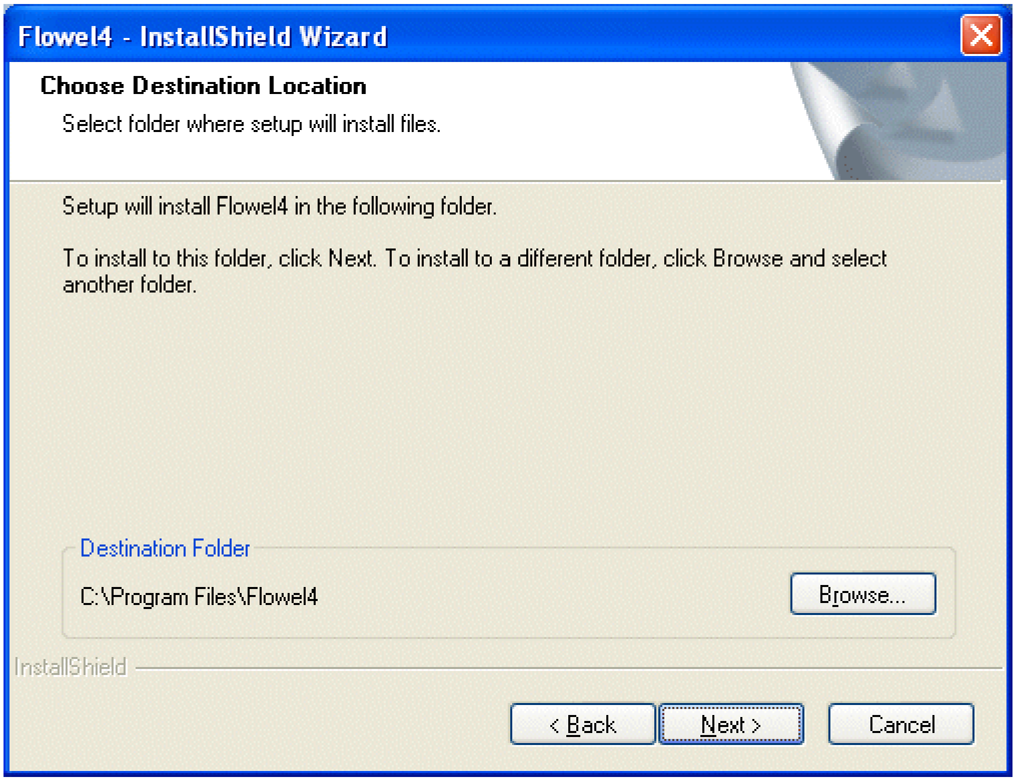
- Flowel calculation modules
- MySQL database
- GNU – Ghostscript for producing PDF files
- CrypKey copy protection

We recommend that users allow the above programs to install in the default directory. This will make program re-installations easier, if this becomes necessary. For a network server installation, additional steps follow the basic installation; see Section 1.8 Network Server Installation for those.

To install Flowel 4, do the following:

1. Navigate to and double-click the *Setup_Flowel4.exe* file.
2. The Flowel 4 InstallShield Wizard dialog box will appear, as shown in Figure 1-1 below.

Figure 1-1 Basic Installation



Flowel4 - InstallShield Wizard

Choose Destination Location

Select folder where setup will install files.

Setup will install Flowel4 in the following folder.

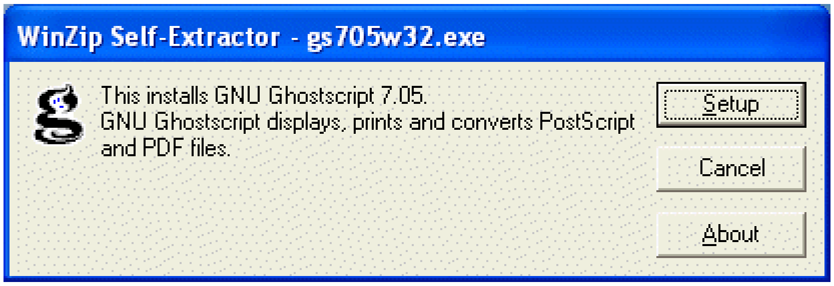
To install to this folder, click Next. To install to a different folder, click Browse and select another folder.

Destination Folder

C:\Program Files\Flowel4

3. Click **Next**. Review the license agreement and click **I accept** to continue the installation.
4. Click **Next,** and continue to follow the InstallShield Wizard instructions to install Flowel.
5. Use all default values, including destination folder locations, directories, etc.
6. The GNU Ghostscript prompt will appear within this process, as shown in Figure 1-2.

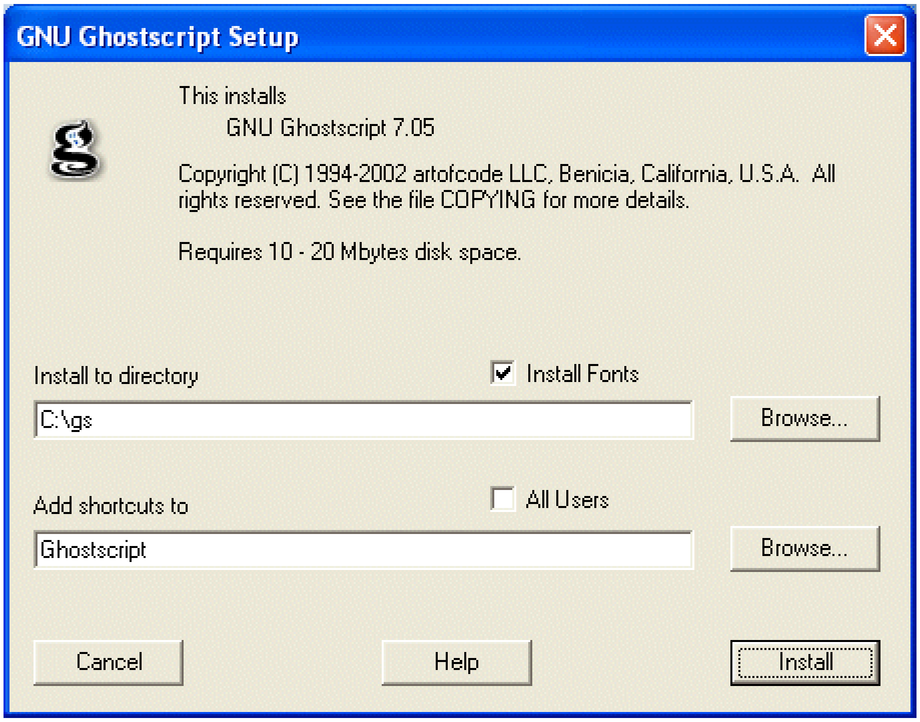
Figure 1-2 GNU Ghostscript



This installs GNU Ghostscript 7.05.
GNU Ghostscript displays, prints and converts PostScript and PDF files.

7. Click **Setup**.
8. Use the default values provided, and click **Install** (as shown in Figure 1-3).

Figure 1-3 Ghostscript Setup



This installs
GNU Ghostscript 7.05

Copyright (C) 1994-2002 artofcode LLC, Benicia, California, U.S.A. All rights reserved. See the file COPYING for more details.

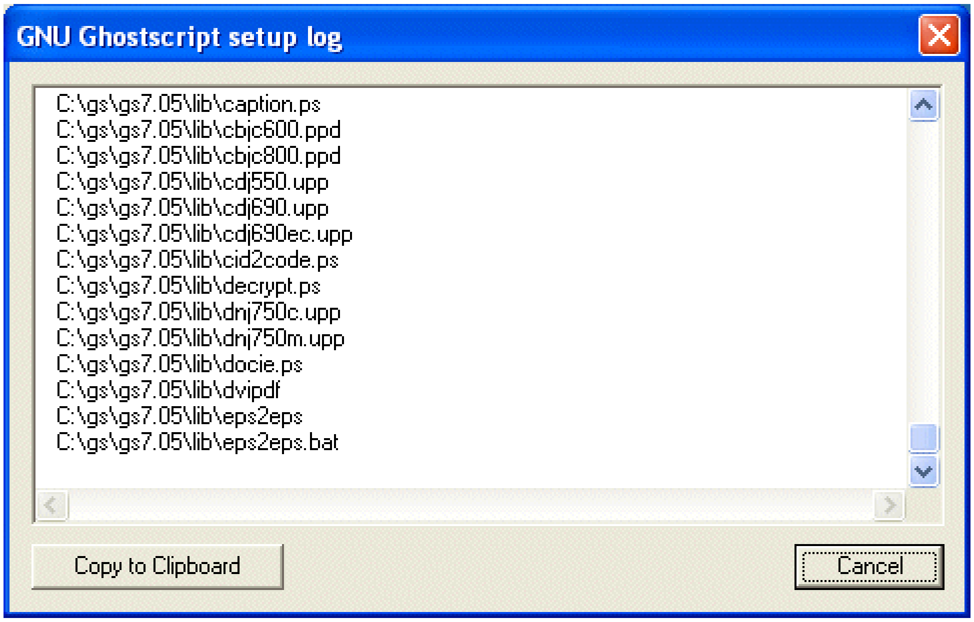
Requires 10 - 20 Mbytes disk space.

Install to directory ☑ Install Fonts
C:\gs

Add shortcuts to ☐ All Users
Ghostscript

9. Wait as Ghostscript performs the setup.

Figure 1-4 Ghostscript Setup Log



```
C:\gs\gs7.05\lib\caption.ps
C:\gs\gs7.05\lib\cbjc600.ppd
C:\gs\gs7.05\lib\cbjc800.ppd
C:\gs\gs7.05\lib\cdj550.upp
C:\gs\gs7.05\lib\cdj690.upp
C:\gs\gs7.05\lib\cdj690ec.upp
C:\gs\gs7.05\lib\cid2code.ps
C:\gs\gs7.05\lib\decrypt.ps
C:\gs\gs7.05\lib\dnj750c.upp
C:\gs\gs7.05\lib\dnj750m.upp
C:\gs\gs7.05\lib\docie.ps
C:\gs\gs7.05\lib\dvipdf
C:\gs\gs7.05\lib\eps2eps
C:\gs\gs7.05\lib\eps2eps.bat
```

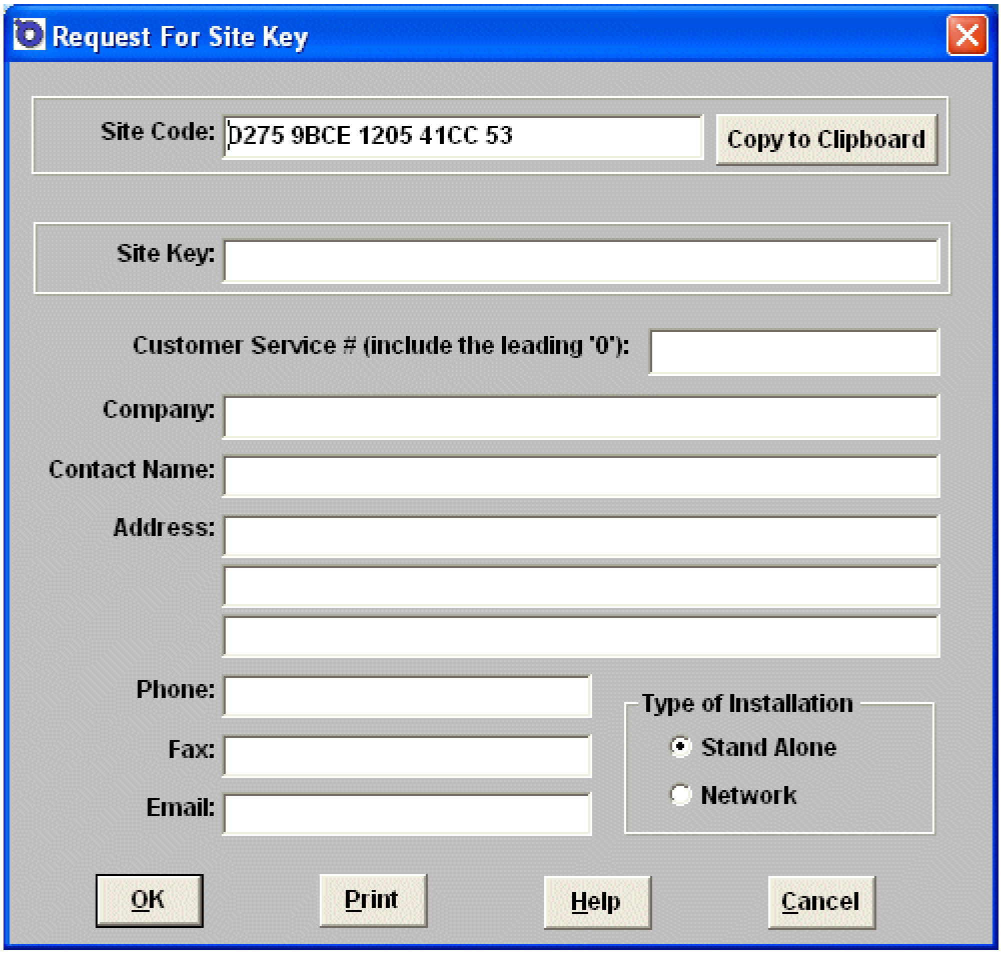
Ensure that the installation completes. The final dialogue box will require the user to click **Finish**. Note that this final dialog box may be hidden due to the installation procedure, and the user may have to minimize other windows to finish the installation.

1.6.1.1 Site Authorization

Once the program is installed, you will need to obtain a site key. To obtain a site key, start Flowel. To do so, select **Flowel** from the **Start** menu, under **Programs**, or double-click the Flowel desktop icon.

The first time you open Flowel, a dialog box will appear with the following options: Get New Authorization or Transfer Authorization. If this is a new installation, select **Get New Authorization**, and the Site Key Request form will appear.

Figure 1-5 Site Key Request Form



Site Code: 0275 9BCE 1205 41CC 53

Type of Installation
● Stand Alone
○ Network

When the site authorization form appears, print the form and fax it to the Hydrocarbon and Energy Industry Center at +1(403) 258-6201. When you receive the site key, enter this into the site key field and click **OK**. You will then be authorized to use Flowel 4.

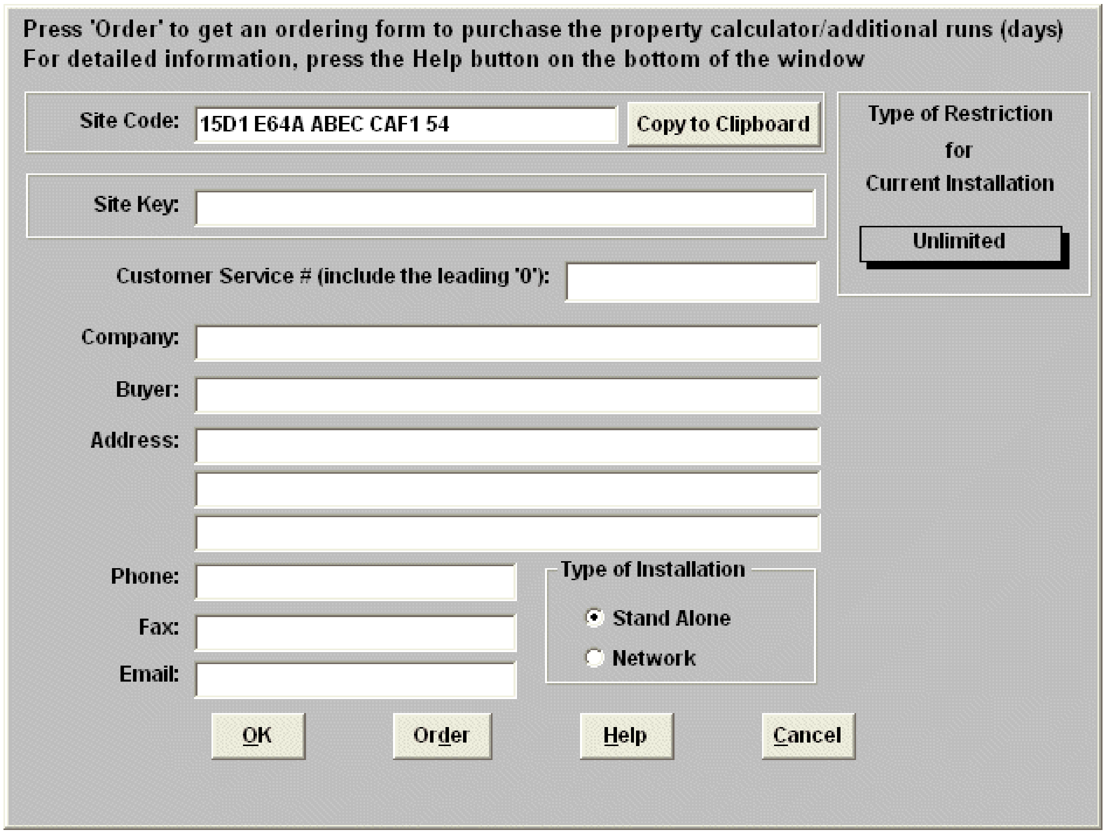
1.6.2 Changing Licensing

To change the licensing of Flowel, (e.g., from basic to a network option), do the following:

1. Open Flowel.
2. Under the **Help** menu, click **Optional Ordering**.
3. As with the basic installation procedure, fill in the Request for Site Key form and print and fax it to Hydrocarbon and Energy at +1 (403) 258-6201.
4. When you receive the new site key, enter the number into the site key form (under **Help**, **Optional Ordering**) and click **OK**.

5. Under the **Help** menu, click **Optional Ordering** again. Note the box on the right side of the form, which will identify the **Type of Restrictions for the Current Installation** (as shown in Figure 1-6).

Figure 1-6 Type of Restriction for Current Installation



Press 'Order' to get an ordering form to purchase the property calculator/additional runs (days)
For detailed information, press the Help button on the bottom of the window

Site Code: 15D1 E64A ABEC CAF1 54

Type of Restriction for Current Installation: Unlimited

Type of Installation: ● Stand Alone ○ Network

1.7 Upgrading from an Earlier Version

Before starting an upgrade, please review the following points.

The upgrade has been designed for a standard installation of Flowel 4. If you require customized modifications to the Flowel setup, please contact Emerson before starting your upgrade.

- When upgrading a network copy of Flowel, you will be required to upgrade the server first and then all of the workstations.
- Stop running all copies of the Flowel program. You will be unable to upgrade to Flowel 4 if Flowel 3.0g is running.

- Backup/copy your database. The name of the Flowel 3.0g database is *Flowel.db*. This file should be in your Flowel folder on the server. Please contact Emerson if *Flowel.db* is not in the Flowel folder.
- Back up all old Flowel databases created or named with an extension other than db.

1.8 Network Server Installation

In order to run Flowel 4 over a network, several additional steps are required. Once the server computer is selected and the basic installation procedure is complete, the following steps must be followed.

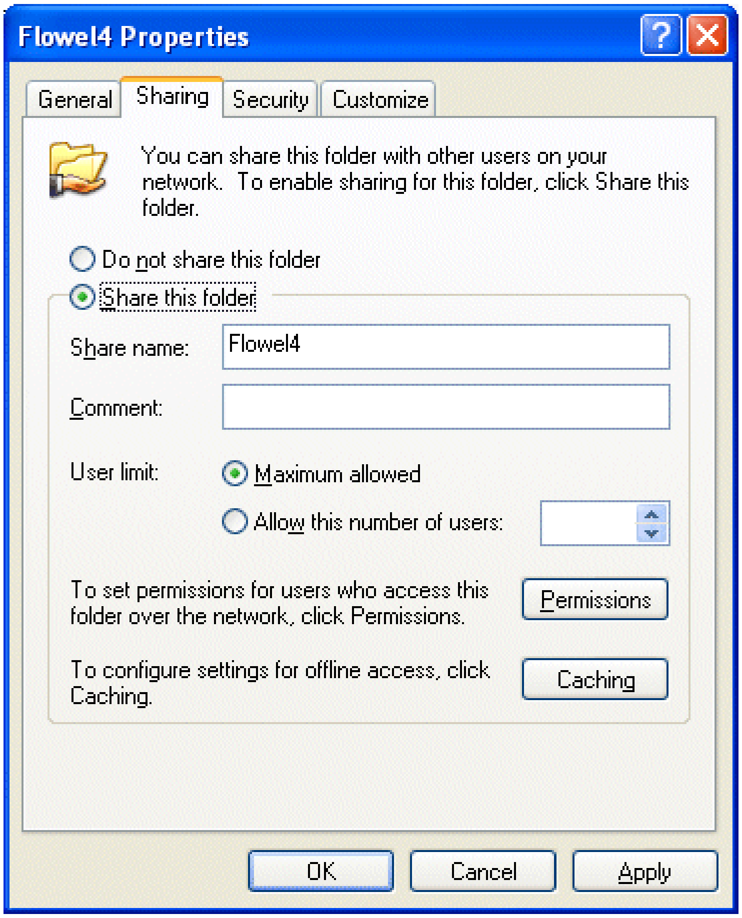
Note: These installation instructions cover the basic procedure. If you have difficulties, please call our support line.

To install Flowel 4 over a network, do the following:

1. Select the computer that will be the Flowel host (server).
   This computer needs to be on and connected to the network when Flowel will be used. Client computers must have full read/write/modify privileges to the Flowel folders; therefore, it is recommended that the person installing Flowel have administration privileges on the server.
2. Allow full control/change/read/write access to the folder where *Flowel.exe* is located (usually under *C:/Program Files/Flowel/*).

   To allow full control, do the following:
   (a) Navigate to *C:/Program Files/Flowel/*.
   (b) Right-click on the *Flowel4* folder.
   (c) Click **Properties**.

Figure 1-7 Flowel 4 Folder Properties



You can share this folder with other users on your network. To enable sharing for this folder, click Share this folder.

○ Do not share this folder

● Share this folder

Share name: Flowel4

Comment:

User limit: ● Maximum allowed

○ Allow this number of users:

To set permissions for users who access this folder over the network, click Permissions.

To configure settings for offline access, click Caching.

(d) Click the **Sharing** tab, and click **Share this folder** (as shown in Figure 1-7 above).

(e) Click the **Permissions** button.

(f) Select the **Allow** checkbox for **Full Control**, and click **OK**.

(g) Click **OK** to close.

(h) Similarly, follow the steps above to allow full control to the folder *C:/Program Files/MySQL/data/.*

1.9 Client Setup

Once Flowel has been installed, you will now have to configure the client(s). To configure each client, do the following at each computer:

1. Copy *Flowel_Client.msi* onto the clients computer.
2. Double-click *Flowel_Client.msi*.
3. The MyODBC Setup window appears, as shown in Figure 1-8.

Figure 1-8 MyODBC Setup

Welcome to the MyODBC Installation Wizard

It is strongly recommended that you exit all Windows programs before running this setup program.

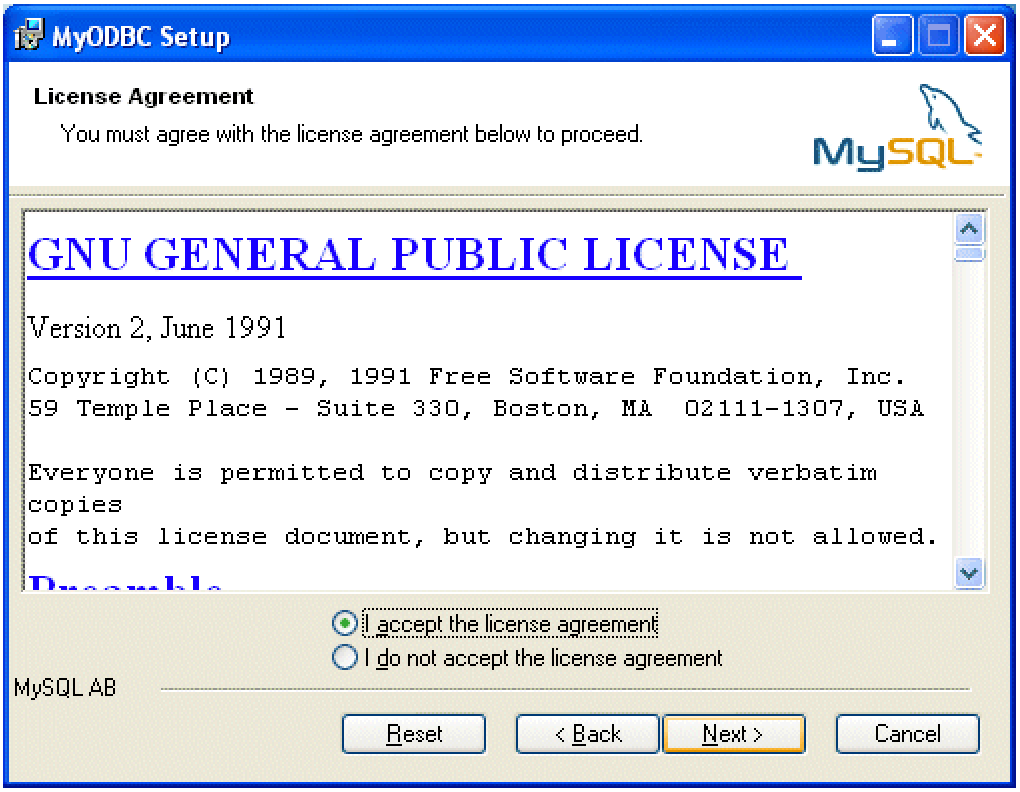
Click Cancel to quit the setup program, then close any programs you have running. Click Next to continue the installation.

WARNING: This program is protected by copyright law and international treaties.

Unauthorized reproduction or distribution of this program, or any portion of it, may result in severe civil and criminal penalties, and will be prosecuted to the maximum extent possible under law.

4. Click **Next**.
5. Review the license agreement and click **I accept the license agreement** (shown in Figure 1-9), and then click **Next**.

Figure 1-9 Accept License Agreement



License Agreement

You must agree with the license agreement below to proceed.

GNU GENERAL PUBLIC LICENSE

Version 2, June 1991

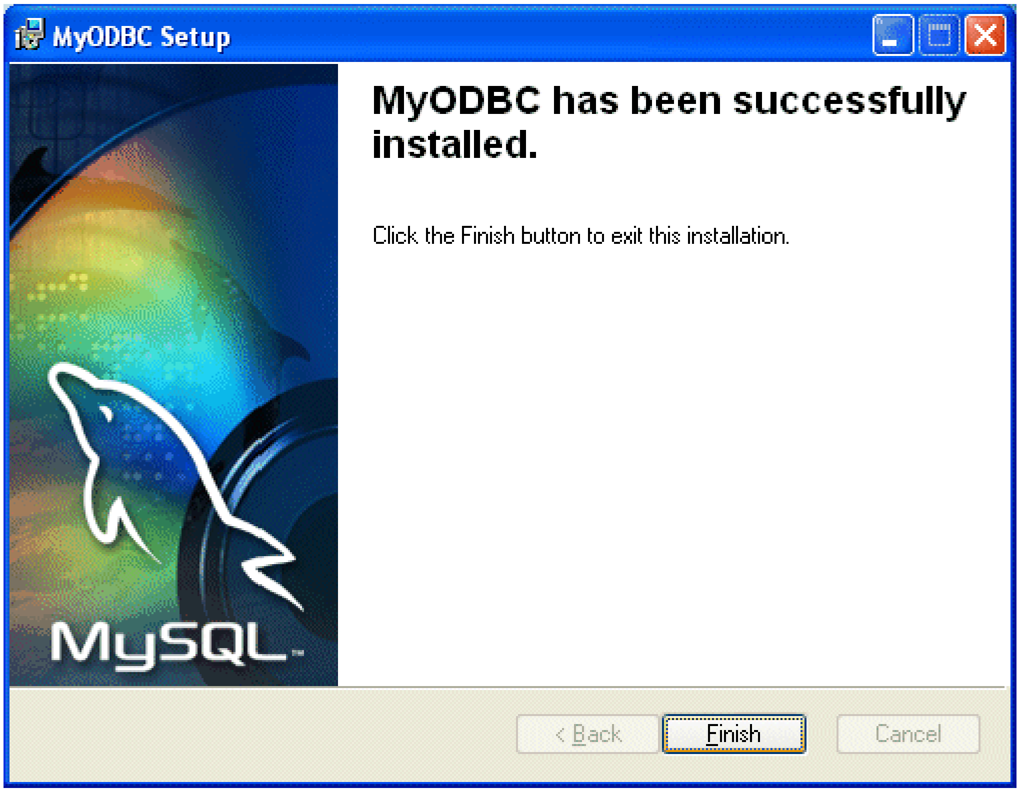
```
Copyright (C) 1989, 1991 Free Software Foundation, Inc.
59 Temple Place - Suite 330, Boston, MA  02111-1307, USA

Everyone is permitted to copy and distribute verbatim
copies
of this license document, but changing it is not allowed.
```

● I accept the license agreement

○ I do not accept the license agreement

6. Continue to click **Next**, following the wizard instructions, until the setup is complete and MyODBC has been successfully installed (as shown in Figure 1-10).

Figure 1-10 Setup Complete



MyODBC has been successfully installed.

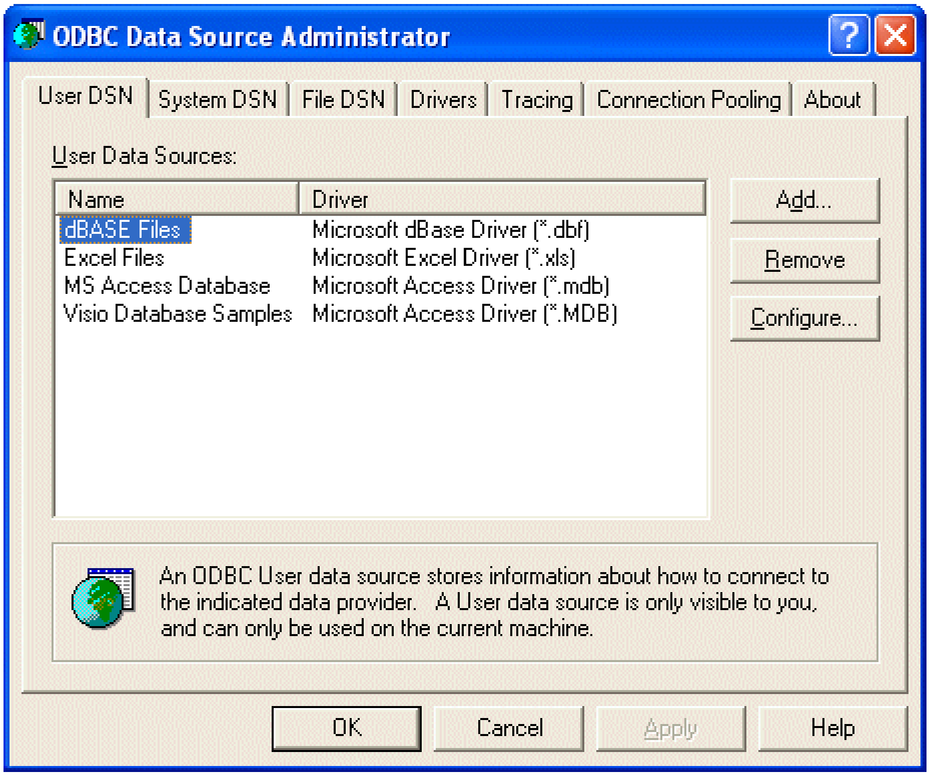
Click the Finish button to exit this installation.

7. Click **Finish** to close.

The second step in client setup is to connect to the database. To connect the Flowel database, do the following:

1. Under the **Start** menu, select **Settings**, then **Control Panel**, then **Administrative Tools**, and then click **Data Sources (ODBC)**.
2. The ODBC Data Source Administrator dialog box will appear (as shown in Figure 1-11).

Figure 1-11 ODBC Data Source Administrator



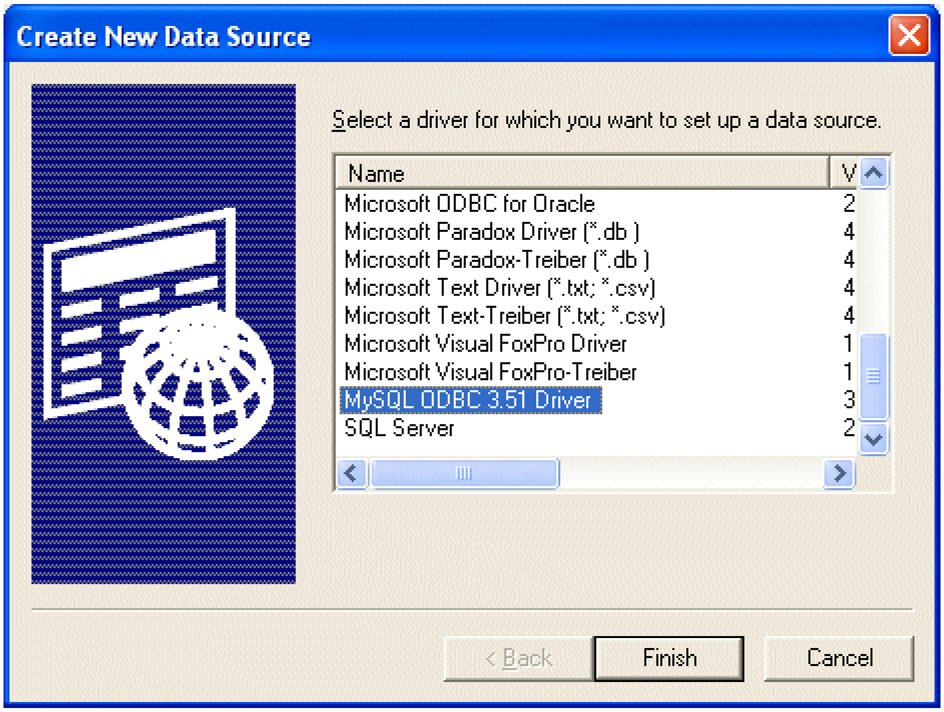
User Data Sources:

Name	Driver
dBASE Files	Microsoft dBase Driver (*.dbf)
Excel Files	Microsoft Excel Driver (*.xls)
MS Access Database	Microsoft Access Driver (*.mdb)
Visio Database Samples	Microsoft Access Driver (*.MDB)

An ODBC User data source stores information about how to connect to the indicated data provider. A User data source is only visible to you, and can only be used on the current machine.

3. Click the **User DSN** tab, and click **Add…**.
4. The Create New Data Source dialog box will appear (as shown in Figure 1-12).

Figure 1-12 Create New Data Source

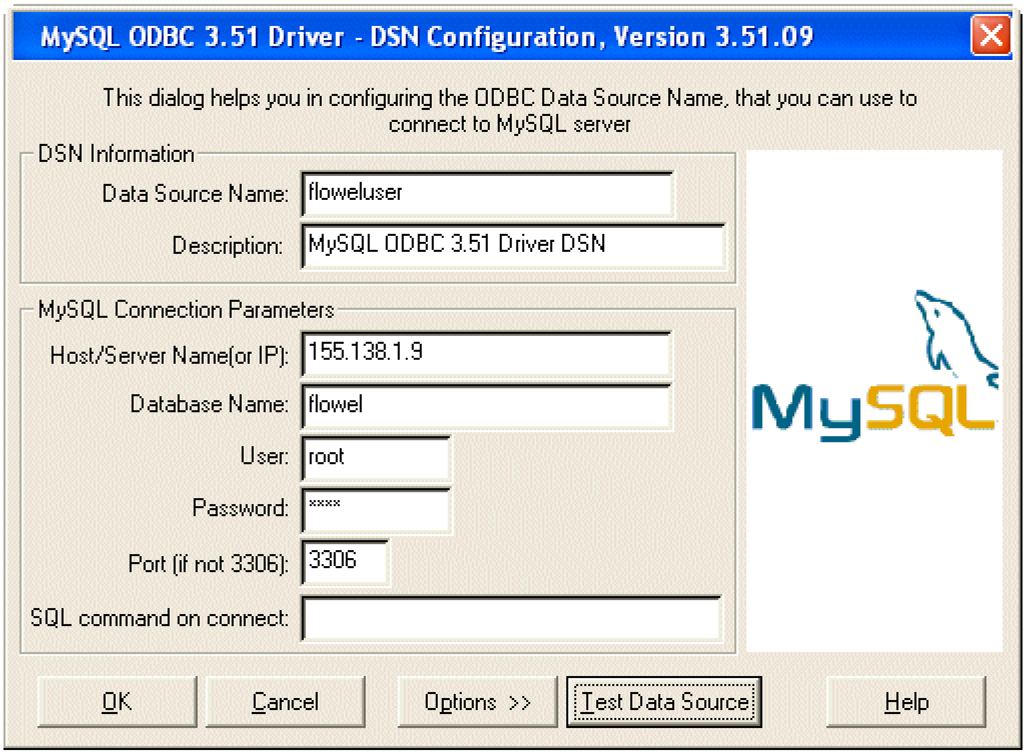


Select a driver for which you want to set up a data source.

Name	V
Microsoft ODBC for Oracle	2
Microsoft Paradox Driver (*.db)	4
Microsoft Paradox-Treiber (*.db)	4
Microsoft Text Driver (*.txt; *.csv)	4
Microsoft Text-Treiber (*.txt; *.csv)	4
Microsoft Visual FoxPro Driver	1
Microsoft Visual FoxPro-Treiber	1
MySQL ODBC 3.51 Driver	3
SQL Server	2

5. Scroll down and select **MySQL ODBC 3.51 Driver**, and click **Finish**.
6. The Configuration dialog box will appear, as shown in Figure 1-13.

Figure 1-13 Configuration



MySQL ODBC 3.51 Driver - DSN Configuration, Version 3.51.09

This dialog helps you in configuring the ODBC Data Source Name, that you can use to connect to MySQL server

DSN Information

Data Source Name: floweluser

Description: MySQL ODBC 3.51 Driver DSN

MySQL Connection Parameters

Host/Server Name(or IP): 155.138.1.9

Database Name: flowel

User: root

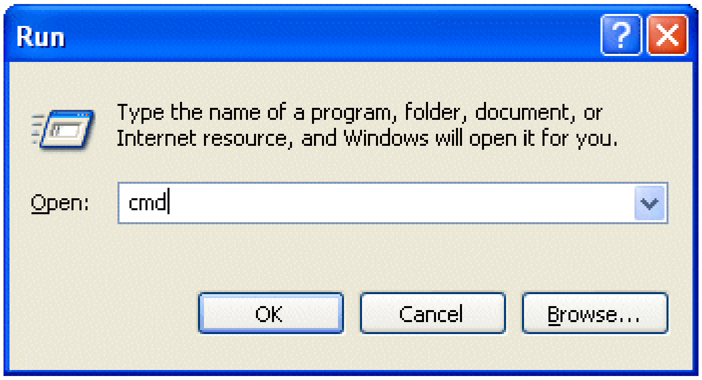
Password: ****

Port (if not 3306): 3306

SQL command on connect:

7. Enter the Data Source Name: `floweluser`.
8. Enter the IP address of the host computer. To obtain the computers IP address, do the following:
   (a) Under the **Start** menu, click **Run**.
   (b) Type “`cmd`” in the Open field, as shown in Figure 1-14, and click **OK**.

Figure 1-14 Run Dialog Box



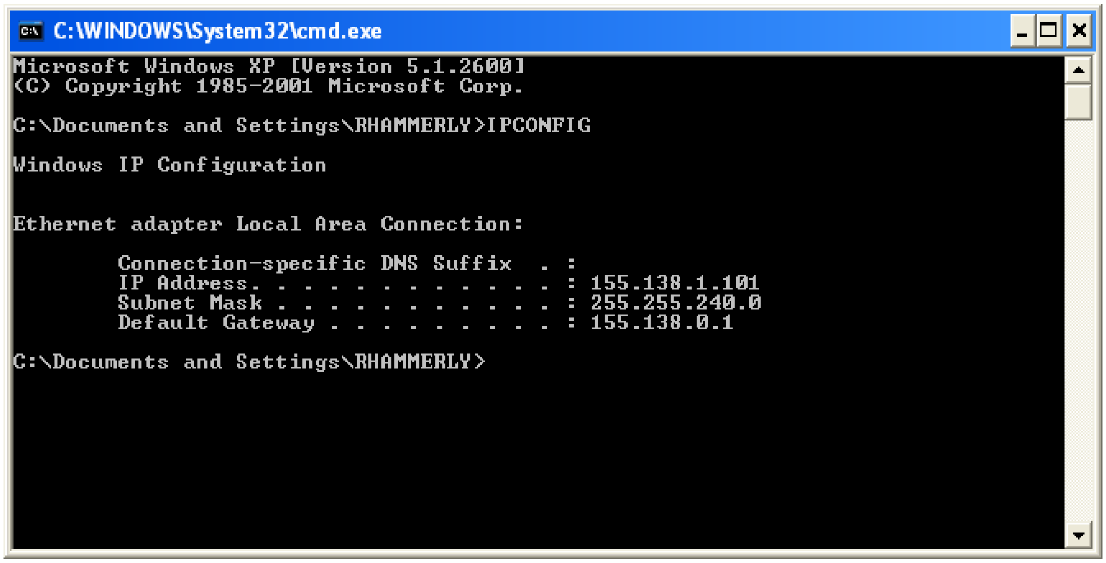
Run

Type the name of a program, folder, document, or Internet resource, and Windows will open it for you.

Open: cmd

   (c) In the DOS window that appears, type in “`IPCONFIG`” and press ENTER (shown in Figure 1-15).

Figure 1-15 IP Address



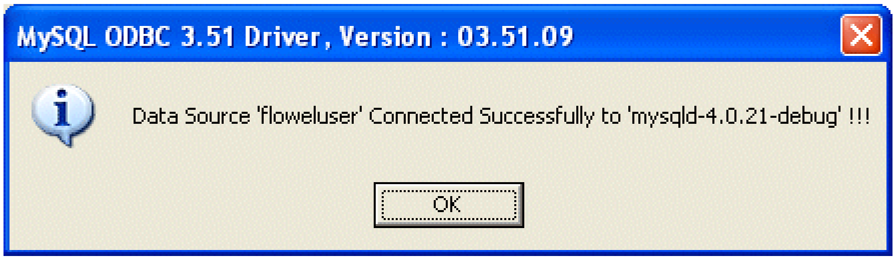
```
Microsoft Windows XP [Version 5.1.2600]
(C) Copyright 1985-2001 Microsoft Corp.

C:\Documents and Settings\RHAMMERLY>IPCONFIG

Windows IP Configuration


Ethernet adapter Local Area Connection:

        Connection-specific DNS Suffix  . :
        IP Address. . . . . . . . . . . . : 155.138.1.101
        Subnet Mask . . . . . . . . . . . : 255.255.240.0
        Default Gateway . . . . . . . . . : 155.138.0.1

C:\Documents and Settings\RHAMMERLY>
```

(d) The window should provide you with additional information including the IP address of the computer (as shown above).

(e) Close the window.

9. Enter the Database Name: `flowel`.
10. Enter the User and Password: `root`.
11. Click **Test Data Source**.
12. If the connection is successful, the following message should appear. If the message does not appear, contact Hydrocarbon and Energy support.

Figure 1-16 Successful Connection Message



Data Source 'floweluser' Connected Successfully to 'mysqld-4.0.21-debug' !!!

13. Click **OK**.
14. Click **OK** to close the configuration dialog box.

Once the ODBC setup is complete, you can run Flowel 4 from the client computer. To do so, open Windows Explorer and navigate over the network to the computer where Flowel is installed. Within that computer, find the folder where Flowel is installed (most likely *C:/Program Files/Flowel*). Right-click *Flowel.exe* and click **Create Shortcut**. Move the shortcut to your desktop and double-click to open.

1.10 User Management Utility

Flowel 4 has built-in security features for controlling data access under a multiple-user environment. Flowel 4 supports three user levels:

1. Super User – view and modify all jobs
2. Manager – view and modify jobs created by users within the same user group
3. User – view and modify jobs created by himself or herself or jobs assigned to the user by a manager

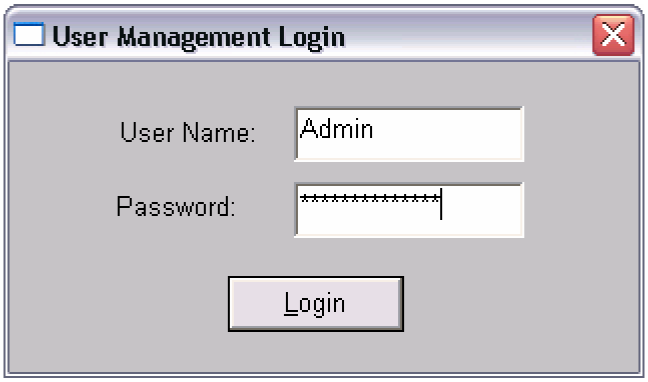
A user group refers to one or more users defined in the same group.

1.10.1 Accessing the User Management Utility

The User Management program is used to administer Flowel 4 user levels. To access the program, under the **Start** menu, click **Programs**, click **Flowel 4**, and then click the **User Management** shortcut.

The User Management utility requires a log in user name and password. Enter “`Admin`” in the **User Name** box. The password is available to network administrators (or the Flowel administrator) by emailing Flowelsoftware@EmersonProcess.com or calling +1(403) 258-6234.

Figure 1-17 User Management Login



User Name: Admin

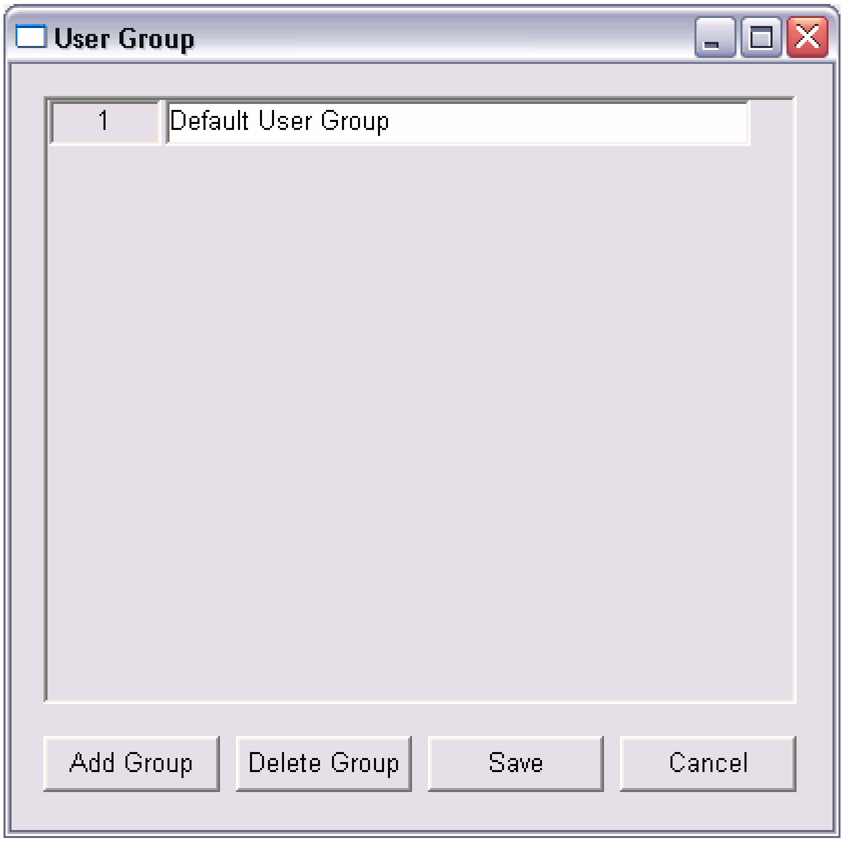
Password: ***************

1.10.2 Defining a User Group

To define a new user group, do the following:

1. Under the **File** menu, click **Group Management**. The following dialog box will appear.

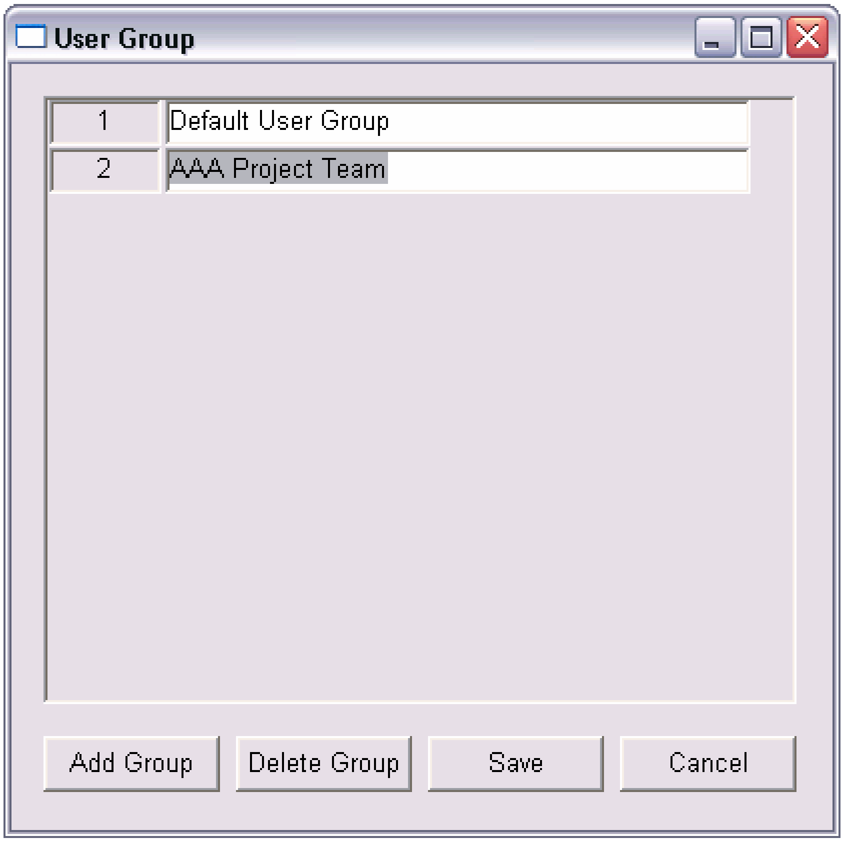
Figure 1-18 User Group



1 Default User Group

2. Click **Add Group**. A blank row will appear.
3. Type a group name in the new text box. For example, in the following figure the group name is **AAA Project Team**.

Figure 1-19 User Group – Group Name



1	Default User Group
2	AAA Project Team

4. Click **Save** to save the new user group.

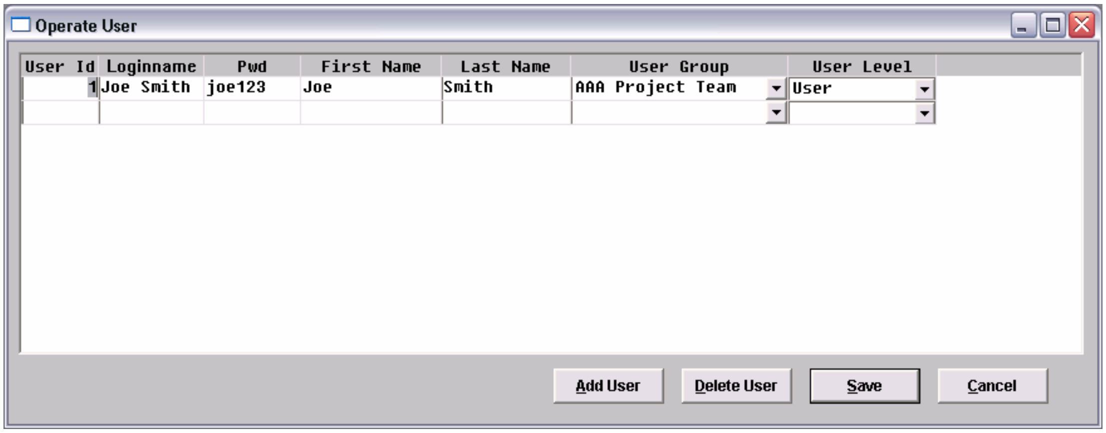
A user group can only be deleted when there are no users assigned to the group. To delete an empty user group, select the user group and click **Delete Group**.

1.10.3 Managing Users

To manage users, do the following:

1. Under the **File** menu, click **User Management**.
2. Click **Add User** to add a blank row.

Figure 1-20 Operate User – Add New Row



User Id	Loginname	Pwd	First Name	Last Name	User Group	User Level
1	Joe Smith	joe123	Joe	Smith	AAA Project Team	User

3. Enter values for the **User Id**, **Loginname**, **Pwd**, **First Name**, and **Last Name**.
4. Select a **User Group** and **User Level**. Note the following for the above values:
    - **User ID** must be a unique integer.
    - **Loginname** is the user name the user will enter to log in to Flowel 4.

      We recommend that the **Loginname** value be the same as the user's network user name. This way, the user will not be prompted to enter a user name or password when starting Flowel 4.
    - **PWD** is the password the user will enter to log in to Flowel 4.
    - The **First Name** and **Last Name** values are the user's first and last name.
    - The **User Group** list contains the groups defined in the user group management dialog and is used to determine the user's group of membership.
    - **User Level** determines the data each user can view and modify.

To delete a user, click in any text box in that user's row and click **Delete User**.

1.11 Data Migration From Flowel 3.0g

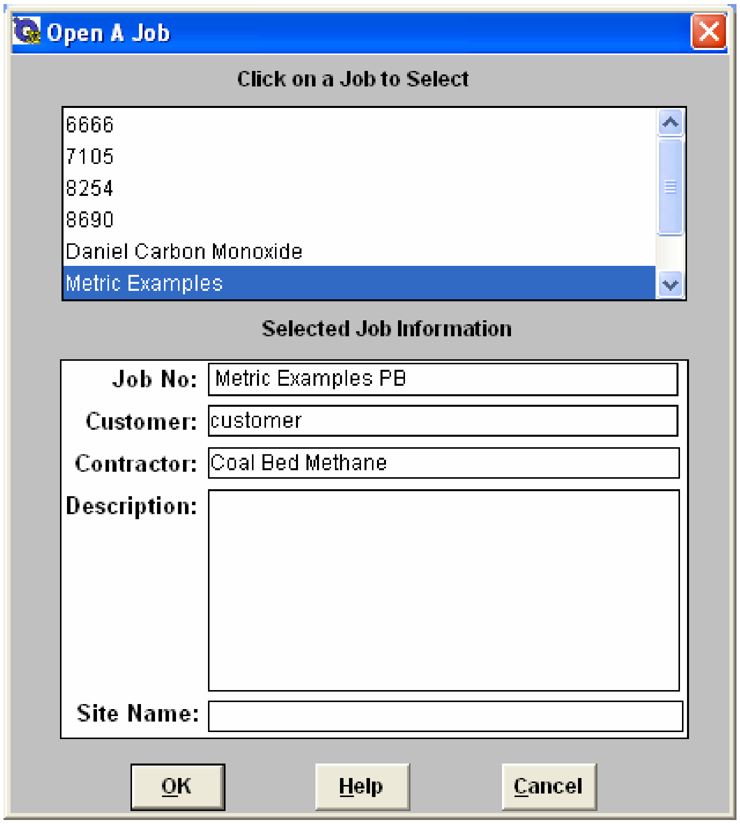
A separate utility program for converting Flowel version 3.0g databases into version Flowel 4 for Windows is included within this package. With this utility, you will not be required to re-enter your existing 3.0g data.

To migrate Flowel 3.0g data, do the following:

1. Backup the Flowel 3.0g database by copying the file *C:/Flowel/Flowel.db* to another location.
2. Under the **Start** menu, select **Programs**, then **Flowel 4**, and click **Data Convert**.

3. Data is now loaded into Flowel 4.
   Note that if there are duplicate job names, the job name will be altered to avoid duplicates. This is done by adding a “-1” to the name (e.g., US Examples-1). To avoid this, delete unused job names in Flowel 3.0g before converting. Also note, that for this reason, it is not useful to run the Data Convert utility repeatedly.
4. If several databases are to be converted, load one at a time into the Flowel 3.0g Flowel folder on the computer where Flowel 4 is located. To reduce issues with duplicate names, the job and tag names should be reviewed and duplicates eliminated where possible.
5. To eliminate duplicate job names in Flowel 3.0g, under the **File** menu, click **Open Job.**
6. Append an identifier (such as the user’s initials) to the Job No: field. In this case, “PB” (shown in Figure 1-21), and click **OK**.

Figure 1-21 Job Name Identifier



6666
7105
8254
8690
Daniel Carbon Monoxide
Metric Examples

Job No: Metric Examples PB
Customer: customer
Contractor: Coal Bed Methane
Description:
Site Name:

7. Once data is loaded, the jobs can be assigned to specific users. See User Maintenance.

For versions older than Flowel 3.0g, data will have to be first migrated to 3.0g. If you are in this situation, please call support at +1 (403) 258-6234.

1.12 Troubleshooting

This section describes various error messages and how to solve them, for both Flowel and CrypKey.

1.12.1 Flowel

Flowel will display appropriate error messages when performing calculations. Some error messages act only as warnings; they allow users to make their own judgments when executing calculations.

Flowel is designed to complete the particular calculation only after the user clicks **OK**. Should you have any questions or concerns about warning messages, please contact the Hydrocarbon and Energy Industry Center.

1.12.1.1 Error Message One

“Could not back up the database”. Please ensure that the database is closed.”

Figure 1-22 Flowel – Error Message One

Could not back up the database. Please ensure that the database is closed.

This message occurs because either Flowel is currently running or there is no copy of *Flowel.db* present in the Flowel folder when the user is trying to perform an upgrade.

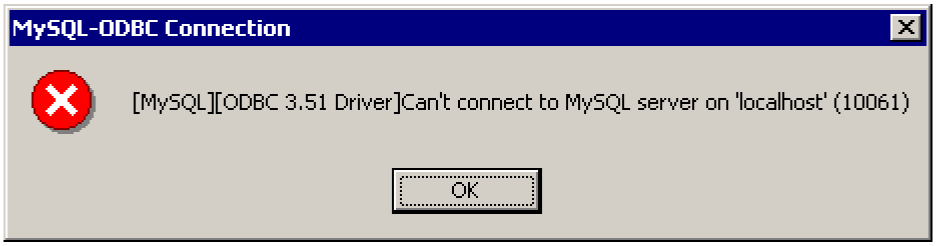
To solve this error, do the following:

1. Stop Flowel.
2. Place a copy of *Flowel.db* into the Flowel folder directory, then modify your registry and restart the upgrade.

1.12.1.2 Error Message Two

The following error message (or similar type) occurs when the system is unable to connect to the database.

Figure 1-23 Flowel – Error Message Two – Unable to Connect to Database



[MySQL][ODBC 3.51 Driver]Can't connect to MySQL server on 'localhost' (10061)

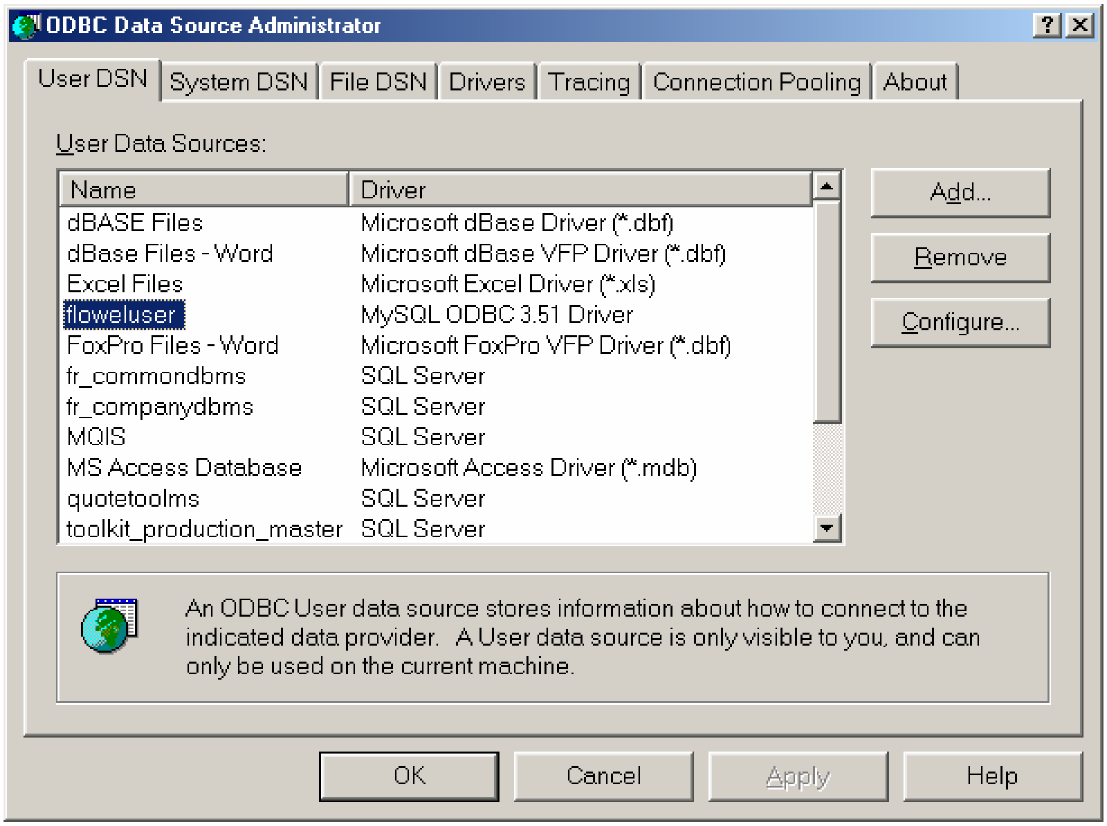
This message occurs because the administrator installed Flowel on the computer. They may have logged in as an “Administrator” rather than as a “User,” so when another user logs in and tries to operate Flowel, this user has no database entry in the *ODBC.ini* file.

Note: Before following the steps below to correct this error, ensure you have full administration permissions, as this process will make entries to the registry.

To correct this database error, do the following:

1. On the **Start** menu, select **Settings**, and click **Control Panel**.
2. Double-click **ODBC** (or select **Administration Tools** and click **Data Sources**).
3. Highlight **floweluser** in the ODBC Data Source Administrator (see figure below).

Figure 1-24 ODBC Data Source Administrator Dialog



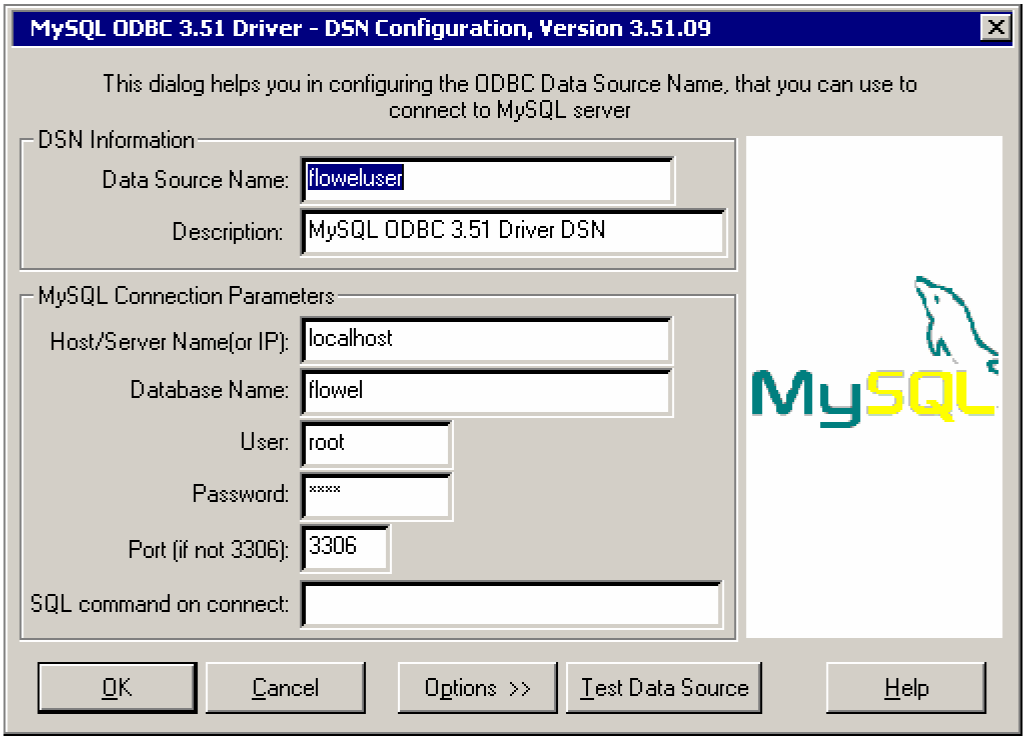
User Data Sources:

Name	Driver
dBASE Files	Microsoft dBase Driver (*.dbf)
dBase Files - Word	Microsoft dBase VFP Driver (*.dbf)
Excel Files	Microsoft Excel Driver (*.xls)
floweluser	MySQL ODBC 3.51 Driver
FoxPro Files - Word	Microsoft FoxPro VFP Driver (*.dbf)
fr_commondbms	SQL Server
fr_companydbms	SQL Server
MQIS	SQL Server
MS Access Database	Microsoft Access Driver (*.mdb)
quotetoolms	SQL Server
toolkit_production_master	SQL Server

An ODBC User data source stores information about how to connect to the indicated data provider. A User data source is only visible to you, and can only be used on the current machine.

4. Click **Configure**. The following dialog box will appear (as shown in Figure 1-25).

Figure 1-25 DSN Configuration



MySQL ODBC 3.51 Driver - DSN Configuration, Version 3.51.09

This dialog helps you in configuring the ODBC Data Source Name, that you can use to connect to MySQL server

DSN Information

Data Source Name: floweluser

Description: MySQL ODBC 3.51 Driver DSN

MySQL Connection Parameters

Host/Server Name(or IP): localhost

Database Name: flowel

User: root

Password: ****

Port (if not 3306): 3306

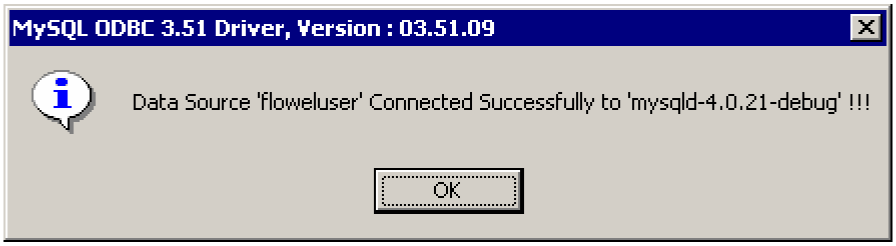
SQL command on connect:

5. In the MySQL dialog box, enter the following information:

Data Source Name:	floweluser
Description:	MySQL ODBC 3.51 Driver DSN
Host/Server Name(orIP):	localhost, IP address (where database exists), or computer name
Database Name:	flowel
User:	root
Password:	root
Port:	3306
Option:	Click **Test Data Source**

6. Click **Test Data Source**. If the connection is successful, the following dialog will appear (Figure 1-26).

Figure 1-26 Test Data Source



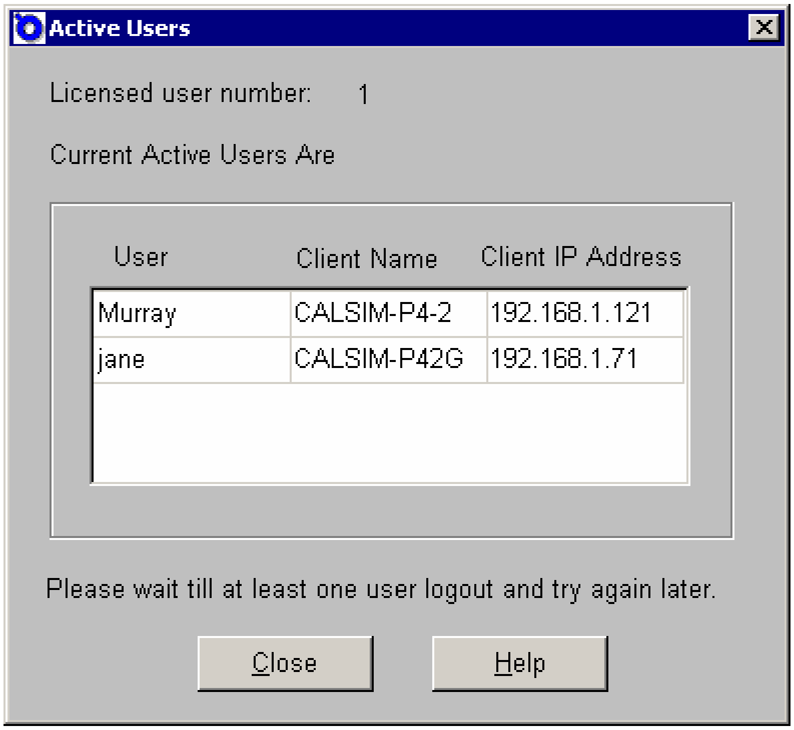
Data Source 'floweluser' Connected Successfully to 'mysqld-4.0.21-debug' !!!

7. Click **OK**.
8. Click **OK**.

1.12.1.3 Error Message Three

The following error message (or similar) will occur if all the Flowel licenses are in use (i.e., if you have one license only one user can use Flowel at any one time). The problem may also occur if the user did not exit properly the last time Flowel was open.

Figure 1-27 Flowel – Error Message Three



Licensed user number: 1

Current Active Users Are

User	Client Name	Client IP Address
Murray	CALSIM-P4-2	192.168.1.121
jane	CALSIM-P42G	192.168.1.71

Please wait till at least one user logout and try again later.

To solve this problem, do the following:

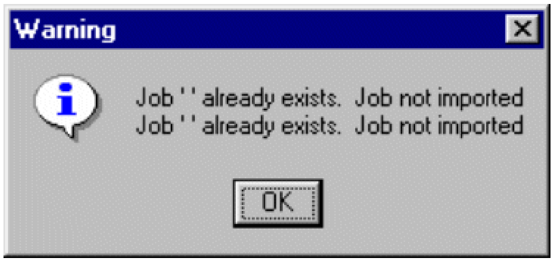
1. Click **Close** and, as the dialog indicates, wait until the user logs out.

2. Or, delete the file called *Flowel._tb* in the Flowel folder. However, before deleting this file, ensure that no users are logged into Flowel. This file is a transaction log; it records when users are in Flowel. If users do not exit properly, this file becomes corrupt. The file will be re-created once Flowel is re-opened.

1.12.1.4 Error Message Four

“Job ‘ ’ already exists. Job not imported. Job ‘ ‘ already exists. Job not imported.”

Figure 1-28 Flowel – Error Message Four



Warning

Job ' ' already exists. Job not imported
Job ' ' already exists. Job not imported

This error occurs because the user is attempting to import the tags or fluids with names that already exist in the database.

To correct this problem, the user should import tags into a job where the tag names do not already exist. In the case of fluids, the fluid name must be changed to a name that does not already exist.

1.12.2 CrypKey

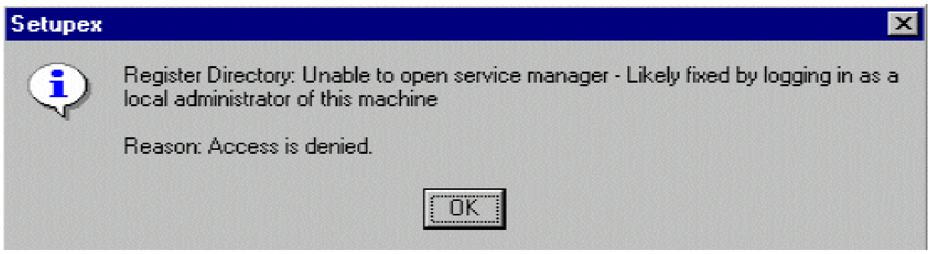
Please contact the Hydrocarbon and Energy Industry Center at +1 (403) 258-6234 for any CypKey or Crypserv error messages.

1.12.3 Windows

1.12.3.1 Error Message One – Registry Error

“Register Directory. Unable to open service manager – Likely fixed by logging in as a local administrator of this machine. Reason: Access is denied.”

Figure 1-29 Windows – Error Message One



Register Directory: Unable to open service manager - Likely fixed by logging in as a local administrator of this machine

Reason: Access is denied.

This error occurs because the person who tried to install Flowel did not have the permission needed to install the drivers.

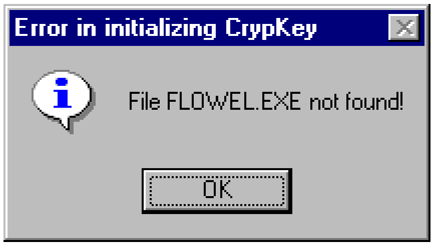
To correct this problem, do the following:

1. On the **Start** menu, click **Control Panel** and select **Add/Remove Programs**.
2. Remove/un-install Flowel.
3. After Flowel is un-installed, the user may log in as a local administrator and re-install the program.

1.12.3.2 Error Message Two

"File FLOWEL.EXE not found!"

Figure 1-30 Windows – Error Message Two



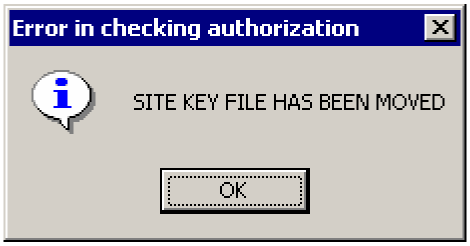
File FLOWEL.EXE not found!

To solve this problem, reinstall Flowel. If the problem persists, contact Hydrocarbon and Energy.

1.12.3.3 Error Message Three

"SITE KEY FILE HAS BEEN MOVED."

Figure 1-31 Windows – Error Message Three



Error in checking authorization

SITE KEY FILE HAS BEEN MOVED

This problem occurs because the *flowel.exe* file has been moved to a new location on the computer since its initial authorization or the folder it's stored in has been renamed (see Copy Protection – CrypKey, Section 1.13).

To solve this problem, move the file back and/or correct the folder name. If the problem still exists you will need to contact Hydrocarbon and Energy for new authorization.

1.13 Copy Protection – CrypKey

CrypKey protects Flowel from any unauthorized use. The protection scheme has two components: a site code and a site key. The site code is specific to your particular installation. The site key, when applied to your site code, unlocks Flowel so that it may be used.

Note: To transfer authorization from one computer to another, follow the instructions provided in Chapter 3, User Reference, under the Transfer Authorization section.

Copy protection comes into effect when Flowel is first activated. To unlock Flowel, do the following:

1. The first time Flowel is activated after installation, a warning message will appear, as shown in Figure 1-32.

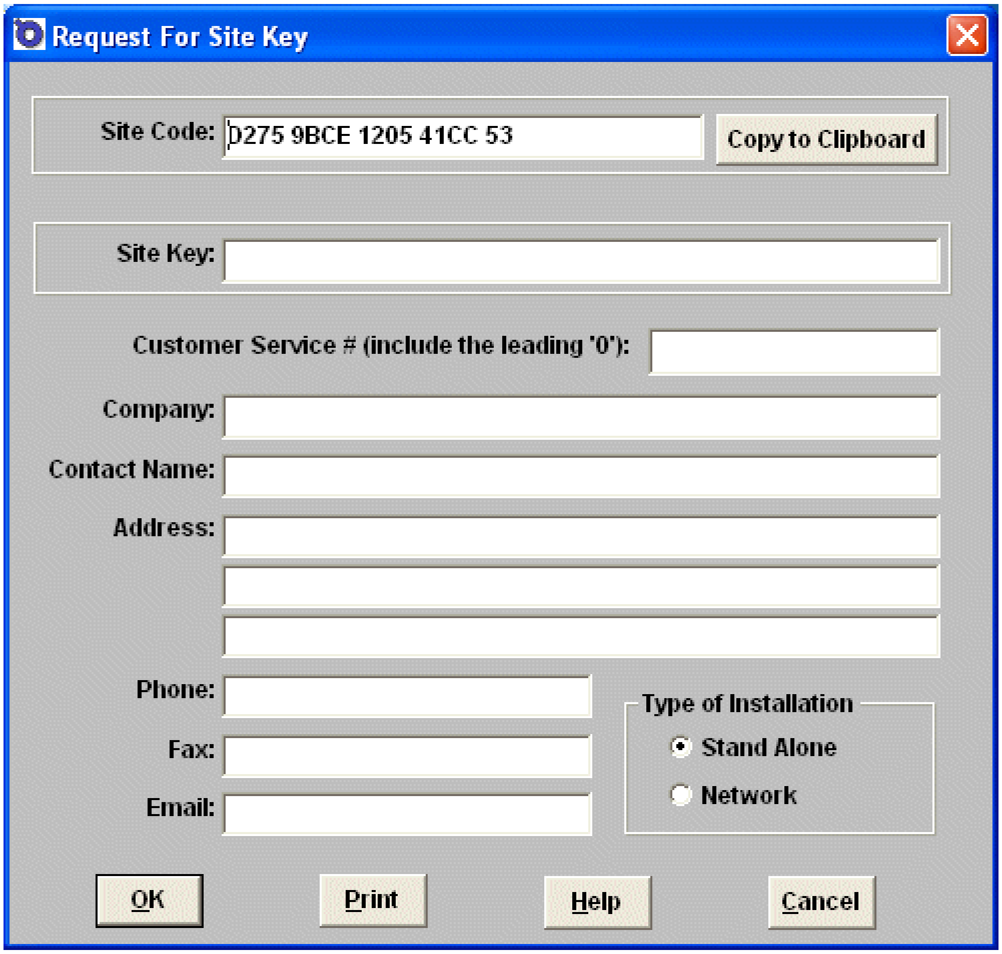
Figure 1-32 Activation Warning Message

Warning

Program has never been authorized at current site

2. Click **OK**.
3. A Request for Authorization dialog box appears. Select **Get new authorization** and click **OK**.
4. A site key request form will appear, as shown in Figure 1-33.

Figure 1-33 Site Key Request Form



Site Code: 0275 9BCE 1205 41CC 53

● Stand Alone

5. Enter your Customer Service Number (#). This number is found on the inside of the Flowel binder front cover.
6. Complete the required fields and click **Print** to print the form.
7. Fax the form to Hydrocarbon and Energy at +1 (403) 258-6201.
   By sending the site code you will register the software package and receive the site key to unlock the program.
8. Close the window until you receive your site key from Hydrocarbon and Energy.
9. Once you receive your site key, re-run Flowel and enter the site key alpha/numeric into the appropriate field.
10. Click **OK** and Flowel will then be unlocked and available for use.

1.13.1 Tips and Tricks

Some do's and don'ts associated with CrypKey are listed below:

- do move the program using the Transfer Authorization function only
- do ensure your computer clock is set properly before installing the program
- do backup the database
- do not move the program or restore the program (*flowel.exe*)
- do not change the system files
- do not move your clock settings

1.14 Starting Flowel

To start Flowel, do the following:

1. On the **Start** menu, click **Programs**, click **Flowel 4**, and then click **Flowel 4**.
2. Or, locate the Flowel icon and double-click the icon to start the program. When the program has completed loading, you will see the main program screen.

1.15 The Flowel Database

1.15.1 MySQL Database

Flowel is actually constructed in two main components: the Flowel GUI, which is the program as you see it, and the MySQL database, which contains all of the data that the program uses. The Flowel database is a multi-user database. Multiple workstations can access the data at a given time, if the correct license has been purchased.

1.15.2 Backing up the Database

The Flowel database is stored under *C:/Program Files/mysql/data/flowel/*. This folder contains all of the job, tag, fluid, and material information and should be backed up on a regular basis to prevent any loss of data. Data can be restored from backup by overwriting the current subdirectory (*C:/Program Files/mysql/data/flowel/*) with the backup version. This will completely replace the database and any tags modified since the backup will not be captured. Use the Import and Export functions to move specific tags from one database to another.

1.15.3 Moving the Database

The Flowel database cannot be moved. Do not move the database.

§

2 Tutorial Instructions

2.1 About This Tutorial

This tutorial is designed to serve two purposes:

- to lead new users through the program while explaining the principles behind the program
- to show users familiar with older tools how to get the job done effectively using this version of Flowel for Windows

The tutorial is divided into three main components: One Time Through, Customizing the Program, and Examples and Applications.

Note: If you are new to the Windows environment, we recommend that you take the tutorial provided by Microsoft before you run Flowel. This tutorial can be run by selecting the Windows Tutorial option from the Windows Program Manager Help menu.

2.2 One Time Through

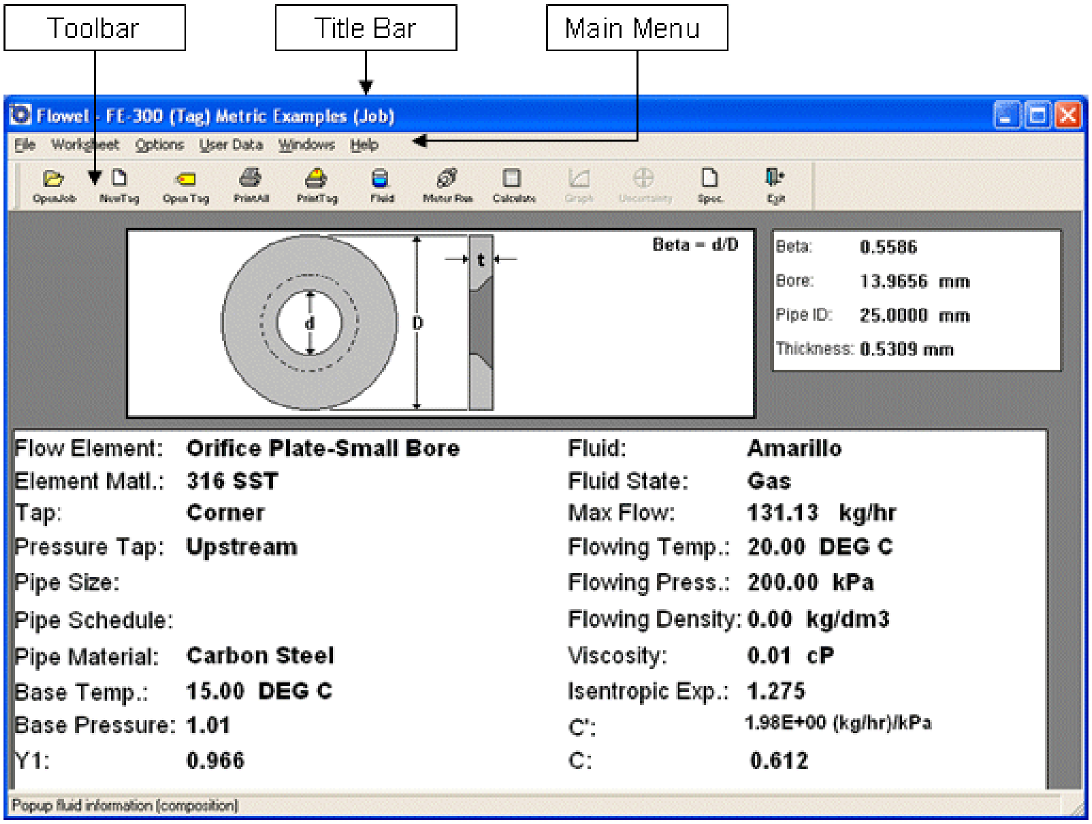
Follow the instructions in this tutorial to learn how to use Flowel 4®. Through this process you will learn the approach that you should take to using this software in order to use the functions as they are intended. As a result, you will have a solid understanding of the most efficient and practical ways to get accurate and usable results with Flowel.

2.2.1 Starting Flowel

To start Flowel, do the following:

1. Double-click the *Shortcut to flowel4.exe* on your desktop.
2. If prompted, add your name to the user list and click **OK**.
3. The main screen appears, as shown in Figure 2-1.

Figure 2-1 Main Flowel Screen



Beta: 0.5586
Bore: 13.9656 mm
Pipe ID: 25.0000 mm
Thickness: 0.5309 mm

Flow Element: Orifice Plate-Small Bore
Element Matl.: 316 SST
Tap: Corner
Pressure Tap: Upstream
Pipe Size:
Pipe Schedule:
Pipe Material: Carbon Steel
Base Temp.: 15.00 DEG C
Base Pressure: 1.01
Y1: 0.966

Fluid: Amarillo
Fluid State: Gas
Max Flow: 131.13 kg/hr
Flowing Temp.: 20.00 DEG C
Flowing Press.: 200.00 kPa
Flowing Density: 0.00 kg/dm3
Viscosity: 0.01 cP
Isentropic Exp.: 1.275
C': 1.98E+00 (kg/hr)/kPa
C: 0.612

Popup fluid information (composition)

This screen provides a summary of the completed work; there are no editable fields. It has some standard Windows components including the control menu and the min/max/restore buttons. The components that are reviewed in this manual are directly related to the operation of Flowel.

2.2.2 Using the Toolbar

The Toolbar is one of the most important components of the main Flowel screen. It can be set so that the function names are on the buttons (in Flowel, on the **Windows** menu, click **Tool Bars**, and select **Show Text**). This will help you learn the function of each button.

Each button on the toolbar corresponds to a command. By using the toolbar from left to right, you follow a logical sequence.

Table 2-1 Toolbar

Icon	Function
OpenJob	Open Job
NewTag	New Tag
Open Tag	Open Tag
PrintAll	Print All
PrintTag	Print Tag
Fluid	Fluid
Meter Run	Meter Run
Calculate	Calculate
Graph	Graph
Uncertainty	Uncertainty
Spec.	Spec Sheets
Exit	Exit

2.2.3 Proceeding to the Next Step

Each of the steps in performing a flow calculation within Flowel are the steps you will use for each new tag. These steps are necessary and are repeated every time. To save you some keystrokes, and to make the process consistent, we have included a way of easily getting to the next step in the procedure.

At the bottom of each of the dialog boxes which are necessary to this process are one or two buttons. Think of these buttons as a way to travel back and forth along the toolbar without all of the closing and opening steps.

We use the previous and next buttons to go forward and backward through the program, following the proper order of use.

The first dialog box to include a button of this type is the New Tag dialog box. It is from this point onward that you can be led through the program in the right order. On some of the dialog boxes, the previous button appears. This will allow you to go backwards in the order so that you can make changes or corrections. Once those changes are made, you can use the next button again to proceed forward as before.

2.3 Create a New Job

The first step in using Flowel is to create a new job. How you use the job number field is up to you but conventionally it refers to your organization's method of keeping track of projects. To create a new job, do the following:

1. On the **File** menu, click **New Job**. The New Job dialog box appears.
2. Type the name of your job. In this case we will use the Job name `Tutorial`. Your company probably has an internal numbering system, and you will likely be issued a job number. This entry field accepts both numbers and letters. This dialog box displays any existing jobs so that you can see what has already been created.
3. Fill in the remaining fields, then click **OK**.

2.3.1 Setting the Default Values for the Job

To configure the default settings for this job, set your default values as per the instructions in the following sections.

2.3.1.1 Default Unit Setting

To set the Default Unit Setting, do the following:

1. On the **Options** menu, select **Default Units**.
2. The Default Unit Settings option is used to set the unit type that will be used in the calculations for each tag. When you make selections here, all new tags that are created will use these settings.

Note: any tags which already exist will not be affected, but any tags can have their units changed afterwards.

3. Select a unit type for each of the options.
4. When you have selected all of the options to be used as defaults, click **OK**.

2.3.1.2 Atmospheric Pressure

To set the Atmospheric Pressure, do the following:

1. On the **Options** menu, select **Atmospheric Pressure**. Use the scroll bar or enter a value into the altitude field. The pressure for that altitude will be automatically calculated.
2. Click **OK** to accept this setting as the default for any tags subsequently created.

2.3.1.3 Significant Digits

To set the Significant Digits, do the following:

1. On the **Options** menu, select **Significant Digits**.
2. The Significant Digits settings are used in the display of numbers on the calculation screen and in the specification sheets. The settings here do not affect the number of digits used in the calculations, only those used for display.
3. Use the horizontal slider bars to adjust the number of digits which are to be displayed for each of the available options. A sample for each is presented on the right-hand side of the dialog box.
4. When you are satisfied with the settings, click **OK**.

2.3.1.4 Default Base Conditions

To set the Default Base Conditions, do the following:

1. On the **Options** menu select **Default Base Conditions**.
2. The program uses some information repeatedly within its calculations. By making a selection from the default base condition setting screen, new tags created will use these settings and therefore require less input later on.
3. Select from one of the types available. In this case we will use the Standard - US selection, which gives us settings of 14.65 psia and 60°F.
4. Click **OK** to continue.

2.3.1.5 Default Element

To set the Default Element Setting, do the following:

1. From the **Options** Menu, select **Default Element**.
2. The program will use the element defined on this screen as the default for all new tags created. Even though this is the default, and this information appears automatically on the meter run screen, you may choose a different element on the meter run screen.
3. Click **OK** to continue.

2.3.2 Create a New Tag

We are now prepared to begin creating tags.

Tags are names for specific devices. There are standards for using tag names, and The Instrumentation, Systems, and Automation Society (ISA) has developed a standard tag naming format (ISA S-20 standard) which uses four fields to pinpoint a device’s location within a site or system. Flowel extends the ISA tag naming standard by using five fields.

The tag name looks like this:

Prefix1	Prefix2	Instrument	Loop	Suffix
8	8	8	8	8

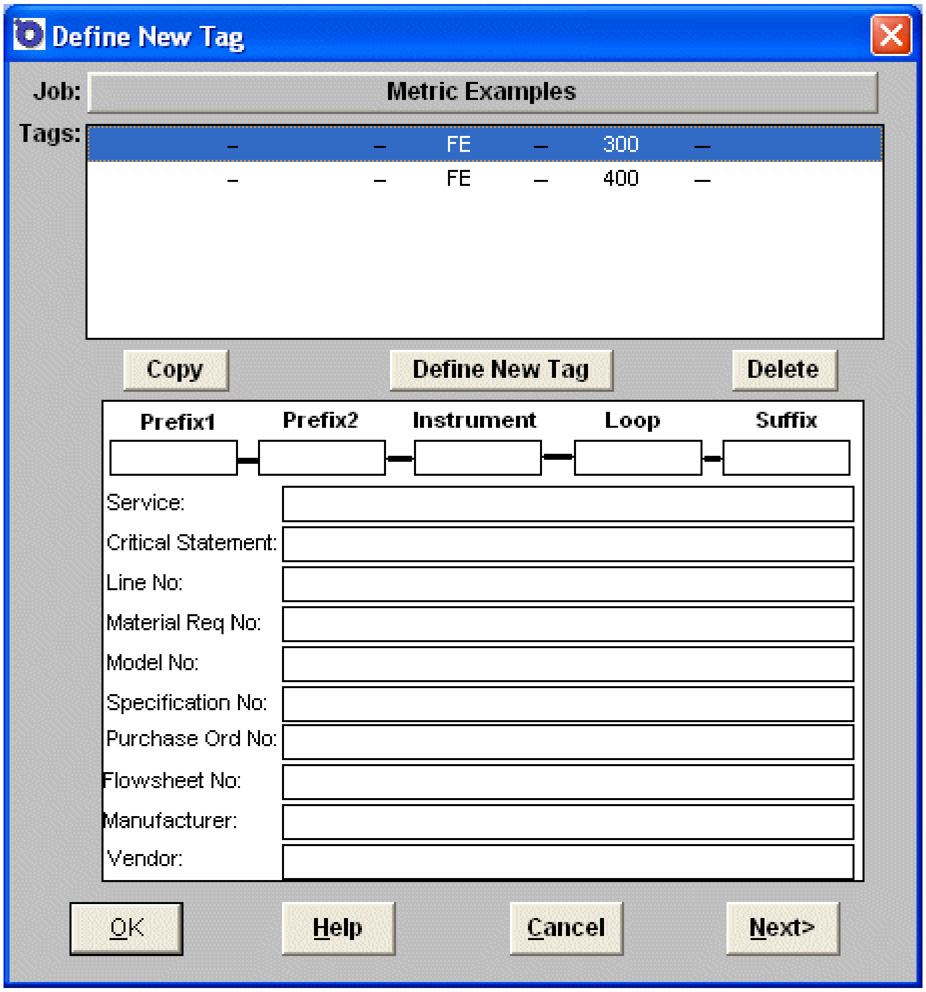
Each of the five components can hold up to eight characters. Here is a brief review of the tag naming convention:

- Prefix1 – an optional general location identifier
- Prefix2 – an optional, more specific location identifier
- Instrument ID – a required field which classifies the function of the device
- Loop number – a required field, usually a grouping of instruments working together toward a common function
- Suffix – additional optional identifier to distinguish between instances of a device in a loop

Each tag would correspond, in the case of Flowel, to a metering device. Since a project may have multiple metering locations, the same relationship holds true for job numbers and tags within Flowel. Each job can have many tags associated with it:

To create a new tag, on the Flowel toolbar, click **New Tag**. The Define New Tag dialog box appears. Click the **Define New Tag** button to begin data entry on this window, otherwise you will not be able to edit any fields.

Figure 2-2 Define New Tag Dialog Box



Job: Metric Examples

Tags:

– – FE – 300 –

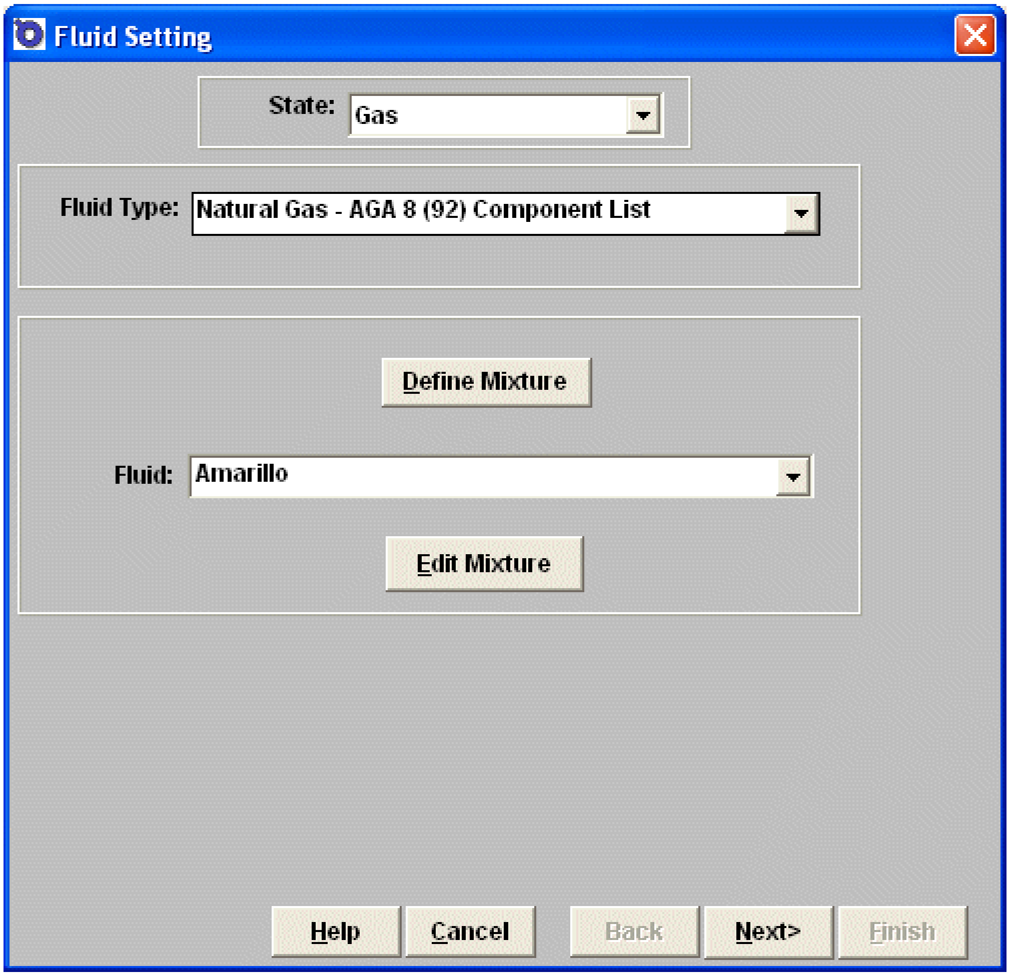
– – FE – 400 –

There is room for a lot of information about each tag. The minimum entry required is the instrument ID and loop number of the tag name. We recommend filling in as much information as you can about a tag, since this information will used in a number of dialog boxes and printouts. For example, enter an Instrument ID of FE and a loop number of `1`. After the information is entered, click **OK** to move to the next topic (or click **Next** to proceed directly to the next dialog box/step in this process).

2.4 Fluid Settings

To set your fluids, click the **Fluid** button on the Flowel toolbar. The Fluid Setting dialog box appears. Use this dialog box to configure each tag’s specific fluid. Flowel requires this information in order to calculate a result.

Figure 2-3 Fluid Setting Dialog Box



State: Gas

Fluid Type: Natural Gas - AGA 8 (92) Component List

Fluid: Amarillo

The Fluid Setting dialog box is described in the following sections.

2.4.1 Fluid State

Select the state from the drop-down list provided. Your choices are:

- Gas
- Gas, Critical Flow
- Liquid
- Liquid, Critical Flow
- Wet Gas

These selections affect how the program operates, as each of these states require different methods and formulas. You must make a fluid state selection. For this example, select **Liquid**.

2.4.2 Selection Lists

Many of the selection lists within Flowel allow for item selection in more than one fashion. In this example we want to select **Liquid** as a fluid state. We have two methods for making the selection:

1. Standard Selection:
    - (a) The first method is the standard selection method. Click the **State** drop-down list box to view the list of states.
    - (b) Select **Liquid**.
2. Alternate Method:
    - (a) Type the first letter of the desired item, in this case the letter `L`.
    - (b) If there are more than one item which begins with the letter `L`, the first will appear.
    - (c) Press `L` again to get to the second one, and so on, until you can select **Liquid**.

These methods apply to many areas of the program. In particular, when selecting pure fluids on the mixture definition function, the letter-selection method allows quick access to a component which might otherwise take a lot of time to scroll to in a list.

2.4.3 Fluid Type

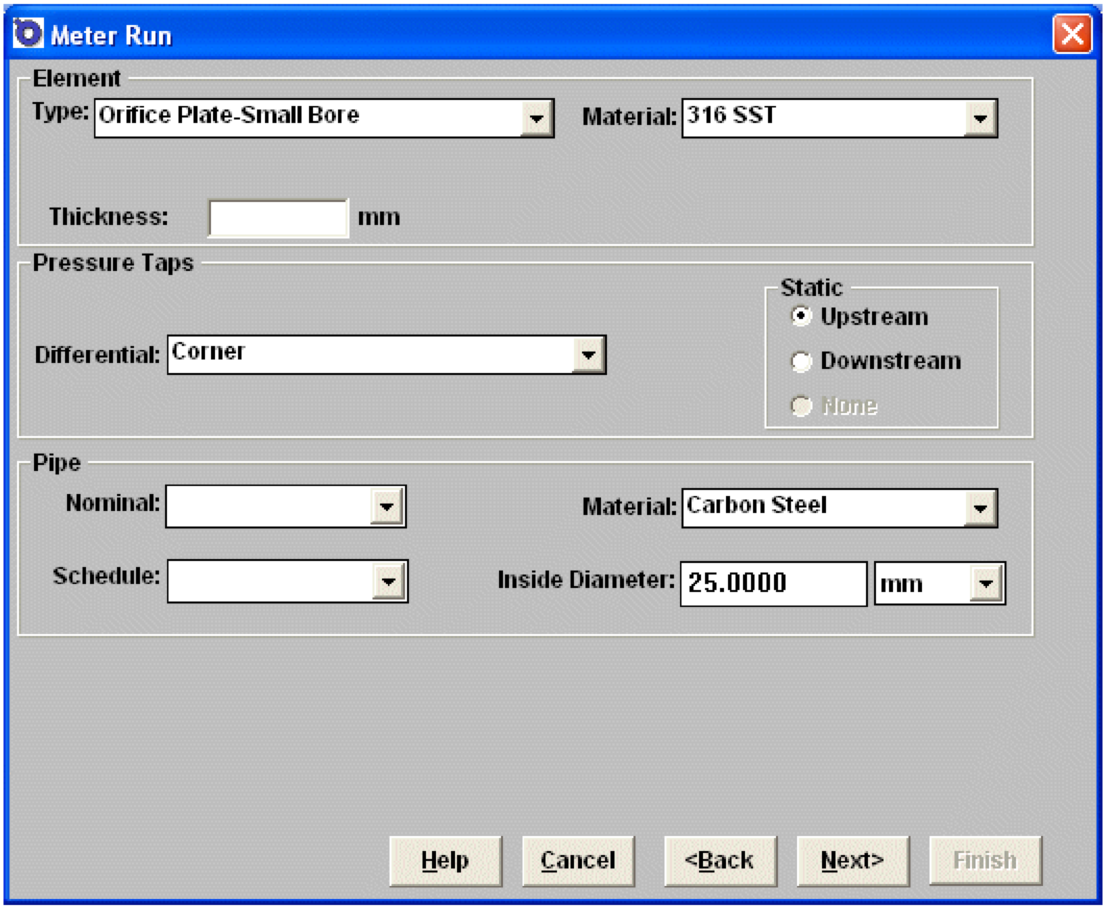
Because there are over 600 fluids available in Flowel, we provide the Fluid Type selection to narrow down the list.

1. To select a fluid type, click the **Fluid Type** drop-down.
    - There are two main fluid types: mixtures and pure components. Mixtures include all of the natural gas selections, plus the General Mixture option. Pure components are selected using the "All" or "Common Fluids" options.
    - If a mixture is selected, it must be defined before it can appear as a "Fluid" in the final fluid list. This procedure involves selecting the components, then setting the mole values for each of the components.
    - Pure components are provided by the program and do not need any further definition; they can be used as they are.
2. For this example, select the **Common Fluids** option.
3. Since we have selected Common Fluids, the list of these fluids is provided for us. We want to use water for this example, so we can either use the scroll bar to move to water, or type in the letter `w`**.** Since water is the first fluid that starts with `w`, it will be highlighted for us.
4. Use your mouse to select **Water and/or Steam**.
5. When you have completed these steps, click **OK** to move to the next topic in the process (or click **Next** to go directly to the Meter Run dialog box).

2.5 Meter Run Settings

To set your meter run, click the **Meter Run** button on the Flowel toolbar. The Meter Run dialog box appears. The Meter Run function activates a dialog box in which specific information about the metering equipment and environment is entered.

Figure 2-4 Meter Run Dialog Box



Meter Run

Element

Type: Orifice Plate-Small Bore

Material: 316 SST

Thickness: mm

Pressure Taps

Differential: Corner

Static

● Upstream

○ Downstream

○ None

Pipe

Nominal:

Material: Carbon Steel

Schedule:

Inside Diameter: 25.0000 mm

2.5.1 Element Type, Material, Pressure Taps, and Thickness

The first step is to select an element type. If you have set an element type in the Default Element Type function, this type will be entered into the fields.

Different element types will be available depending on the fluid state selected earlier. If you want to select a different element type, follow the procedure as outlined below.

1. Click the **Type** drop-down arrow. You can use the scroll bars to see all of the options on this list. In this case, select a standard orifice plate (**Orifice Plate-Standard**) as the element type for this meter run location.
2. Select a material type for this metering element. Select **316 SS**.

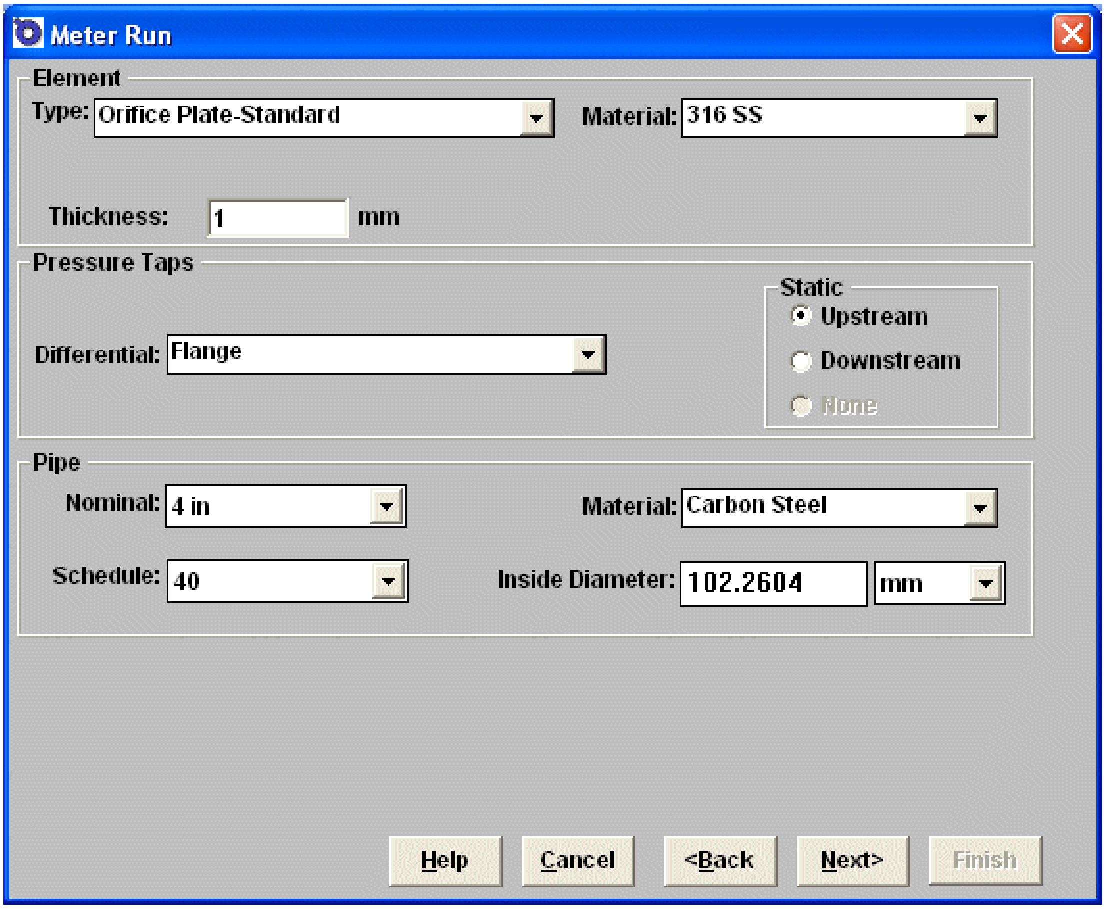
3. Enter the orifice plate thickness, if required (this field will appear if required). Flowel will calculate and warn the user if the entered valued is less than the minimum thickness according to AGA-3 (2000).
4. The next group box on the dialog is where pressure taps are defined by type and location. The list of differentials provided depends upon the element type selected. Also, the Flowel display activates only the static locations which are applicable for the differential selected.
5. For this example, select **Flange** for the differential and leave the static as the default (upstream).

2.5.2 Pipe

As the final task on this dialog box, you must select a pipe. To select a pipe, do the following:

1. Select a pipe nominal size. For this example, select **4 in**.
2. The program defaults to a pipe schedule of 40 (if there is one for that pipe). We need to enter a material for the pipe so that the program can compensate for thermal expansion in the calculations. Select **Carbon Steel** for the material.
    - Flowel's database for pipe will provide the inside diameter of the pipe.

Figure 2-5 Meter Run Selections



Element

Type: Orifice Plate-Standard

Material: 316 SS

Thickness: 1 mm

Pressure Taps

Differential: Flange

Static

● Upstream

○ Downstream

○ None

Pipe

Nominal: 4 in

Material: Carbon Steel

Schedule: 40

Inside Diameter: 102.2604 mm

3. When you have completed your selections in the Meter Run dialog box (which will appear as shown in Figure 2-5 above), click **Next**. This will activate the Calculate dialog box.

2.6 Calculate

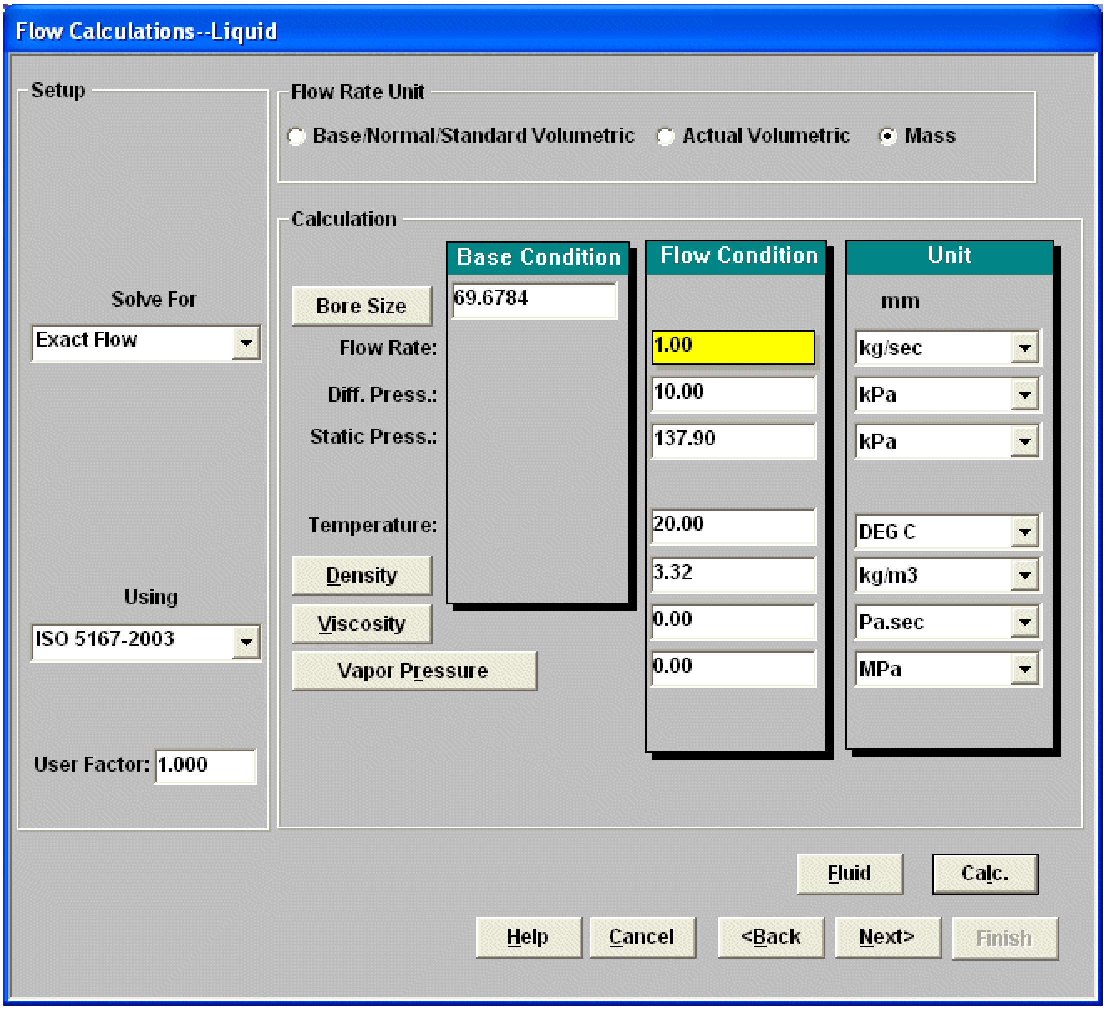
The Calculate dialog box is the area in which the final results are calculated. The Flowel program can solve for different variables. You select both the variable to solve for and the method in which that variable is solved. The list of methods available is dependent on your previous selections for fluid state, flow element type, differential pressure tap, and static pressure tap selection.

There are five versions of the calculate screen – one for each of the fluid states.

As you select different Solve options in the setup area, you may notice that some of the other fields change. This screen automatically activates the fields that are necessary to complete the equation. Only when the last of the required fields has valid data entered into it will the program be able to perform a calculation. Until then, it will warn you that there are fields that are incomplete.

The results of the calculation will be displayed in the colored field box.

Figure 2-6 Flow Calculation Dialog Box



Flow Rate Unit: ○ Base/Normal/Standard Volumetric ○ Actual Volumetric ● Mass

Solve For: Exact Flow

Using: ISO 5167-2003

User Factor: 1.000

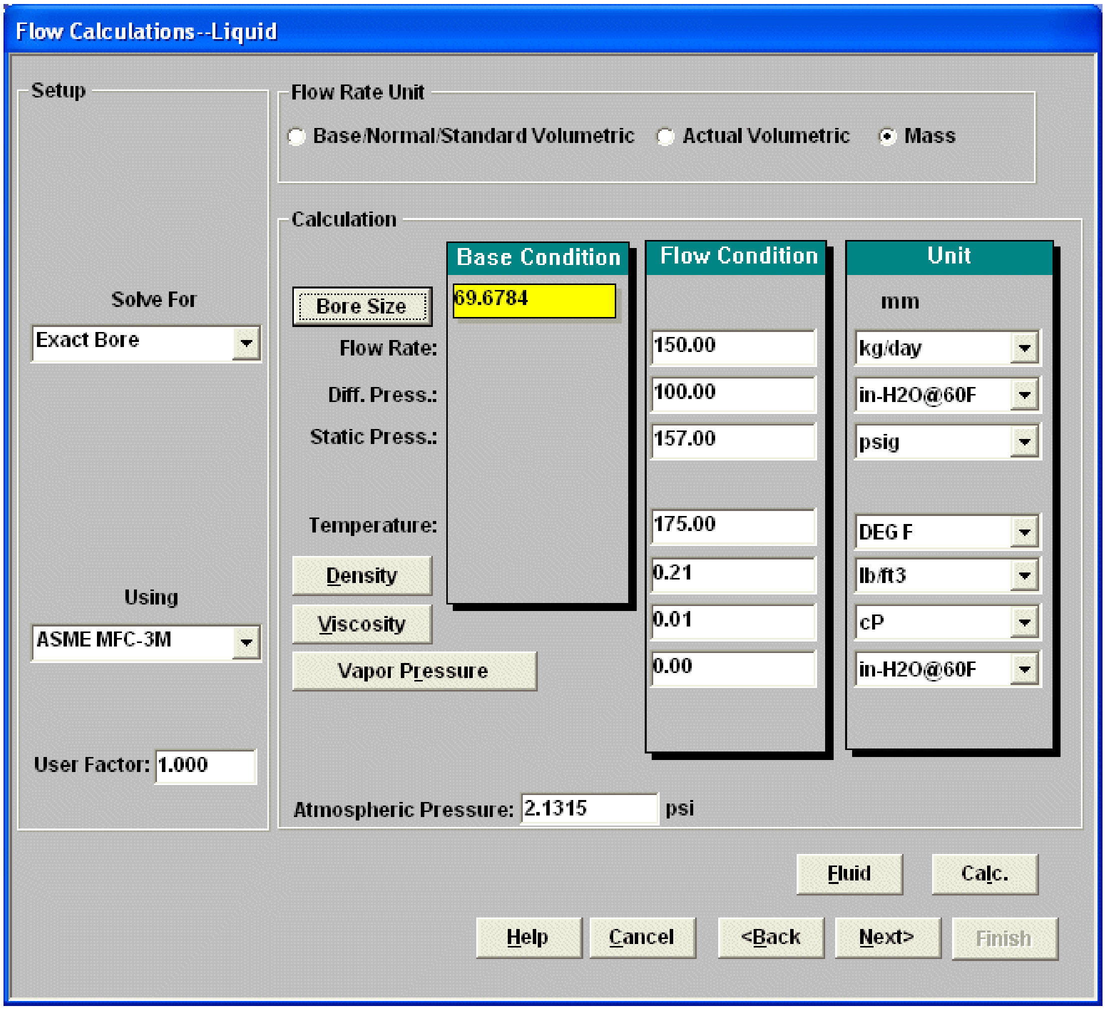
	Base Condition	Flow Condition	Unit
Bore Size	69.6784		mm
Flow Rate:		1.00	kg/sec
Diff. Press.:		10.00	kPa
Static Press.:		137.90	kPa
Temperature:		20.00	DEG C
Density		3.32	kg/m3
Viscosity		0.00	Pa.sec
Vapor Pressure		0.00	MPa

In this example, you will set up the program to solve for Exact Bore, using the ASME MFC-3M method. To set this up, do the following:

1. Select **Exact Bore** from the Solve For drop-down list and **ASME MFC-3M** from the **Using** drop-down list.

2. Ensure that all of the units are set for each of the fields. You do not have to use the default settings (even though you set them earlier). Enter the following values:
   - Flow Rate: 150 kg/day
   - Differential Pressure: 100 in-H20@60F
   - Static Pressure: 57 psig
   - Temperature: 175 DEG F
3. We can calculate the density of the fluid automatically because water is defined in the Flowel database. The program performs the necessary calculations based on the data we entered, and brings the results back into the calculate screen, as shown in Figure 2-7 below.

Figure 2-7 Flow Calculation Example – Solve For Exact Bore



Flow Calculations--Liquid

Setup

Solve For: Exact Bore

Using: ASME MFC-3M

User Factor: 1.000

Flow Rate Unit: ○ Base/Normal/Standard Volumetric ○ Actual Volumetric ● Mass

Calculation

	Base Condition	Flow Condition	Unit
Bore Size	69.6784		mm
Flow Rate:		150.00	kg/day
Diff. Press.:		100.00	in-H2O@60F
Static Press.:		157.00	psig
Temperature:		175.00	DEG F
Density		0.21	lb/ft3
Viscosity		0.01	cP
Vapor Pressure		0.00	in-H2O@60F

Atmospheric Pressure: 2.1315 psi

2.6.1 Density Calculator

To calculate density, do the following:

1. On the Flow Calculation dialog box, click **Density**.
2. Flowel will ask you to select a density solution method. The list which appears will reflect the possible options available given the current fluid state, fluid type, and fluid selected.
3. The temperature and pressure of the base and flow conditions will appear as entered into the calculate screen. These values will be used in the density calculation.
4. Scroll through the list to view the available methods. In this case, select the **NBS/NRC Steam Eqn.** method. You should normally always use this method for steam or water.
5. Click **Calculate** to retrieve the density values (see Section 2.6.1.1 below). The Calculate H_2O Flowing Density (NBS) Equation dialog box will appear.
6. Click **OK** to bring these values back to the Density Calculator dialog box.
7. On the Density Calculator dialog box, click **OK** to bring these values to the Calculate dialog box.

2.6.1.1 Water and/or Steam Calculations

The H_2O density calculator with the NBS equation operates as follows:

1. To calculate a flowing density, you are presented with three options:
   - H_2O saturated, use Temperature
   - H_2O saturated, use Pressure
   - H_2O not saturated, use Both Temp. and Press.

   (a) If **H_20 saturated, use Temperature** is selected, a saturated density at flowing temperature in the selected state (gas or liquid) is calculated. This state is selected in the Fluid Setting dialog box. The flowing pressure is changed to the pressure corresponding to the saturated temperature.

   (b) If **H_2O saturated, use Pressure** is selected, a saturated density at flowing pressure in the selected state (gas or liquid) is calculated. This state is selected in the Fluid Settings dialog box. The flowing temperature is changed to the temperature corresponding to the saturated pressure.

   (c) If **H_2O not saturated, use Both Temp. and Press.** is selected, a density at flowing temperature and flowing pressure is calculated. The density calculated may be either for a gas or a liquid depending on the temperature and pressure and may not correspond to the state selected in the Fluid Setting dialog box. Whether the calculated density is gas or liquid is determined by calculating the vapor pressure at the flowing temperature. If the flowing pressure is greater than the calculated vapor pressure, a liquid density is calculated. If the flowing pressure is less than the calculated vapor pressure, then a gas density is calculated. Neither the flowing temperature or pressure are changed.

2. To calculate the base density, always use both the base temperature and base pressure (no matter what method option is selected for flowing density). The density calculated may be either for a gas or a liquid depending on the temperature and pressure and may not correspond to the state selected on the fluid settings window. Whether the calculated density is gas or liquid is determined by calculating a vapor pressure at the base temperature. If the base pressure is greater than the calculated vapor pressure, a liquid density is calculated. If the base pressure is less than the calculated vapor pressure, a gas density is calculated. Neither the base temperature or pressure are changed.

2.6.2 Viscosity

Viscosity can be calculated automatically from the data entered in the program. If you have defined and configured the program as we have so far, click the **Viscosity** button to calculate the value. There are two occasions in which the Viscosity button will not appear: if the fluid properties option has not been purchased or the viscosity calculation is not available for the current fluid.

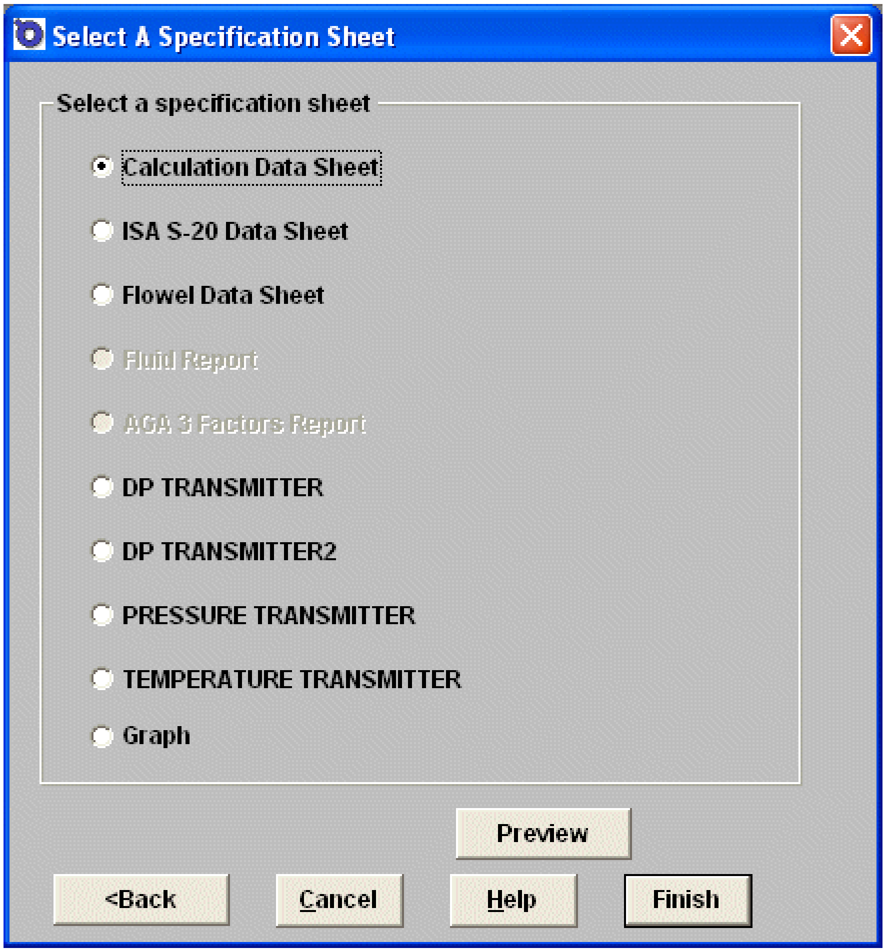
2.6.3 Vapor Pressure

The vapor pressure for the defined fluid can be automatically calculated if you have purchased this option.

To calculate vapor pressure, do the following:

1. On the Flow Calculation dialog box, click **Vapor Pressure**.
2. You are now prepared to ask Flowel to calculate the result. Click **Calc.**
3. The result of the calculation is shown in the Beta Ratio field. If you would like to know the bore size, click the **Beta Ratio/Bore Size** button to toggle this value.
4. Once you have completed your calculations, you may want to look at a graph or specification sheet of the function. Click **Next** to automatically branch to the Select A Specification Sheet dialog box (shown in Figure 2-8).

Figure 2-8 Select a Specification Sheet Dialog Box



Select A Specification Sheet

Select a specification sheet

● Calculation Data Sheet

○ ISA S-20 Data Sheet

○ Flowel Data Sheet

○ Fluid Report

○ AGA 3 Factors Report

○ DP TRANSMITTER

○ DP TRANSMITTER2

○ PRESSURE TRANSMITTER

○ TEMPERATURE TRANSMITTER

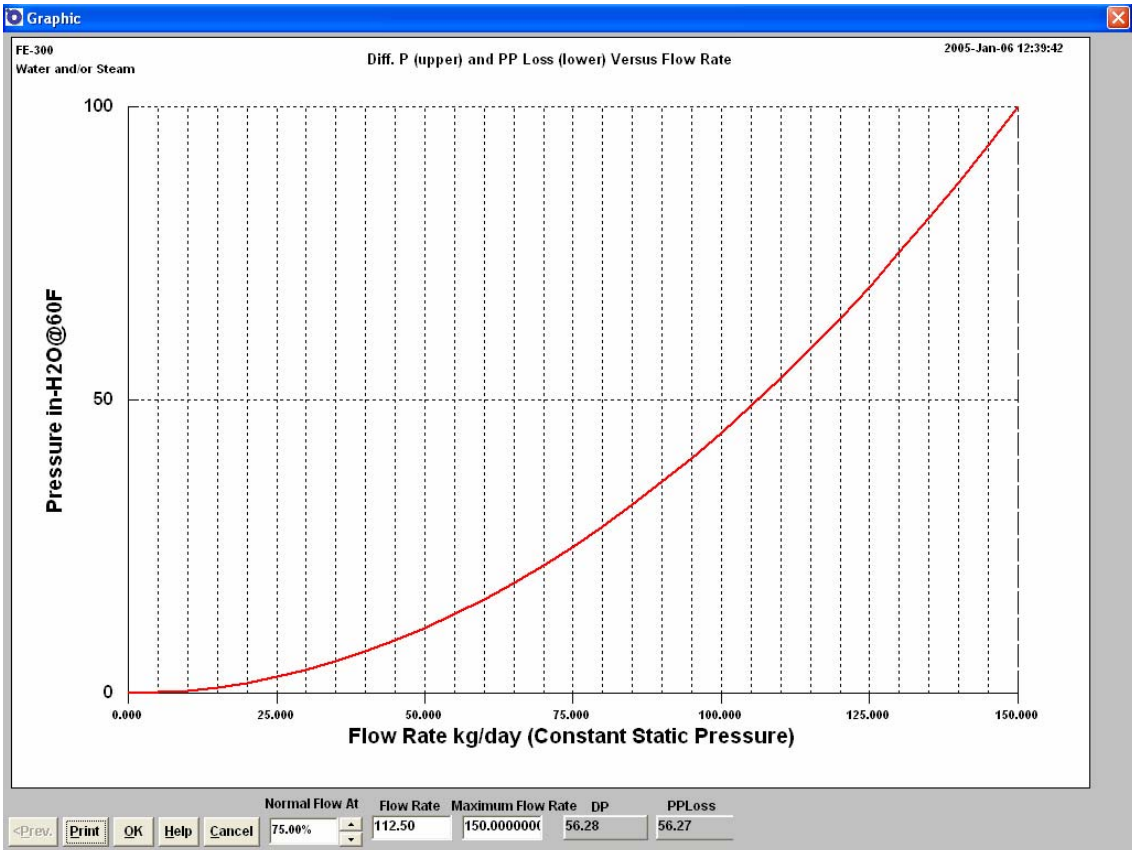
○ Graph

5. In this case, select **Graph**, and click **Preview** to view the graph.

2.7 *Graph*

A graph is shown of the relationship between flow rate and both differential pressure and permanent pressure loss, as shown in Figure 2-9.

Figure 2-9 Graph Dialog Box



Normal Flow At: 75.00%

Flow Rate: 112.50

Maximum Flow Rate: 150.000000(

DP: 56.28

PPLoss: 56.27

This function assumes a constant upstream pressure. To set the normal flow rate, do the following:

1. Adjust the percentage value which appears in the field at the bottom of the graph window. Adjust this value using the spin controls (up and down arrows) until the value which appears is the value you want.
2. If you do not set the normal flow rate, Flowel will not perform certain calculations such as the normal flow reading for meter charts.

This option displays the graph of the function in a scaleable window. Click **Print** to print the graph.

2.8 Specification Sheets and Reports

The Specification Sheet option allows you to view, edit, and print a specification sheet for the active tag. Much of the content will come directly from the information you have entered thus far. This dialog box will let you add the remaining type of information.

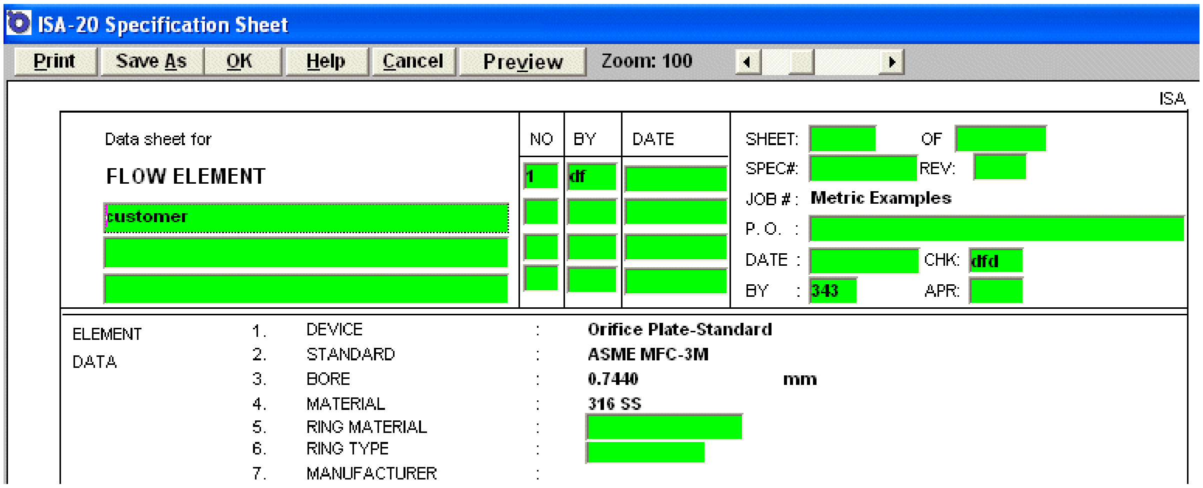
There are several sheets and reports to choose from, including:

- Calculate Data Sheet – provides a summary of the calculated data according to the information you have input to the program
- ISA S-20 Data Sheet – similar to the standards specified by ISA
- Flowel Data Sheet – expands on the ISA standard by facilitating the addition of information which is relevant and important to specifications
- Fluid Report – produces a listing of the fluid composition of the selected fluid, if it is a mixture
- AGA3 Factor Report – produces a listing of the factors used in an AGA 3 factors method, if the method being used is applicable
- DP Transmitter, DP Transmitter 2, Pressure Transmitter, and Temperature Transmitter – ISA S-20 specification sheet – allows users to keep all of the specification sheets for the flow element in one place

To complete a specification sheet or report, do the following:

1. On the **Worksheet** menu, click **Spec Sheet**, and for this example, choose **ISA S-20 Data Sheet**.

Figure 2-10 ISA S-20 Data Sheet



ISA

Data sheet for
FLOW ELEMENT
customer

NO	BY	DATE
1	df	

SHEET: OF
SPEC#: REV:
JOB # : Metric Examples
P. O. :
DATE : CHK: dfd
BY : 343 APR:

ELEMENT DATA
1. DEVICE : Orifice Plate-Standard
2. STANDARD : ASME MFC-3M
3. BORE : 0.7440 mm
4. MATERIAL : 316 SS
5. RING MATERIAL :
6. RING TYPE :
7. MANUFACTURER :

2. The program fills in all of the data it can from the information you have entered into the tag. All of the fields that remain to be filled in can be accessed using the **Tab** key.
3. The first available field for editing or adding data will appear with a box around it. A cursor will appear in the field. Once you are satisfied with the information that appears in this field, press **Tab**. The cursor will move to the next available field.
4. Continue until all of the information you require has been entered.

All of the specification sheets have a zoom control for viewing the form at different magnifications. This will allow you to preview the entire form clearly even on the most basic monitor. Slide the zoom scroll bar to the left to reduce the image and to the right to enlarge the image. The window itself is a standard window and is scaleable by dragging on any of its corners.

Each specification sheet can be printed directly from this screen. Click **Print** to print the current sheet.

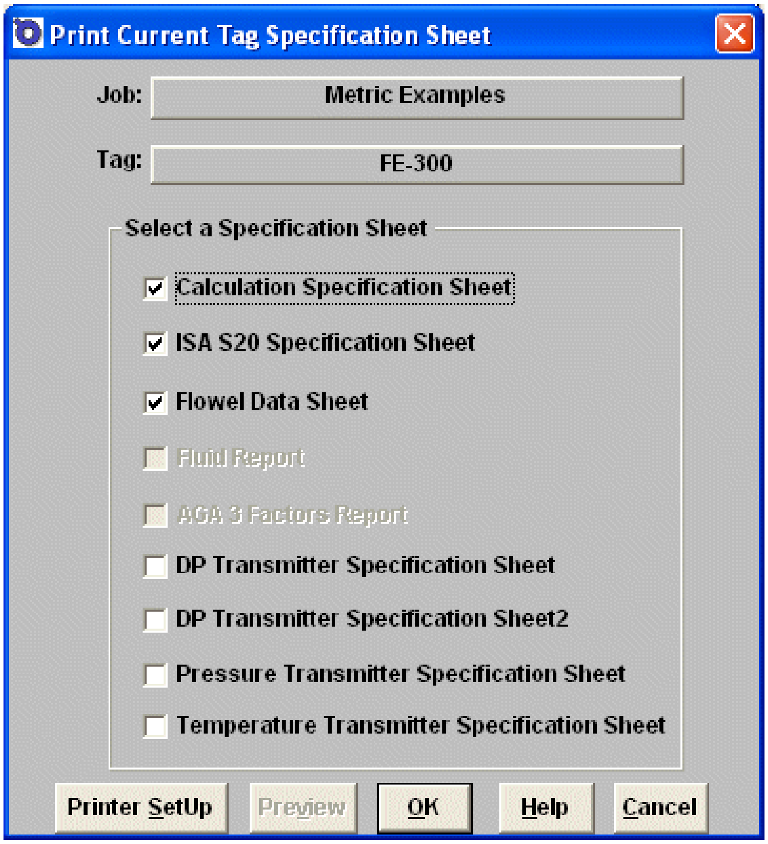
2.9 Printing

There are a number of printing options available for your use, depending on the output you require, including:

- Print Tag – print the information associated with a specific tag
- Print Spec – print all of the tags with the same specification number
- Print All – print all of the tags associated with a specific job

From the **File** menu, select the option which corresponds with the output you require. From each of these printing options, you may select the type of specification that the program will use, as shown in Figure 2-11.

Figure 2-11 Output Formats



Print Current Tag Specification Sheet

Job: Metric Examples

Tag: FE-300

Select a Specification Sheet

☑ Calculation Specification Sheet
☑ ISA S20 Specification Sheet
☑ Flowel Data Sheet
☐ Fluid Report
☐ AGA 3 Factors Report
☐ DP Transmitter Specification Sheet
☐ DP Transmitter Specification Sheet2
☐ Pressure Transmitter Specification Sheet
☐ Temperature Transmitter Specification Sheet

5. Select the check boxes next to the specification sheets you require and click **OK**.

2.9.1 Printer Setup

Each of the printing options allows you to activate the Window printer setup function by clicking on the **Printer SetUp** button. This permits you to make last minute changes to the setup, check that the printer settings are correct, or select another printer from those available.

2.9.2 Print Preview

The print dialog box also allows you to use the Print Preview function by clicking the **Preview** button. This function makes it possible to look at a representation of the printout before you send it to a printer. On the preview window, you will see a scaleable version of the form to be printed. If the preview is satisfactory, click **OK**. Printing will commence, followed by a confirmation message.

2.10 Customizing the Program

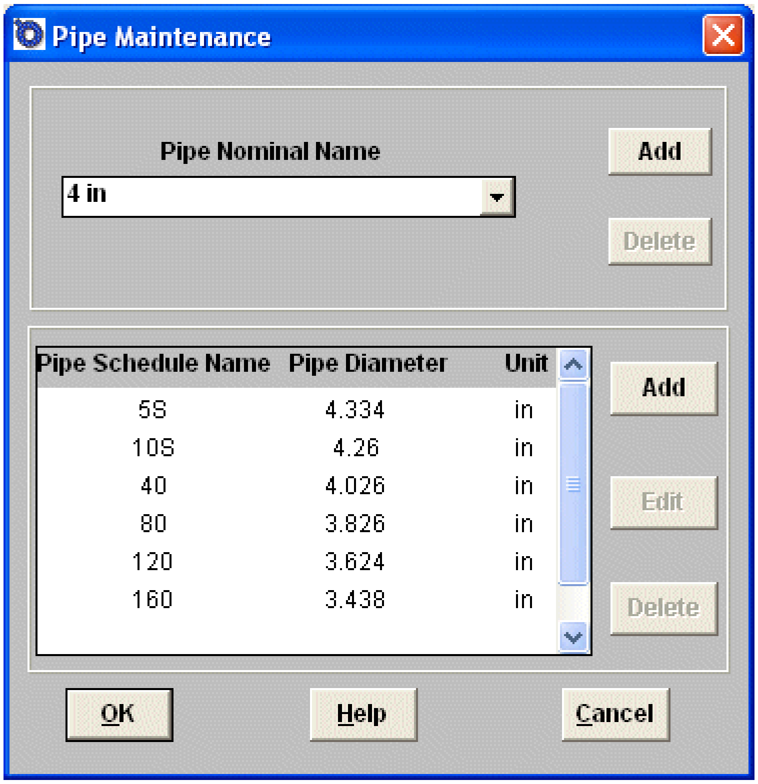
The program is usable immediately following installation, but there are some tasks you may want to do before you start working with the program. First, you will want to set the default units as we have done in the One Time Through example in Section 2.2. Doing this at the beginning means that every time you create a new job or tag, it will use your default units and will not require modification. Also, the program is shipped with an extensive database of fluids, pipe, and flow element materials. While this database is adequate for most users, your may require additional information.

Flowel is designed to help create and store fluids and materials. Use the definition dialog boxes to make these modifications.

2.10.1 Pipe Maintenance

To activate the pipe maintenance function, on the **User Data** menu, click **Pipe Maintenance**. The Pipe Maintenance dialog box appears, as shown in Figure 2-12.

Figure 2-12 Pipe Maintenance Dialog Box



Pipe Nominal Name: 4 in

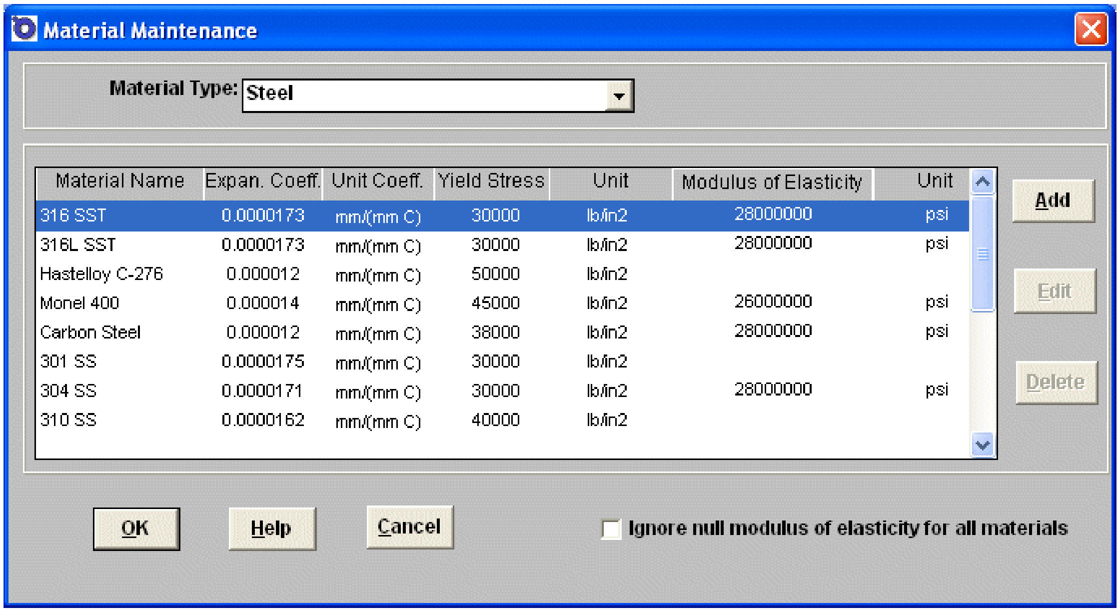
Pipe Schedule Name	Pipe Diameter	Unit
5S	4.334	in
10S	4.26	in
40	4.026	in
80	3.826	in
120	3.624	in
160	3.438	in

Add or change pipe specifications to suit your applications. Most standard pipe sizes and materials are already included in Flowel, so before adding a new pipe size be sure to check that it does not already exist.

2.10.2 Material Maintenance

To activate the material maintenance function, on the **User Data** menu, click **Material Maintenance**. The Material Maintenance dialog box appears, as shown in Figure 2-13.

Figure 2-13 Material Maintenance Dialog Box



Material Type: Steel

Material Name	Expan. Coeff.	Unit Coeff.	Yield Stress	Unit	Modulus of Elasticity	Unit
316 SST	0.0000173	mm/(mm C)	30000	lb/in2	28000000	psi
316L SST	0.0000173	mm/(mm C)	30000	lb/in2	28000000	psi
Hastelloy C-276	0.000012	mm/(mm C)	50000	lb/in2		
Monel 400	0.000014	mm/(mm C)	45000	lb/in2	26000000	psi
Carbon Steel	0.000012	mm/(mm C)	38000	lb/in2	28000000	psi
301 SS	0.0000175	mm/(mm C)	30000	lb/in2		
304 SS	0.0000171	mm/(mm C)	30000	lb/in2	28000000	psi
310 SS	0.0000162	mm/(mm C)	40000	lb/in2		

☐ Ignore null modulus of elasticity for all materials

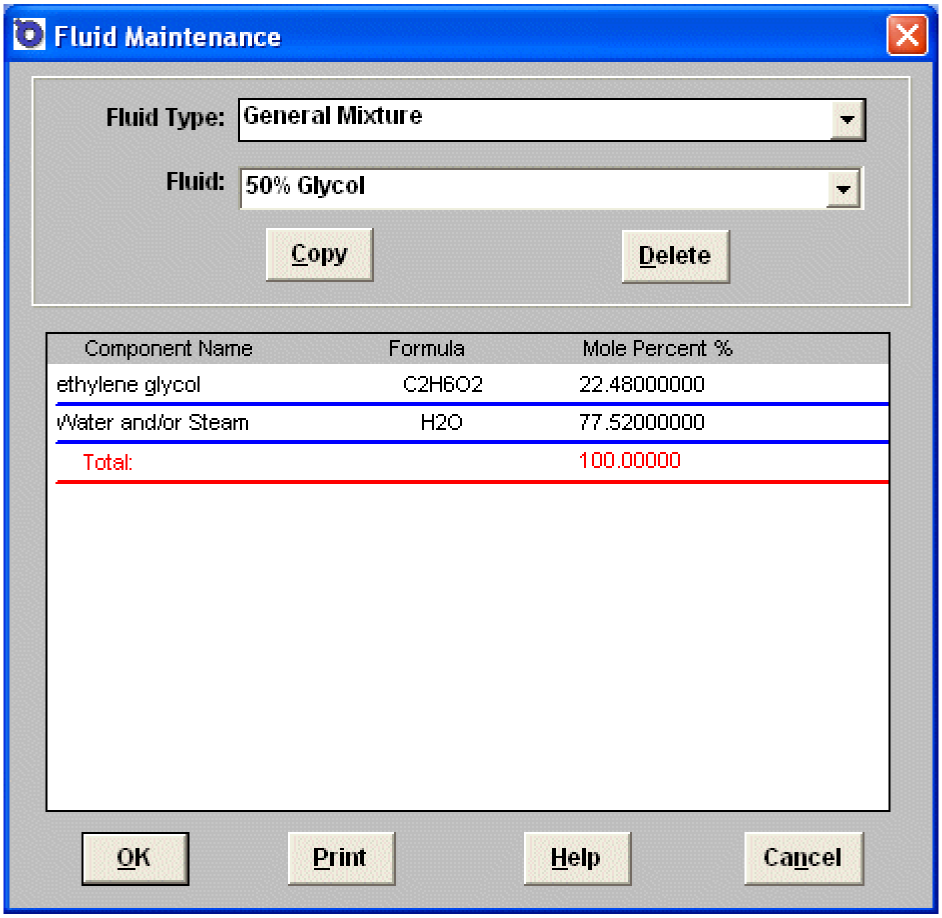
Add or change material specifications to suit your applications. A comprehensive list of materials is already included with Flowel, but you may add your own custom materials if you know the specifications.

2.10.3 Fluid Maintenance

To activate the fluid maintenance function, do the following:

1. On the **User Data** menu, click **Fluid Maintenance**. The Fluid Maintenance dialog box appears, as shown in Figure 2-14.

Figure 2-14 Fluid Maintenance Dialog Box



Fluid Type: General Mixture

Fluid: 50% Glycol

Component Name	Formula	Mole Percent %
ethylene glycol	C2H6O2	22.48000000
Water and/or Steam	H2O	77.52000000
Total:		100.00000

2. Add fluids that have the same composition as existing fluids, but have different mole fractions, or copy an existing fluid and adjust the mole fractions to suit the new mixture.

2.11 Examples and Applications

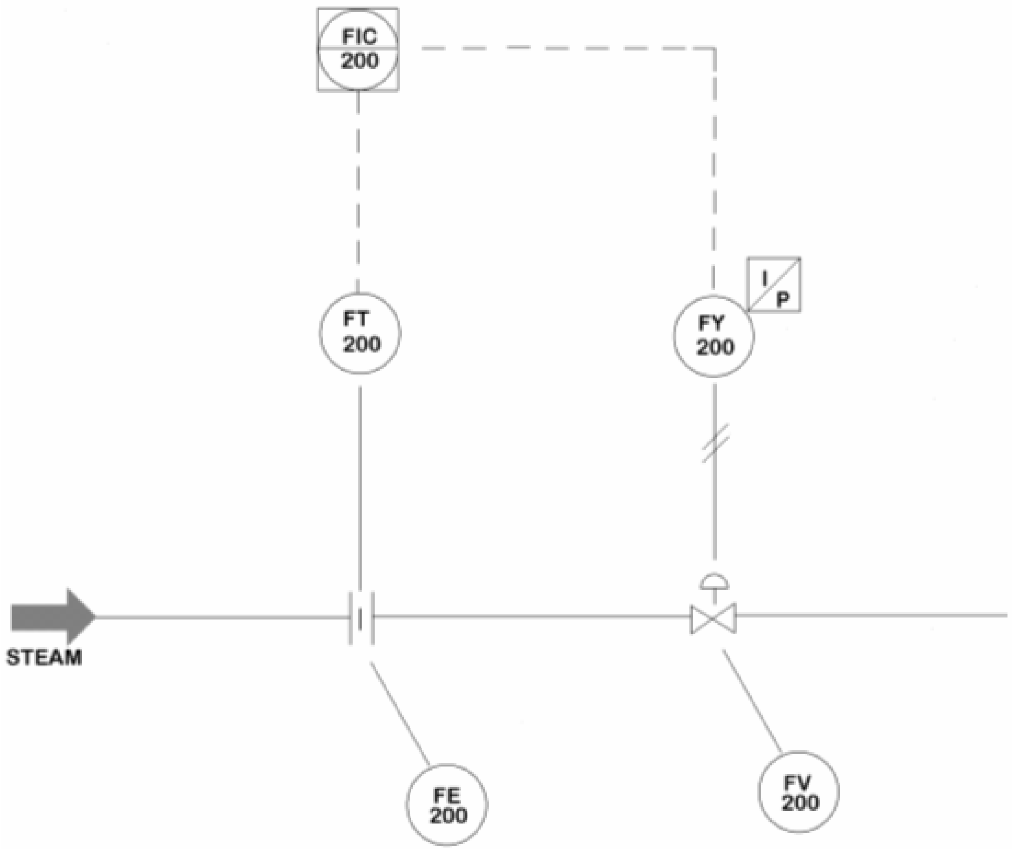
The following examples describe real-world applications of Flowel. The examples look at sample calculations and how they are implemented in Flowel.

Note: These examples are included with Flowel and have been installed with the program.

2.11.1 Example One

There is an existing single-loop controller on a steam line for which the flow rate will be increased. This example will illustrate how you can use Flowel to determine the new size required for the orifice plate.

Figure 2-15 Example One



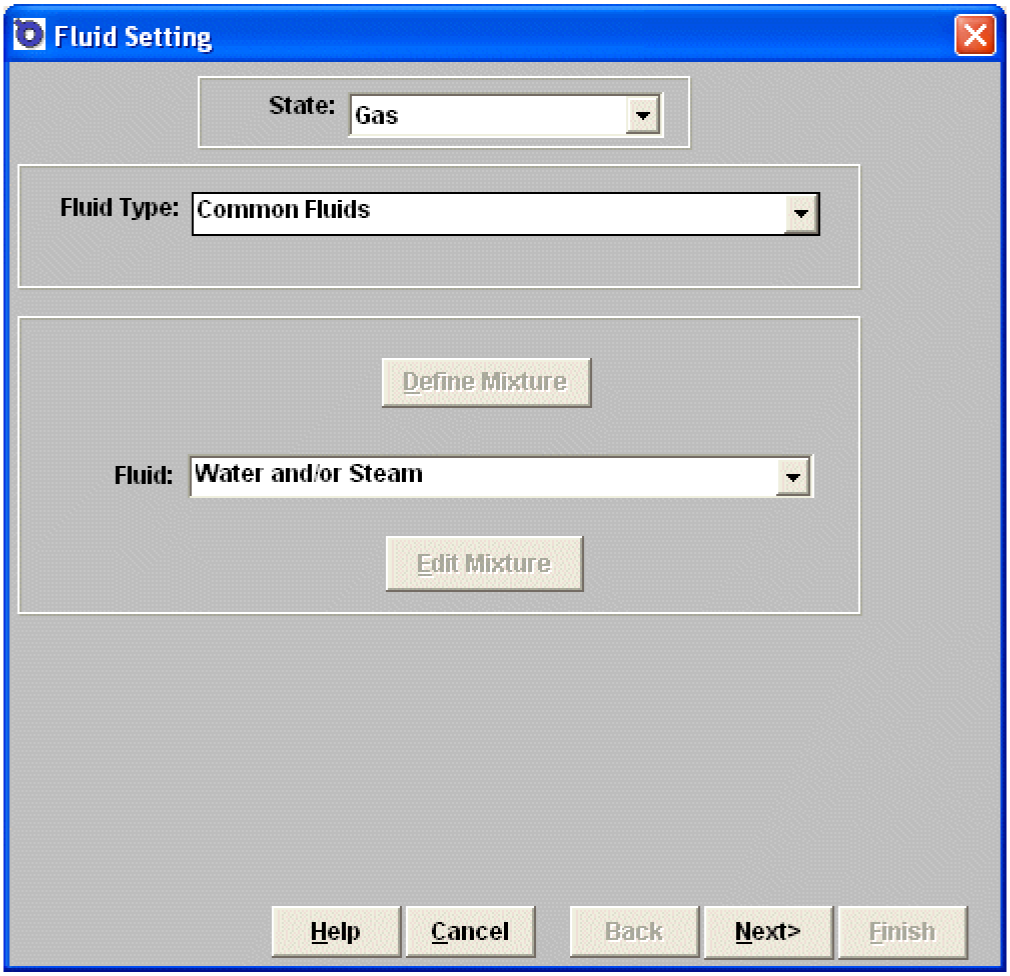
The tag number is FE-200. The information known about the system includes:

- 6" schedule 40 line composed of carbon steel
- upstream static pressure is 155 psig
- flowing temperature is 375°F
- normal flow rate will be about 8,500 lbs/hr
- existing meter uses radius differential pressure taps
- existing static pressure tap is upstream

To complete this example, do the following:

1. On the Flowel toolbar, click **Open Job** or on the **File** menu, click **Open Job**.
2. The Define a New Job dialog box will appear. From the Existing Jobs, select **US Examples**, and click **OK**.
3. Now we must retrieve the tag information. To do this, from the **File** menu, select **Open Tag**.
4. The Open a Tag dialog box appears. Select the **FE-200** tag, and click **Next**.
5. The Fluid Setting dialog box appears. This dialog is used to select the fluid state and type, and to define the fluid. For this example, select water in a gas state, as shown in Figure 2-16.

Figure 2-16 Example One – Fluid Setting



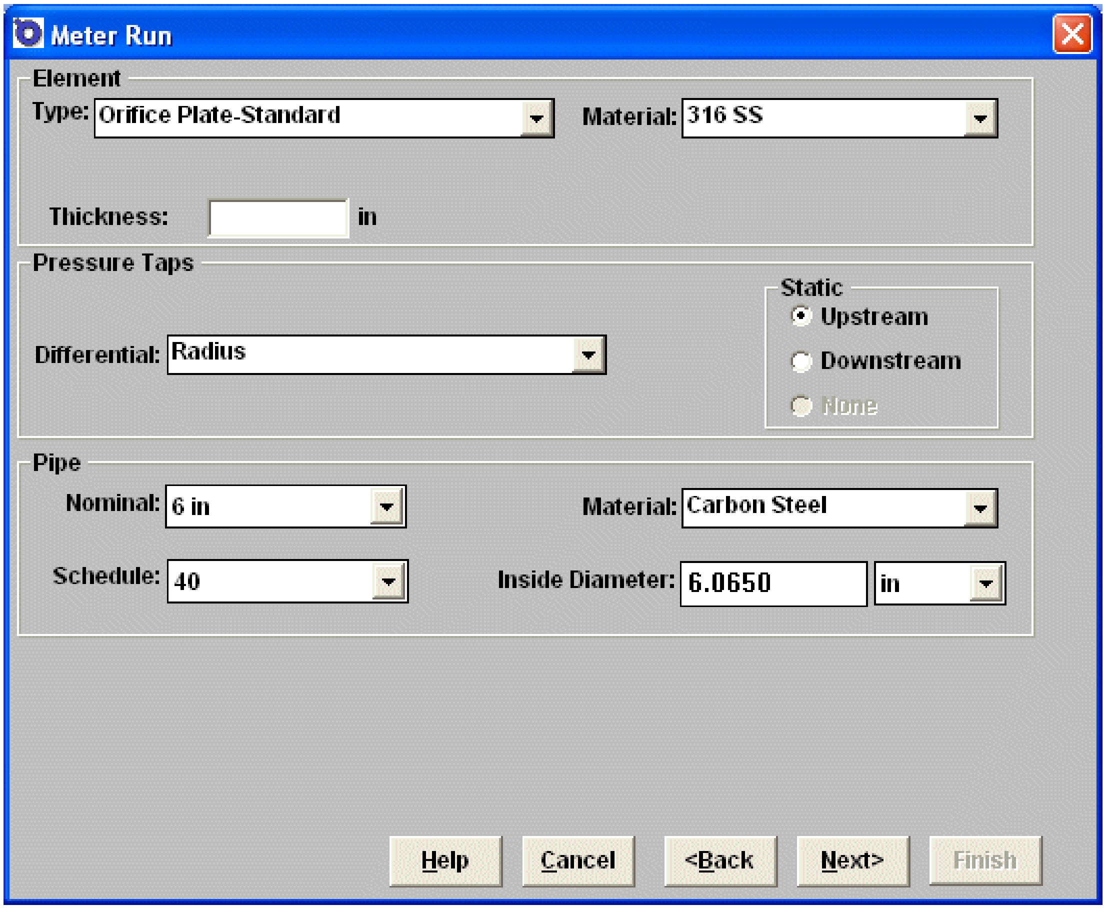
State: Gas

Fluid Type: Common Fluids

Fluid: Water and/or Steam

6. Click **Next**.
7. The Meter Run dialog box appears. For this example, select a standard orifice plate made of 316 stainless steel, as shown in Figure 2-17.

Figure 2-17 Example One – Meter Run



Meter Run

Element

Type: Orifice Plate-Standard

Material: 316 SS

Thickness: in

Pressure Taps

Differential: Radius

Static

● Upstream

○ Downstream

○ None

Pipe

Nominal: 6 in

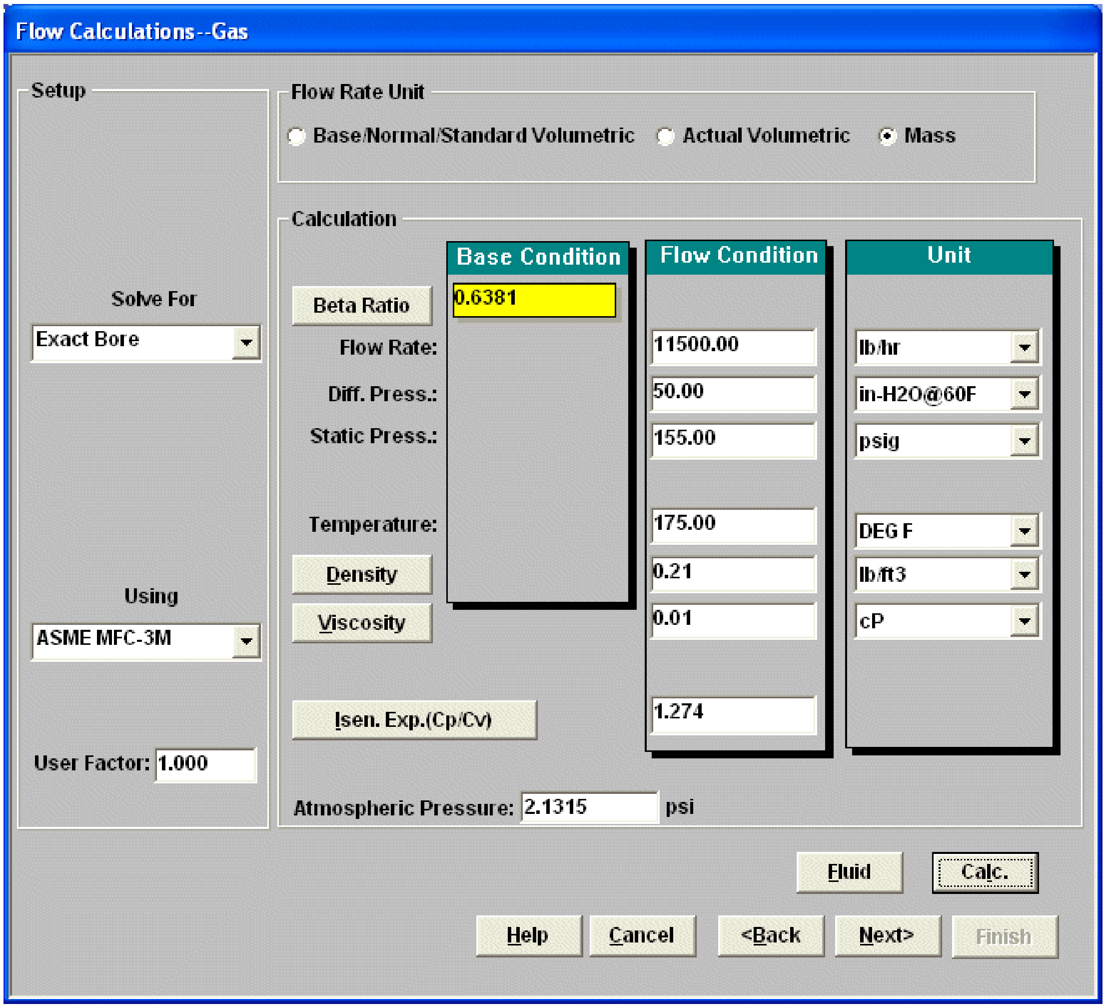
Material: Carbon Steel

Schedule: 40

Inside Diameter: 6.0650 in

8. Note that there are fields for defining the pressure taps and the pipe used in this meter run. These fields have been filled out as per the information given at the start of this example.
9. When all of the information is entered, click **Next**. The Flow Calculation dialog box appears.
10. Use the beta ratio button to toggle between displaying the beta ratio and the bore size for the calculated result.
11. For an orifice plate with radius taps, the options for methods available are ISO 5167 (1980), ISO 5167 (1991) and ASME MFC-3M. In North America, select ASME; in Europe, select ISO 5167.
12. If the normal flow rate is 8500 lb/hr, it is good practice to size the plate for a maximum flow that is 1.3 to 1.4 times larger. Lets use 11500 lb/hr. For differential pressure, start with a convenient value like 50 in-H2O. Use the appropriate calculator to calculate density, viscosity, and isentropic exponent.
13. Fill in the appropriate values as shown in Figure 2-18.

Figure 2-18 Example One – Flow Calculation



Flow Calculations--Gas

Setup

Solve For: Exact Bore

Using: ASME MFC-3M

User Factor: 1.000

Flow Rate Unit: ○ Base/Normal/Standard Volumetric ○ Actual Volumetric ● Mass

Calculation

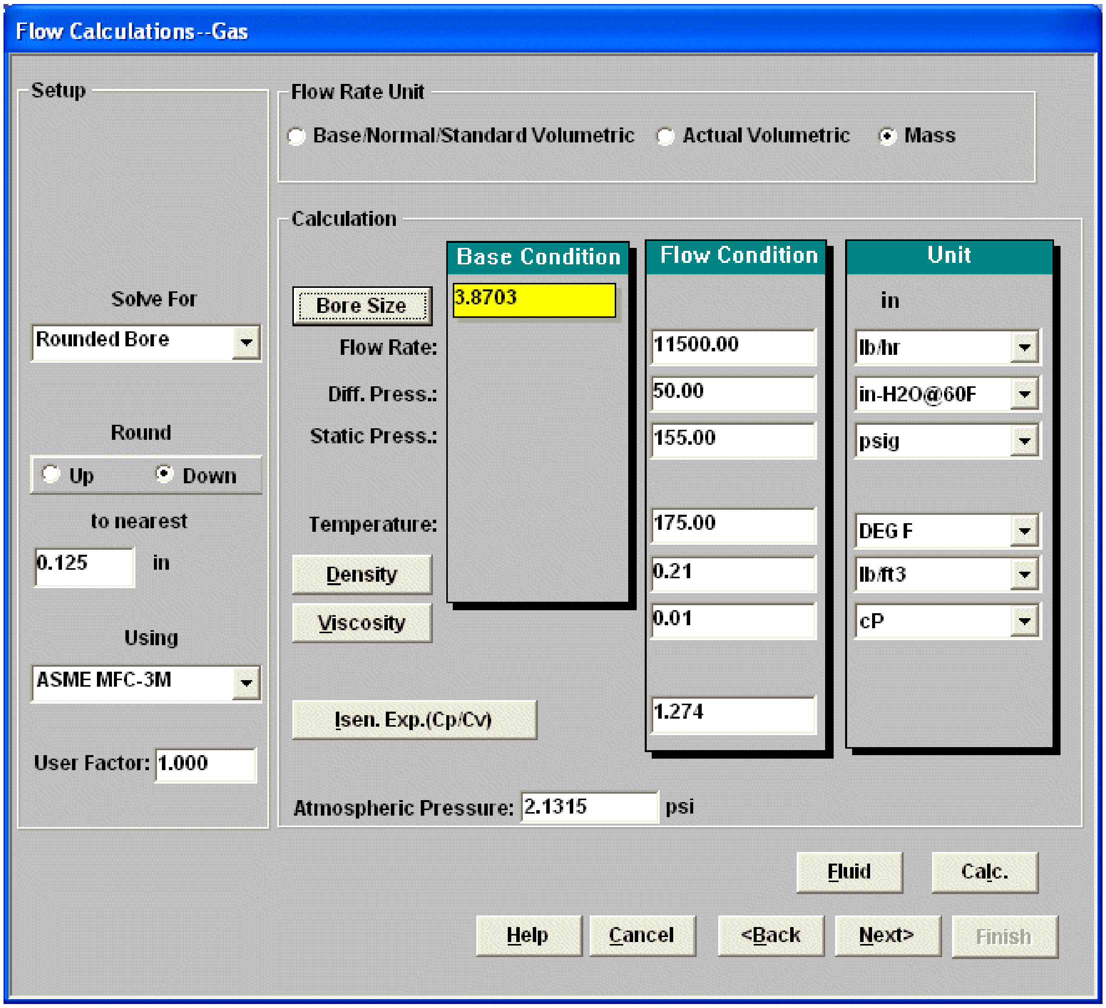
	Base Condition	Flow Condition	Unit
Beta Ratio	0.6381		
Flow Rate:		11500.00	lb/hr
Diff. Press.:		50.00	in-H2O@60F
Static Press.:		155.00	psig
Temperature:		175.00	DEG F
Density		0.21	lb/ft3
Viscosity		0.01	cP
Isen. Exp.(Cp/Cv)		1.274	

Atmospheric Pressure: 2.1315 psi

Note: Refer to Section 2.6.1 for details on density calculations and water and/or steam calculations.

14. If you want the beta ratio to be higher, try a differential value of 100 in-H20. Click **Calc.** to recalculate the equation. The beta ratio changes.
15. Next, you may want to use an orifice plate from your existing inventory. Stock plates come in 1/8 inch sizes. Solve for Rounded Bore by picking the **Rounded Bore** option from the Solve For selections. Set the “round” setting to down and the “to nearest” to 0.125 in. Click **Calc.**
16. Click **Beta Ratio** to toggle the display from beta ratio to bore size. The value that appears is shown with its units (shown in Figure 2-19).

Figure 2-19 Example One – Calculated Bore Size



Flow Calculations--Gas

Setup

Solve For: Rounded Bore

Round: ○ Up ● Down

to nearest 0.125 in

Using: ASME MFC-3M

User Factor: 1.000

Flow Rate Unit: ○ Base/Normal/Standard Volumetric ○ Actual Volumetric ● Mass

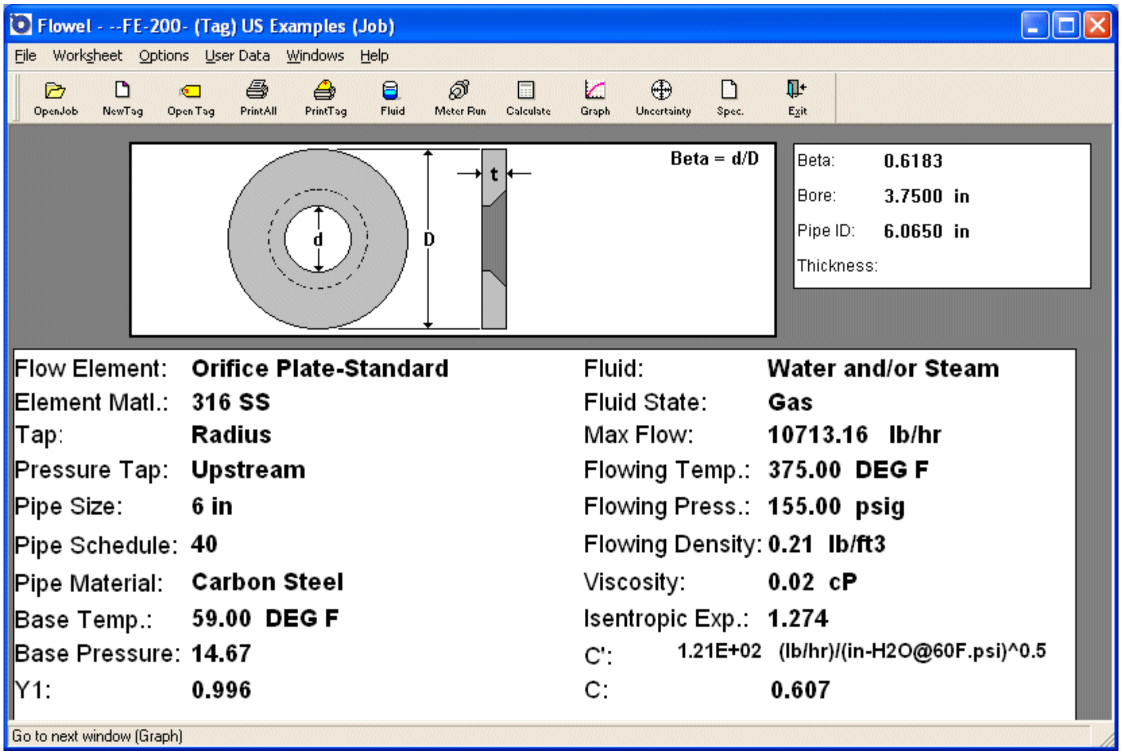
Calculation

	Base Condition	Flow Condition	Unit
Bore Size	3.8703		in
Flow Rate:		11500.00	lb/hr
Diff. Press.:		50.00	in-H2O@60F
Static Press.:		155.00	psig
Temperature:		175.00	DEG F
Density		0.21	lb/ft3
Viscosity		0.01	cP
Isen. Exp.(Cp/Cv)		1.274	

Atmospheric Pressure: 2.1315 psi

17. Now that a bore size has been successfully calculated, click **Next**.
18. The Select a Specification Sheet dialog will appear. Select the specification sheet you would like to preview and click **Preview** (or click **Finish** to exit).
19. In the specification sheet preview, click **OK** to close the window. Now that you are done entering data, the program displays a summary screen which shows the results of your work (shown in Figure 2-20).

Figure 2-20 Example One – Summary Screen



Beta: 0.6183
Bore: 3.7500 in
Pipe ID: 6.0650 in
Thickness:

Flow Element:	**Orifice Plate-Standard**	Fluid:	**Water and/or Steam**
Element Matl.:	**316 SS**	Fluid State:	**Gas**
Tap:	**Radius**	Max Flow:	**10713.16 lb/hr**
Pressure Tap:	**Upstream**	Flowing Temp.:	**375.00 DEG F**
Pipe Size:	**6 in**	Flowing Press.:	**155.00 psig**
Pipe Schedule:	**40**	Flowing Density:	**0.21 lb/ft3**
Pipe Material:	**Carbon Steel**	Viscosity:	**0.02 cP**
Base Temp.:	**59.00 DEG F**	Isentropic Exp.:	**1.274**
Base Pressure:	**14.67**	C':	1.21E+02 (lb/hr)/(in-H2O@60F.psi)^0.5
Y1:	**0.996**	C:	**0.607**

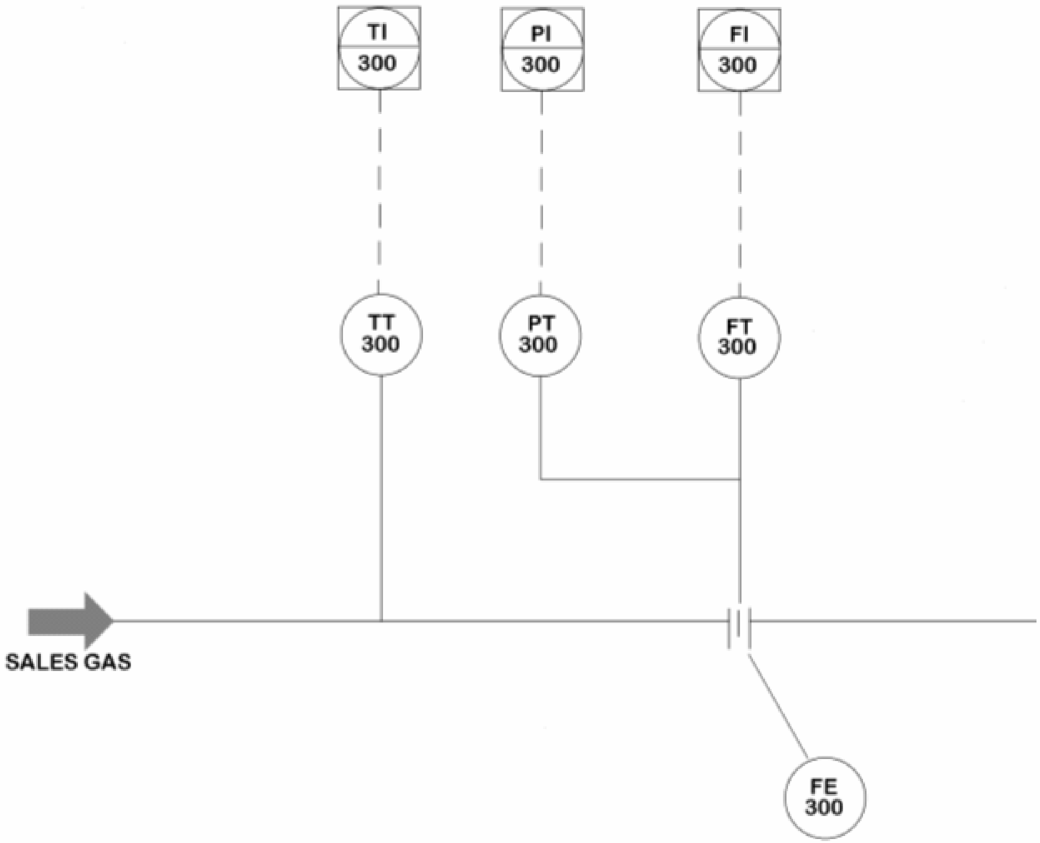
Go to next window (Graph)

20. Print out a datasheet for this newly calculated tag. On the Flowel toolbar, select **Spec. Sheet** and click the **Calculation Data Sheet** from the specification sheets available.
21. The Calculation Data Sheet window appears. This window displays a preview of the sheet as it will be printed, but this screen also allows you to enter additional information which could not be found in the data entered in so far. These fields appear on the screen as highlights. You can scroll around this screen, as well as zoom in and out.
22. When you have completed this form, click **Print** to print the form.

2.11.2 Example Two

This situation involves an existing sales gas meter. You must validate the results of the meter at a certain flow rate. The flow rate will be calculated using AGA 3 (92). Gas density will be calculated using AGA 8 (92). Determine the volumetric flow rate at standard conditions and associated uncertainty.

Figure 2-21 Example Two



The tag number in this example is FE-300. The information known about the system includes:

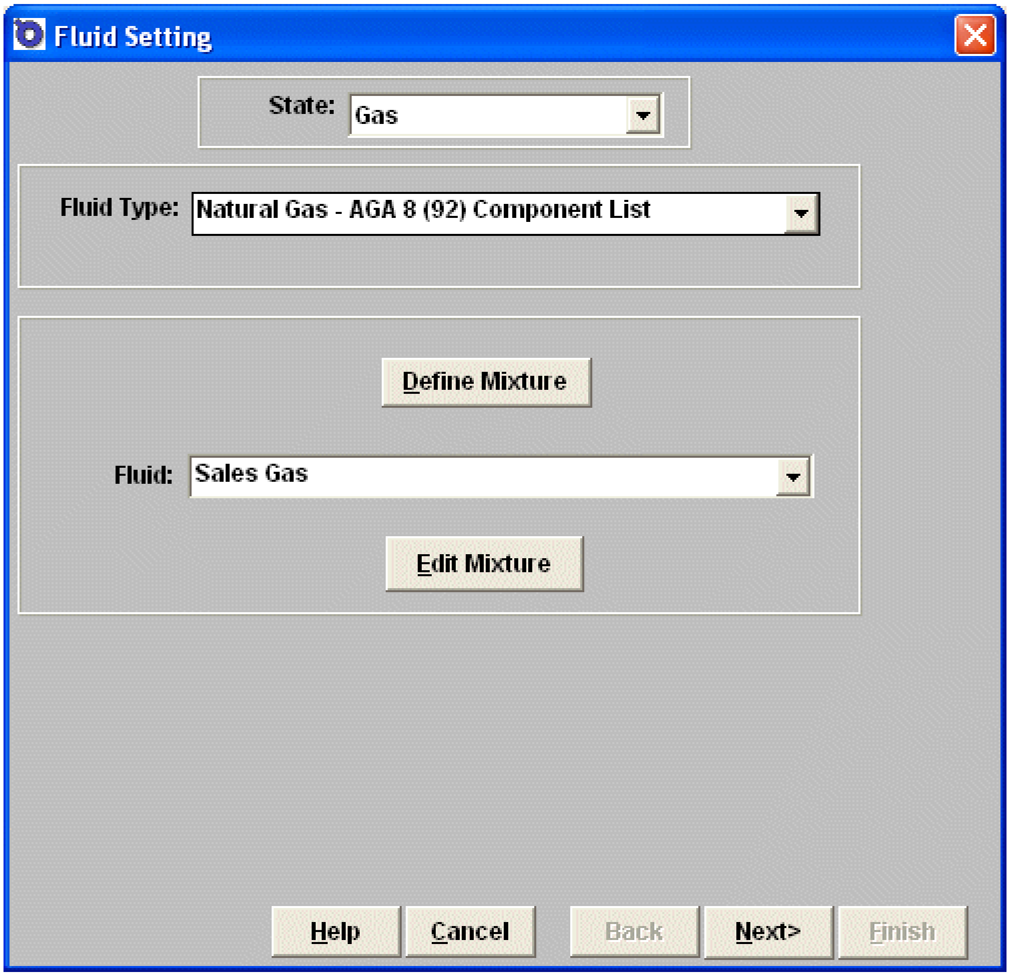
- pipe is 8”, schedule 40
- composition is known from lab tests done with a gas chromatograph
- upstream pressure is 5,850 kPa
- flowing temperature is 45 C
- bore size is 105 mm

To complete this example, do the following:

1. Open the Job labeled **Metric Examples** and open tag **FE-300**, using techniques previously shown.
2. On the **Worksheet** menu, click **Fluid** (or click **Fluid** on the Flowel toolbar).
3. This gas has already been defined for you. Ensure the state is Gas, and select Fluid type **Natural Gas AGA 8 (92) Component List**, as shown in Figure 2-22.

   Note: Flowel supports more than 600 pure fluids, plus user-defined mixtures. The Fluid type selection is used to narrow down the number of fluids that appear in the Fluid list box.

Figure 2-22 Example Two – Fluid Setting



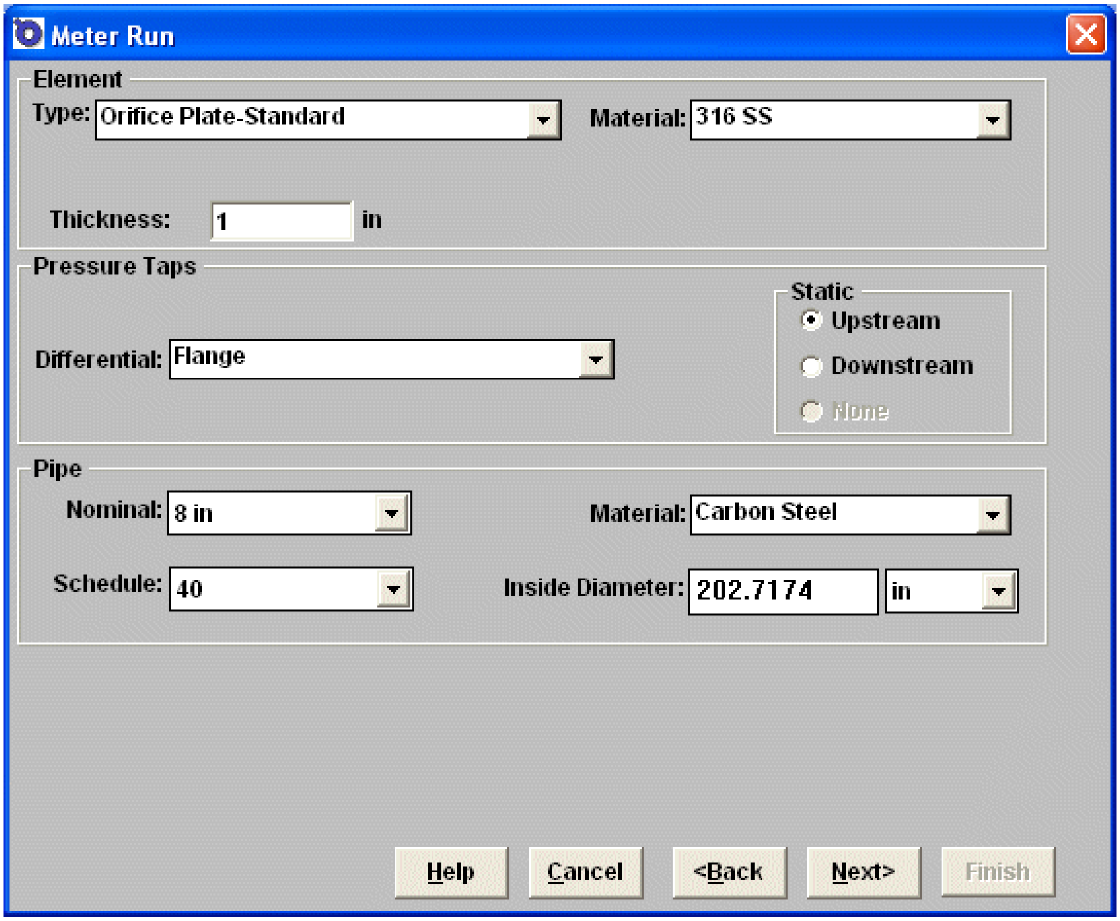
State: Gas

Fluid Type: Natural Gas - AGA 8 (92) Component List

Fluid: Sales Gas

4. Select **Sales Gas** from the Fluid drop-down list.
5. Click **Edit Mixture** to review the gas composition. Gas composition is derived from lab results of gas chromatography performed on a Sales Gas sample. The gas composition with corresponding mole percentage values for each component is shown on the mixture editing dialog. The mole percentage values can be edited at this point. Click **OK**.
6. Click **Next** to continue.
7. In the Meter Run dialog, enter the required information for this example, as shown in Figure 2-23.

Figure 2-23 Example Two – Meter Run



Element

Type: Orifice Plate-Standard

Material: 316 SS

Thickness: 1 in

Pressure Taps

Differential: Flange

Static

● Upstream

○ Downstream

○ None

Pipe

Nominal: 8 in

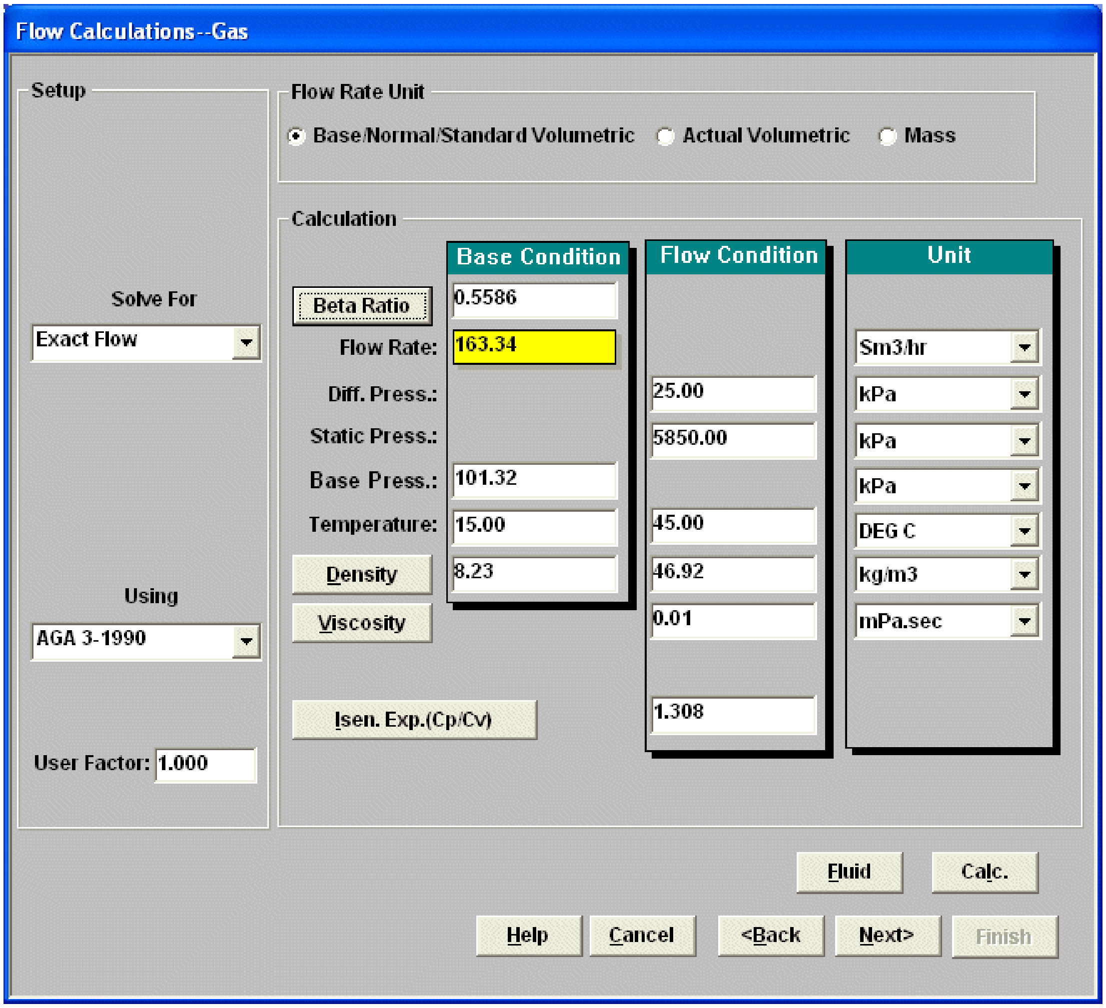
Material: Carbon Steel

Schedule: 40

Inside Diameter: 202.7174 in

8. Click **Next** to continue. The Flow Calculation dialog box appears.
9. Select and insert the values as shown in Figure 2-24 (these values were provided at the beginning of this example).

Figure 2-24 Example Two – Flow Calculation



Flow Calculations--Gas

Flow Rate Unit: ● Base/Normal/Standard Volumetric ○ Actual Volumetric ○ Mass

Solve For: Exact Flow

Using: AGA 3-1990

User Factor: 1.000

	Base Condition	Flow Condition	Unit
Beta Ratio	0.5586		
Flow Rate:	163.34		Sm3/hr
Diff. Press.:		25.00	kPa
Static Press.:		5850.00	kPa
Base Press.:	101.32		kPa
Temperature:	15.00	45.00	DEG C
Density	8.23	46.92	kg/m3
Viscosity		0.01	mPa.sec
Isen. Exp.(Cp/Cv)		1.308	

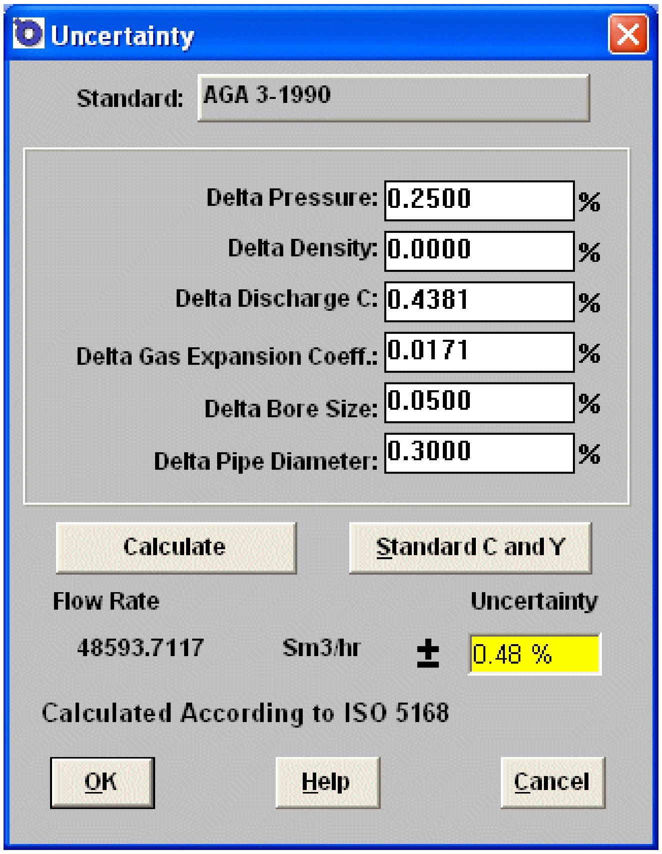
10. This flow calculation uses flow units of standard cubic meters per hour (Sm3/hr). Notice that the Flow Rate box appears in the base condition column. This indicates that the displayed flow will be at base conditions, not flowing conditions.
11. Any time you select a normal (e.g., Nm3/hr) or standard (e.g., Sm3/hr) volumetric flow unit, Flowel moves the flow rate edit box to the base condition column. Also, edit boxes will appear for the base temperature and pressure.
12. If you select a mass (e.g., kg/m3) or volumetric (e.g., m3/hr) flow unit, the program moves the flow rate edit box to the flowing condition column. The edit boxes for base temperature and pressure disappear.
13. The reason for this dynamic behavior is actually quite straight forward. Internally, Flowel performs all flow calculations using mass flow rate. If you want to enter a volumetric flow rate, Flowel needs to know the density: mass flow rate = volumetric flow rate x density. The following table illustrates the conversion process.

Table 2-2 Conversion Process

Flow Rate Unit	Required Inputs
volumetric flow rate such as m3/hr	• flow rate at flowing conditions • density at flowing conditions
mass flow rate such as kg/m3	• flow rate at flowing conditions • density at flowing conditions (required for calculation of fluid velocity, but not for volume to mass conversion)
volumetric flow rate at a standard or normal conditions such as Sm3/hr or Nm3/hr	• flow rate at base conditions • density at flowing conditions • density at base conditions • pressure at base conditions • temperature at base conditions

14. Click **Density** to activate the density calculator. Use the AGA 8 (1992), Detailed method. For natural gas, this is the most accurate method available and should be your first choice.
15. Close the Density Calculator dialog box and then, click **OK** to close the Flow Calculation dialog box.
16. On the Flowel toolbar, click **Uncertainty**. The Uncertainty dialog appears, as shown in Figure 2-25.

Figure 2-25 Example Two – Uncertainty



Standard: AGA 3-1990

Delta Pressure: 0.2500 %
Delta Density: 0.0000 %
Delta Discharge C: 0.4381 %
Delta Gas Expansion Coeff.: 0.0171 %
Delta Bore Size: 0.0500 %
Delta Pipe Diameter: 0.3000 %

Flow Rate: 48593.7117 Sm3/hr
Uncertainty: ± 0.48 %

Calculated According to ISO 5168

17. The uncertainty calculation uses a method described in the ISO 5168 standard. The uncertainties associated with the discharge coefficient and the gas expansion coefficient depend on the flow calculation standard method. In this case, the standard is AGA 3-1990. Flowel calculates these uncertainties for you.
18. The uncertainty in pressure depends on the accuracy of the pressure sensing instrument. In this case, we have used a quarter percent as a typical value for a modern temperature transmitter. Most instrument manufacturers provide methods to determine instrument uncertainty.
19. The uncertainty for the bore size and pipe diameter will be filled in by Flowel. It will use the minimum uncertainty values specified in the flow calculation standard. In this case, AGA 3-1990 states that bore size must be within 0.05% of the desired value. Similarly, the pipe diameter must be known within 0.5 %. The best way to confirm these values is to actually measure the plate and pipe.
20. The uncertainty associated with density is a complicated issue, and a complete discussion is outside the scope of this manual. However, one approach would be to use AGA 8 to calculate density using various compositions. Vary the compositions to reflect the uncertainty of the chromatograph and the variations in compositions. The range of densities thus calculated, assuming AGA 8 is perfectly accurate, represents the density uncertainty.

§

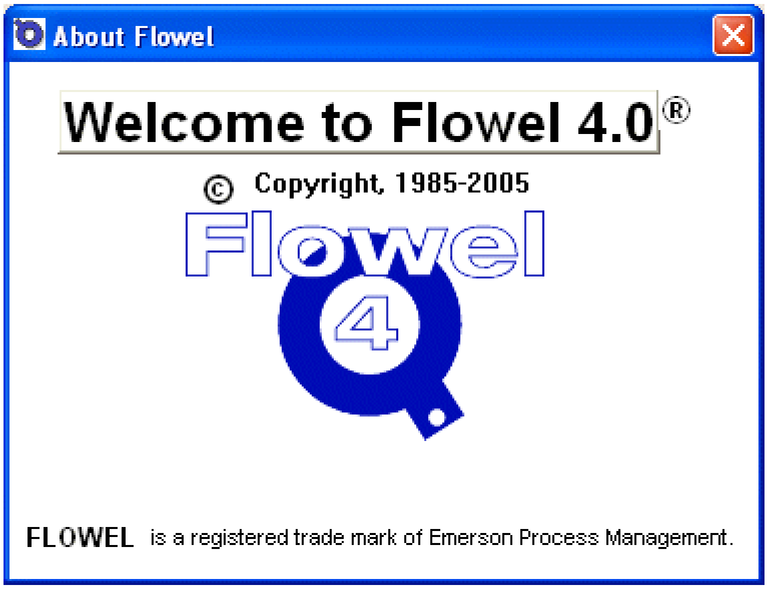
3 User Reference

The User Reference section of this manual describes all menus and functions found within Flowel 4®. This section is organized alphabetically. Please use the table of contents to find a topic, or the index to get to an exact page number for the subject matter.

3.1 About Menu Item

To activate the About menu item, type Alt-H-A, or on the **Help** menu, click **About**.

This dialog box contains the program name and version, copyright notice, and logo. For customer support information consult the index, or use the online help system.



Welcome to Flowel 4.0®

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3.2 AGA 3 Factors Report

To access the AGA 3 Factors Report, type Alt-S-S-A, or under the **Worksheet** menu, select **Spec Sheet,** and click **AGA 3 Factor Report**.

Description

The AGA-3 Factors Report is a datasheet containing information related to the AGA-3 calculation–factors approach–for a tag, including a listing of factors. The factors are not used to calculate flow, and are provided only for reference. Be careful when using factors to calculate the flow rate. The pressure used in the flowing equations must be the absolute static pressure P_1. $Q_v = C' \sqrt{Pxh}w$

Notes:

1. When this option is selected, the factors report will print only if the method used for the selected tag is AGA 3 and the fluid state is gas. If a multiple-tag printing function is selected, only those tags using AGA 3 will have a factors report printed for them.
2. The heating value will be available for natural gas with the AGA 8 method only. Some of the fields may be blank if not enough information is available. The recommended use of this report is for natural gas with a defined fluid composition.
3. Job and tag related fields can be edited through the Calculate Data, ISA-S20, and Emerson data sheets.

Please see Appendix A for the definitions of the factors. These definitions are extended over the original AGA definitions. Flowel supports all unit types for these factors.

Related topics include:

- Print All
- Print Spec
- Print Tag

3.3 Atmospheric Pressure

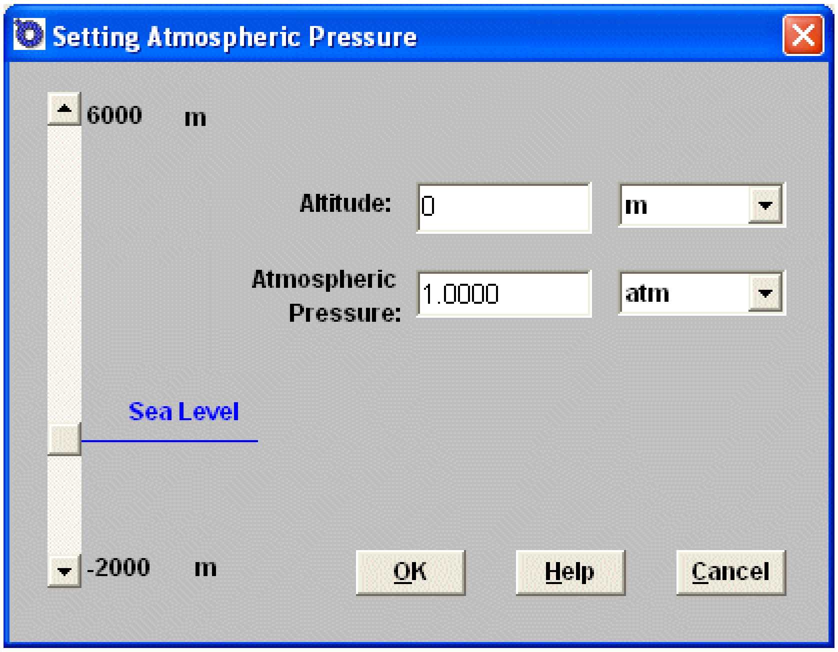
To change the default pressure function, type Alt-O-A, or under the **Options** menu, click **Atmospheric Pressure**.

Description

Use the Atmospheric Pressure function to set the altitude/atmospheric pressure for this tag. The atmospheric pressure will only be used when a gauge pressure unit is selected, or when changing from a gauge to absolute pressure and vice versa. The atmospheric pressure will be added to the gauge pressure to produce an absolute pressure used in the flow calculations.

The atmospheric pressure is NOT the same as the base pressure.

Figure 3-1 Atmospheric Pressure Dialog Box



Altitude: 0 m

Atmospheric Pressure: 1.0000 atm

First, select the units for altitude and atmospheric pressure if they are not correct. Next, you have two ways of setting the pressure: click and drag the scroll bar up or down until the correct values appear in the fields, or enter either altitude or atmospheric pressure directly into the appropriate field.

Once the gauge pressure has been set, click **OK**. This value is saved and will be used as the new default gauge pressure for the next new tag.

Note: Atmospheric pressure can also be changed for an individual tag on the Calculate dialog box.

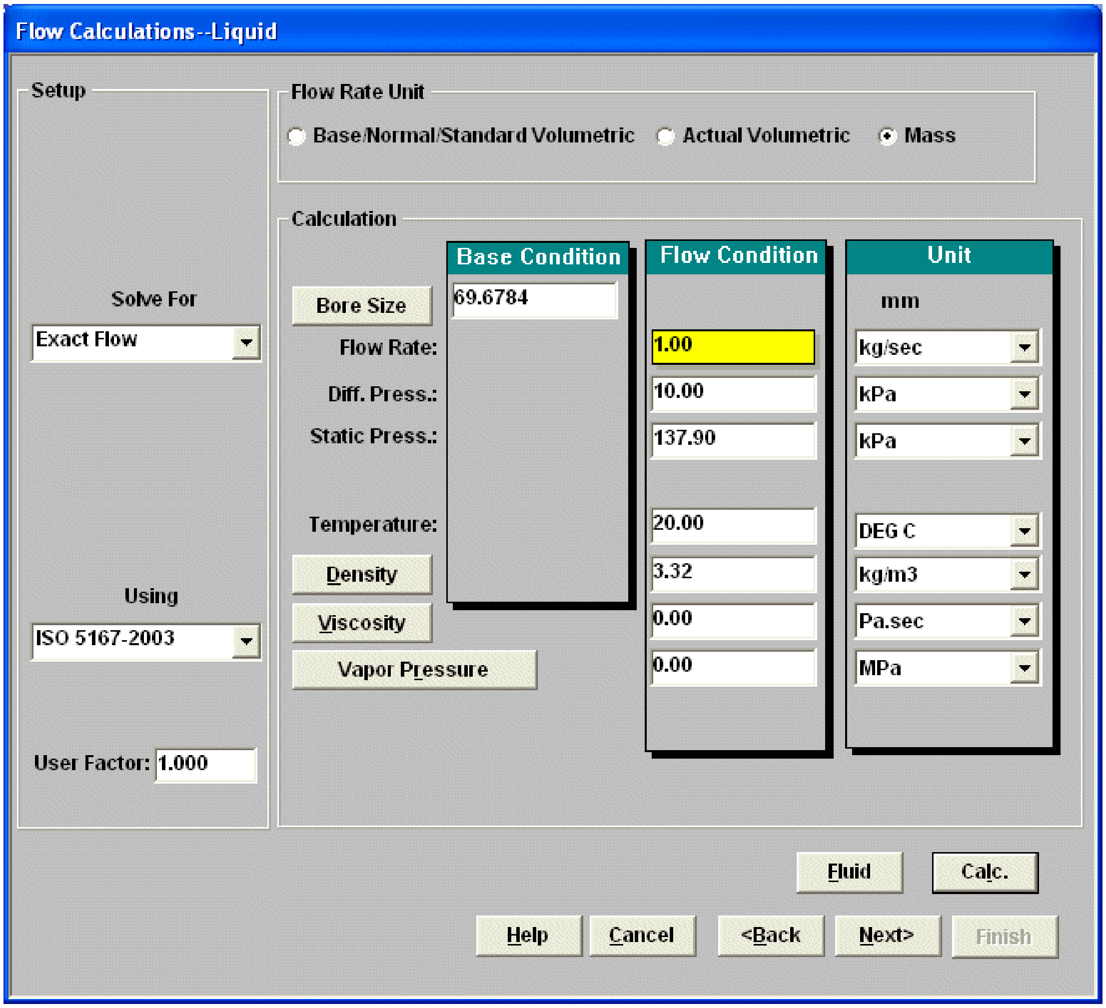
3.4 Calculate

To activate the calculate function, type Alt-S-C, or under the **Worksheet** menu, click **Calculate**.

Description

This command activates the calculation window. This is a dynamic window in which the fields displayed depend on the variable to be "solved for", fluid state, and flow rate units.

Figure 3-2 Flow Calculation Dialog Box



Flow Rate Unit: ○ Base/Normal/Standard Volumetric ○ Actual Volumetric ● Mass

Solve For: Exact Flow

Using: ISO 5167-2003

User Factor: 1.000

	Base Condition	Flow Condition	Unit
Bore Size	69.6784		mm
Flow Rate:		1.00	kg/sec
Diff. Press.:		10.00	kPa
Static Press.:		137.90	kPa
Temperature:		20.00	DEG C
Density		3.32	kg/m3
Viscosity		0.00	Pa.sec
Vapor Pressure		0.00	MPa

At the top of the window is the Flow Rate Unit selection. Available flow rate units are categorized into three groups:

- **Base/Normal/Standard Volumetric** are units of volumetric flow at a base, normal, or standard condition. This condition is defined under the **Options** menu, and **Default Base Condition**. These base conditions can also be changed for each tag.
- **Actual Volumetric** are units of volumetric flow at flowing conditions.
- **Mass** are mass flow units.

If the category of units is changed on the calculate screen, it is necessary to populate the flow rate units before the numeric value is entered.

The flow rate, differential pressure, static pressure, temperature, and density fields under the base condition column will appear and disappear depending on the flow rate unit selections. These fields will show up for any normal or standard flow rate. Information must be entered into each of the displayed fields in order to perform a calculation. If a value is out of range for that field, the program will display a warning message and force you to enter valid data.

If you select a mass (e.g., kg/m3) or volumetric (e.g., m3/hr) flow unit, the program moves the flow rate edit box to the flowing condition column. The edit boxes for base temperature and pressure disappear.

Internally, Flowel performs all flow calculations using mass flow rate. If you want to enter a volumetric flow rate, Flowel needs to know the density: mass flow rate = volumetric flow rate x density. The following table illustrates the conversion process.

Table 3-1 Flow Calculation

Flow Rate Unit	Required Inputs
volumetric flow rate such as m3/hr	• flow rate at flowing conditions • density at flowing conditions
mass flow rate such as kg/sec	• flow rate at flowing conditions • density at flowing conditions (required for calculation of flowing velocity, but not for volume to mass conversion)
volumetric flow rate at standard or normal conditions such as Sm3/hr or Nm3/hr	• flow rate at base conditions • density at flowing conditions • density at base conditions

3.4.1 Solve For

Flowel is capable of solving different types of flow-related calculation problems. The Solve For selection list lets you choose the variable to be solved for. These are as listed below.

3.4.1.1 Exact Bore Size

Calculates an exact bore diameter given the maximum flow rate and maximum differential pressure.

3.4.1.2 Exact Differential Pressure

Calculates the exact differential pressure given the maximum flow rate and element bore.

3.4.1.3 Exact Flow Rate

Calculates the exact flow rate given the element bore and differential pressure.

3.4.1.4 Rounded Bore Size

Performs an exact bore calculation. However, before displaying the results, it determines the next nearest bore size (round up/down 1/8 in. by default, you may use a different value) and recalculates the maximum flow rate based upon the new bore size.

3.4.2 *Using*

Use the Using option to select the calculation methodology. This list will change depending on the fluid state and meter run settings. Some of the solve methods available are:

- ISO 5167-1980
- ISO 5167-1991
- ISO 5167-2003
- ASME MFC-3M
- ASME MFC-7M-1987
- ASME MFC-14M-2003
- AGA 3-1985
- AGA 3-1990
- General
- BS 1042

3.4.3 *Options*

A description of the available calculation options are listed in Table 3-2 below.

Table 3-2 Options

Name	Availability	Description
Density Calculator	*If you have not purchased the Fluid Properties add-on, the following function will operate for a smaller set of fluids:*	Press the **Density** button to calculate the density of the selected fluid based upon the static temperature and pressure entered into this calculation screen. There are a number of methods provided in the program.
Viscosity	*If you have not purchased the Fluid Properties add-on, the following function will not be available to you.*	This button is enabled only for gas with a defined composition, and liquid water or steam. Press the **Viscosity** button to calculate the viscosity of pure gases or gas mixtures based upon the static pressure and temperature provided on the calculation screen.

Name	Availability	Description
Isentropic Exponent	*If you have not purchased the Fluid Properties add-on, the following function will not be available to you.*	This button is enabled only for gas with a defined composition. Press **Isentropic Exponent** to select the Isentropic Exponent method to use. There are three calculation methods available: • Ideal Gas Heat Capacity Ratio • Real Gas with Redlich-Kwong Equation of State Correction • Real Gas with Lee-Kesler Equation of State Correction • AGA10 (natural gas only)
Vapor Pressure/ Bubblepoint	*If you have not purchased the Fluid Properties add-on, the following function will not be available to you.*	The Vapor Pressure / Bubblepoint button activates a function which calculates the vapor pressure of liquid at a static temperature. This function applies only to pure liquids or liquid mixtures. This calculation is not used in the calculation of flow rate, however, you can use the result to determine the difference between the bubble point of the liquid and your operating pressure. This value is required when performing liquid critical flow calculations.
		Fluid The Fluid button allows you to view the defined fluid. You can also change the composition of the defined fluid. It does not activate the full fluid definition function. To make changes other than adjustments to the composition, you will have to return and use the fluid setting screen. **Calculate** The Calc. button is used to perform the final calculation once all of the required fields have been filled in. The program will indicate if there are any fields which do not include data. **Previous and Next Buttons** The Previous button opens up the Meter run dialog box. You can change the meter run information without having to start the tag definition from the beginning. The Next button activates the Graph window. It displays a graph of differential pressure and permanent pressure loss versus flow rate. You can set the Normal Flow Rate on the graph screen. The next button is disabled for critical flow.

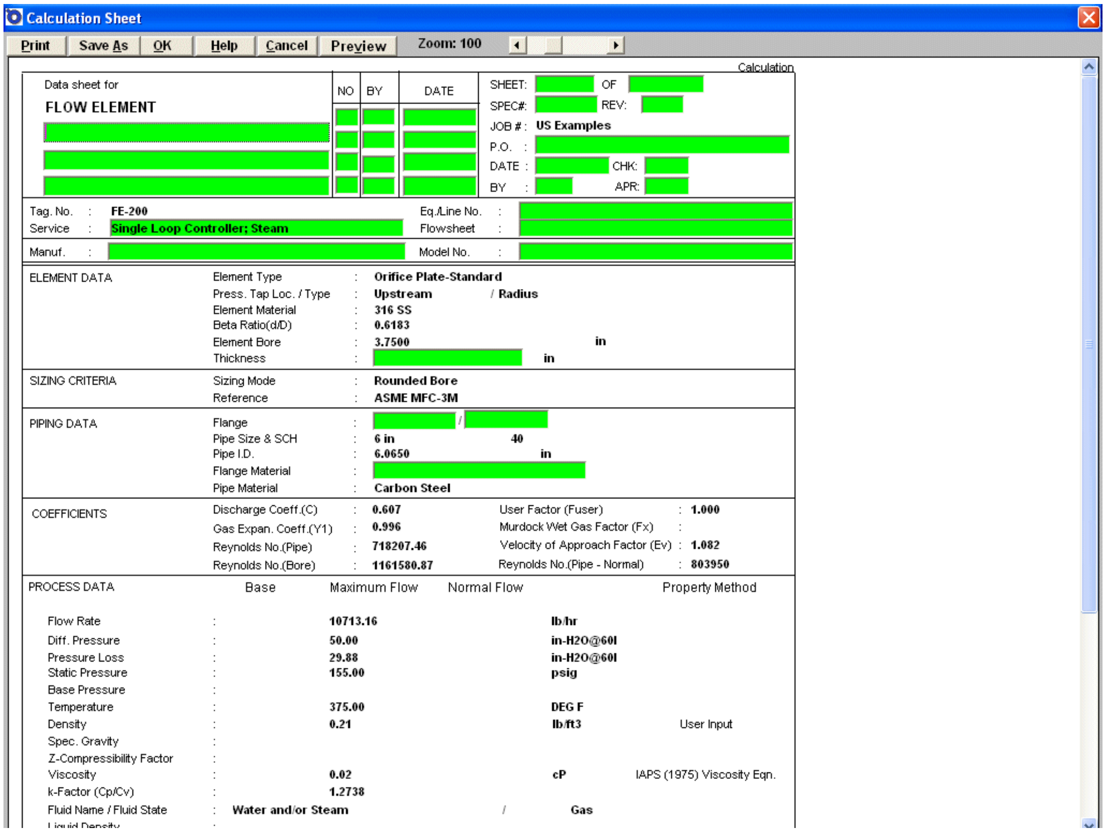
Name	Availability	Description
		Wet Gas Calculation When using wet gas, you need to remember that is essentially a gas calculation with a correction factor for a small amount of liquid. No standards organization (such as AGA or ISO) provides methods for dealing with wet gas. Flowel modifies the ISO 5167 method by applying a correction factor developed by Murdoch. See Appendix C for more details. Internally, Flowel performs all calculations using mass flow. If you select flowing volumetric units (e.g., CFH), then Flowel calculates: $Q_m = Q_v \cdot \rho$ where $\rho = \frac{\rho g \rho liq}{\rho liq \cdot \mathrm{x} + \rho g \cdot (1 - \mathrm{x})}$ If you select Normal or Standard volumetric units (e.g. SCFH) then Flowel calculates mass flow = base volumetric flow x base density, where the base density is entered by you. Flowel uses a single, user-entered value for the base density because it is highly likely that a wet gas will be totally liquid at base conditions. If your calculated volumetric flow seem very high, please remember that a given mass of gas will occupy much more volume than the same mass of liquid.

3.5 Calculation Data Sheet

To activate the calculation data sheet function, type Alt-S-S-C, or under the **Worksheet** menu, select **Spec Sheet**, and click **Calculation Data Sheet**.

This command produces a report showing the calculated data specification sheet. This form appears on the screen, with some of the fields already filled in by the program. You fill in the remaining fields.

Figure 3-3 Calculation Data Sheet



Data sheet for

FLOW ELEMENT

NO BY DATE

SHEET: OF

SPEC#: REV:

JOB # : US Examples

P.O. :

DATE : CHK:

BY : APR:

Tag. No. : FE-200

Service : Single Loop Controller; Steam

Eq./Line No. :

Flowsheet :

Manuf. :

Model No. :

ELEMENT DATA

Element Type : Orifice Plate-Standard

Press. Tap Loc. / Type : Upstream / Radius

Element Material : 316 SS

Beta Ratio(d/D) : 0.6183

Element Bore : 3.7500 in

Thickness : in

SIZING CRITERIA

Sizing Mode : Rounded Bore

Reference : ASME MFC-3M

PIPING DATA

Flange : /

Pipe Size & SCH : 6 in 40

Pipe I.D. : 6.0650 in

Flange Material :

Pipe Material : Carbon Steel

COEFFICIENTS

Discharge Coeff.(C) : 0.607

Gas Expan. Coeff.(Y1) : 0.996

Reynolds No.(Pipe) : 718207.46

Reynolds No.(Bore) : 1161580.87

User Factor (Fuser) : 1.000

Murdock Wet Gas Factor (Fx) :

Velocity of Approach Factor (Ev) : 1.082

Reynolds No.(Pipe - Normal) : 803950

PROCESS DATA Base Maximum Flow Normal Flow Property Method

Flow Rate : 10713.16 lb/hr

Diff. Pressure : 50.00 in-H2O@60I

Pressure Loss : 29.88 in-H2O@60I

Static Pressure : 155.00 psig

Base Pressure :

Temperature : 375.00 DEG F

Density : 0.21 lb/ft3 User Input

Spec. Gravity :

Z-Compressibility Factor :

Viscosity : 0.02 cP IAPS (1975) Viscosity Eqn.

k-Factor (Cp/Cv) : 1.2738

Fluid Name / Fluid State : Water and/or Steam / Gas

Liquid Density :

3.5.1 Entering Data

Data may be entered into this specification sheet. Use the Tab key to move between fields which allow user input. As you finish entering data into a field, press Tab to move to the next field.

All of the colored fields indicate that they are editable. Some of these fields are drop down selection list boxes which will activate as you click on them.

3.5.2 Zoom

The zoom control will allow the spec. sheet page to be zoomed from 60 to 200% in size. To change the zoom in 1% increments, click on the arrows which appear on the horizontal scroll bar to the right of the zoom display. To change the zoom in 5% increments, click on the scroll bar, on either side of the scroll button in the direction you wish to zoom. Use the button on the scroll bar to click and drag the zoom factor.

The scale you set for the specification sheet is saved for re-use, until you set it again. This allows scaling (normally 95%) for proper printing for European paper sizes.

3.5.3 Print

Print this sheet by clicking the **Print** button. A prompt will indicate printing status. You can change the printed sheet size by changing the zoom factor. The paper size is either A4 or letter, as selected under the **Options** menu and **Print Paper Format**.

3.5.4 Save

The data sheet can be saved to a PDF file. The paper size is either A4 or letter, as selected under the **Options** menu and **Print Paper Format**.

3.5.5 Adding Your Logo to the Datasheet

You may add your logo to the datasheets through a simple process. Do the following:

1. Create a bitmap (.BMP) file containing your logo. This file should be a maximum of 1.5 inches wide and 1 inch tall.
2. Name the file `LOGO.BMP`.
3. Copy the file into the directory which contains the Flowel program.

The logo will automatically be added to each of the datasheets. To remove the logo, either rename the logo filename, or move it from the Flowel directory.

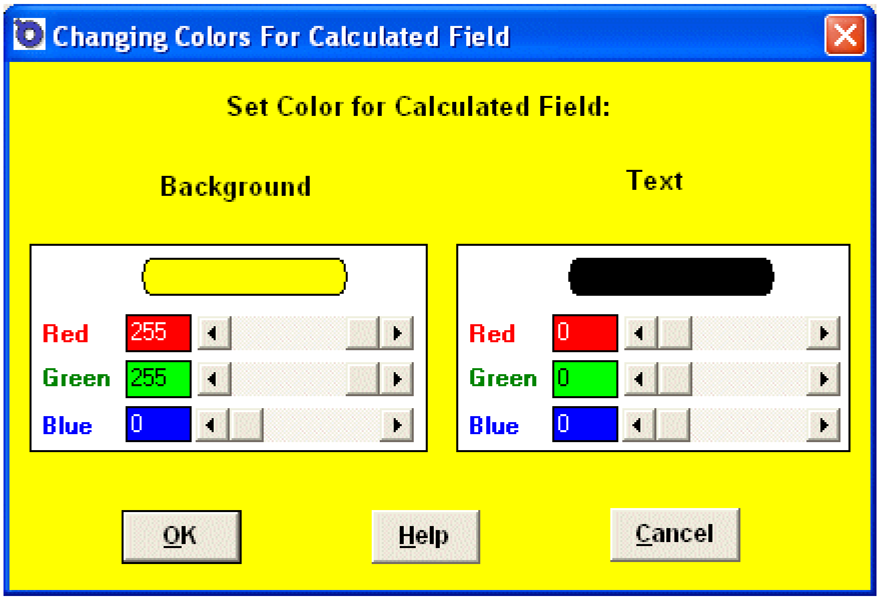
3.6 Color

To activate the color function, type Alt-W-C, or under the **Windows** menu, click **Color**.

The results field in the calculation window displays the final calculated value. This field is important since the result it produces is the reason for using the program. On some computers, notably LCD and other "gray" screens, this result may be difficult to read using the default colors. Use this function to select a color which allows the result to be clearly viewed.

Note: All other colors in the program use the Windows colors. Use the Colors function in the Windows Control Panel to make changes.

Figure 3-4 Color Selection Dialog Box



Changing Colors For Calculated Field

Set Color for Calculated Field:

Background

Red 255

Green 255

Blue 0

Text

Red 0

Green 0

Blue 0

Using the scroll bars for each of the color components (red, green, and blue), adjust each component color until you can clearly distinguish the text from the background. The text line, "Set Color for Calculated Field:" is an example of the current color selection.

3.6.1 *Setting RGB Colors*

Setting colors using a red, green, and blue (RGB) color model can be difficult if not understood. Each of the colors components is defined by a number from 0 to 255. Zero means that none of that color component is included in the overall color; 255 is the maximum a color component can be assigned.

Some values used in making standard colors are listed in Table 3-3.

Table 3-3 Setting RGB Colors

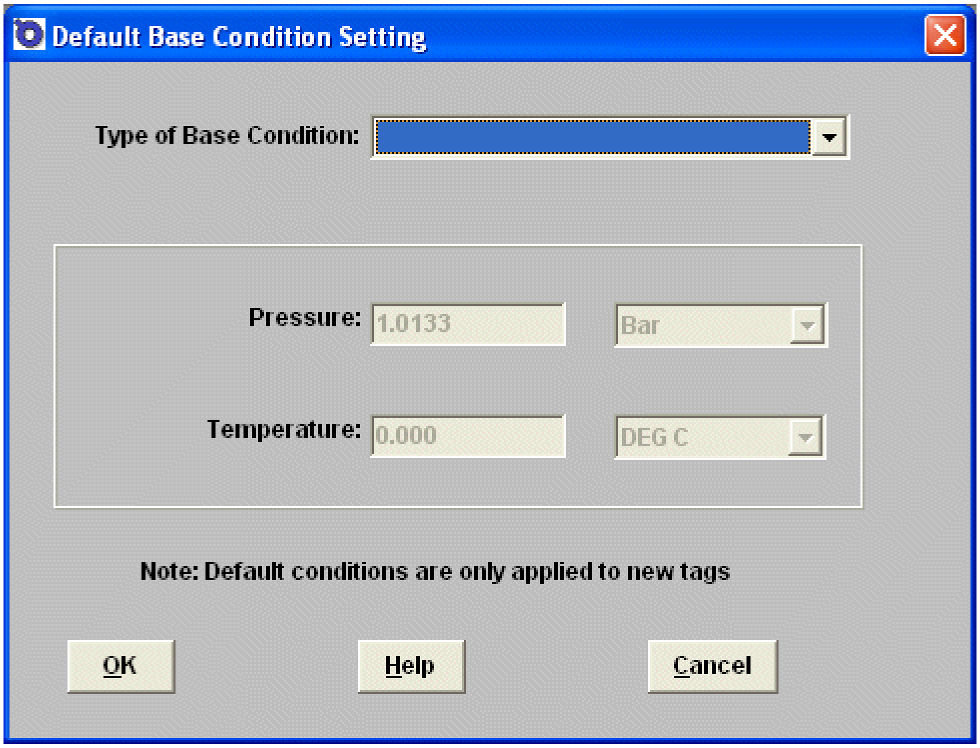
Color	R	G	B
Black	0	0	0
White	255	255	255
Red	255	0	0
Green	0	255	0
Blue	0	0	255
Yellow	255	255	0
Magenta	255	0	255
Cyan	0	255	255

3.7 Default Base Conditions

To activate the default base condition function, type Alt-O-B, or under the **Options** menu, click **Default Base Conditions**.

The Base Condition function allows you to set the base conditions which will apply to the system being designed.

Figure 3-5 Default Base Condition Setting Dialog Box



Default Base Condition Setting

Type of Base Condition:

Pressure: 1.0133 Bar

Temperature: 0.000 DEG C

Note: Default conditions are only applied to new tags

The default base condition options are listed in Table 3-4.

Table 3-4 Default Base Condition Options

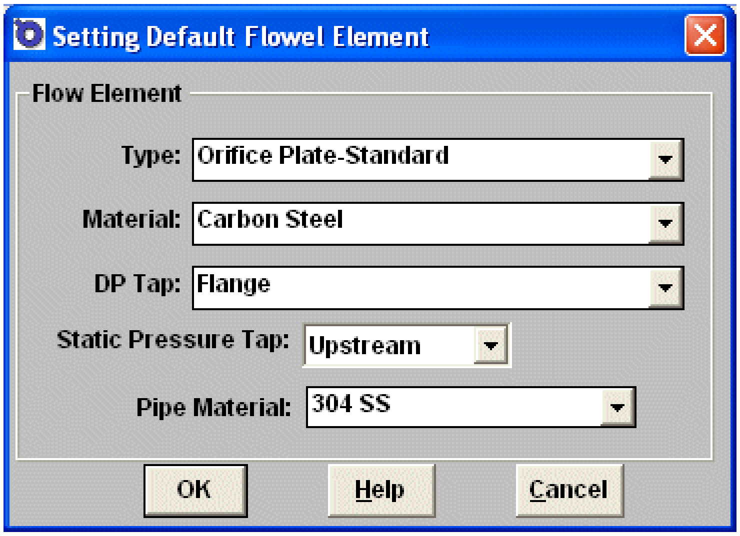
Name	Description
Standard – US	This option sets the base conditions for the program to 14.65 psia at 60°F.
Standard – Metric	This option sets the base conditions for the program to 101.325 kPa at 15°C.
Normal – US	This option sets the base conditions for the program to 14.73 psia at 32°F.
Normal – Metric	This option sets the base conditions for the program to 101.325 kPa at 0°C.
Other	This option allows you to define values and units to be used throughout the program.

3.8 Default Element

To activate the Default Element function, type Alt-O-F, or under the **Options** menu, click **Default Element**.

The Default Element function is used to set the default flow element for new tags.

Figure 3-6 Default Flow Element Setting Dialog Box



Type: Orifice Plate-Standard
Material: Carbon Steel
DP Tap: Flange
Static Pressure Tap: Upstream
Pipe Material: 304 SS

The options available are the same as the settings on the Meter Run screen. All new tags created will use this default setting, but this setting can be altered at any point.

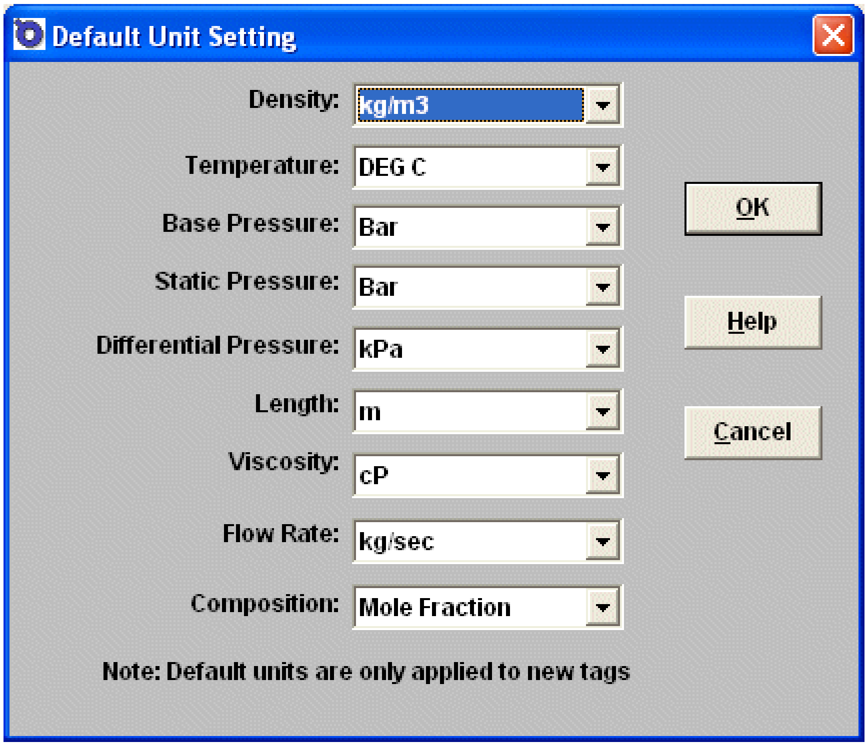
3.9 Default Units

To activate the Default Units function, type Alt-O-U, or under the **Options** menu, click **Default Units**.

Use the Default Units option to set the program defaults for your preferred units. This function sets defaults for the whole program. You may change the units associated with a tag, and have those new units saved with the tag.

Any new tags created will use the defaults, but each tag may be altered at any point. This setting will not alter the units you set for the existing tag. Your preferred default units will be saved for future use.

Figure 3-7 Default Units Dialog Box



Default Unit Setting

Density: kg/m3

Temperature: DEG C

Base Pressure: Bar

Static Pressure: Bar

Differential Pressure: kPa

Length: m

Viscosity: cP

Flow Rate: kg/sec

Composition: Mole Fraction

Note: Default units are only applied to new tags

The following table shows the options available under each category.

Table 3-5 Category Options

<table>
<tr><th>Density</th><th>Temperature</th><th>Base Pressure</th><th>Viscosity</th><th colspan="2">Flow Rate</th></tr>
<tr><td>g/cm^3
kg/dm^3
kg/m^3
lb/ft^3</td><td>Deg C
Deg F
Deg K
Deg R</td><td>Atm
Bar
in- H_2O
kg/cm^2
kPa
mm- H_2O
MPa
psia</td><td>cP
gm/cm-sec
$gmf\text{-}sec/cm^2$
kg/m-hr
lb/ft-hr
lb/ft-sec
lb/in-sec
$lbf\text{-}sec/m^2$
mPa.S
$N\text{-}sec/m^2$
P</td><td rowspan="3">CFD
CFH
CFS
E3M3/day
E3M3/hr
E6M3/day
E6M3/hr
hL/day
hL/hr
IMPBPD
IMPBPH
IMPGPD
IMPGPH
IMPGPM
IMPGPS
kg/day
kg/hr
kg/min
kg/sec
L/day
L/hr
L/min
L/sec
lb/day
lb/hr
lb/min
lb/sec
m^3/day
m^3/hr
m^3/min
m^3/sec</td><td rowspan="3">NCFD
NCFH
NCFM
NCFS
Nm^3/day
Nm^3/hr
Nm^3/min
Nm^3/sec
SCFD
SCFH
SCFM
SCFS
Sm^3/day
Sm^3/hr
Sm^3/min
Sm^3/sec
ton/day
ton/hr
ton/min
ton/sec
tonne/day
tonne/hr
tonne/min
tonne/sec
USBPD
USBPH
USGPD
USGPH
USGPM
USGPS</td></tr>
<tr><th>Static Pressure</th><th>Differential Pressure</th><th>Length</th><th>Composition</th></tr>
<tr><td>Atm
atm-g
Bar
Bar-g
in-H_2O
in-H_2O-g
kg/cm^2
kg/cm^2-g
kPa
kPa-g
mm-H_2O
mm-H_2O-g
MPa
MPa-g
psia
psig</td><td>Atm
Bar
in- H_2O
kg/cm^2
kPa
mm- H_2O
MPa
psia</td><td>Cm
ft
in
m
micron
mm
yd</td><td>Mole Fraction
Mole Percentage</td></tr>
</table>

Once the default settings have been selected, click **OK** to save the settings and return to the main program.

The default unit determines the type of unit (base/normal/standard volumetric, actual volumetric, or mass).

3.10 Density Calculator

The Density Calculator will calculate the density of a fluid based upon the temperature and pressure entered in the flow calculation screen, and in the case of base conditions, those that can be entered in the density calculator.

3.10.1 Method

The method used to calculate density must be selected from the list provided in the dialog box. The methods available depend on fluid state, composition, and whether you have the optional fluid property calculator package with your program.

Some of these methods will require additional information. A prompt will automatically appear when you click on the **Calculate** button. Enter the required values, then click **OK** to return to the Density Calculator dialog box.

Once a method has been selected, click on the **Calculate** button to obtain the result. Once the **OK** button has been clicked, the program will return to the flow calculation screen, with the calculated density value placed into the density field.

The following sections list the calculation methods available within Flowel.

3.10.2 Soave-Redlich-Kwong

The Soave-Redlich-Kwong equation of state can be used for all pure component or fluid mixtures defined using the component lists. The fluid may be gas or liquid. If the fluid is in two phases, only the density for the specified fluid state will be displayed.

The flowing temperature and pressure for this window are taken from the flow calculation screen, and are not editable fields. However, the base condition temperature and pressure, whether entered in the flow calculation screen or not, are editable.

3.10.3 Peng-Robinson

The Peng-Robinson equation of state can be used for all pure components or fluid mixtures defined using the component lists. The fluid may be gas or liquid. If the fluid is in two phases, only the density for the specified fluid state will be displayed.

The flowing temperature and pressure for this window are taken from the flow calculation screen, and are not editable fields. However, the base condition temperature and pressure, whether entered in the flow calculation screen or not, are editable.

3.10.4 Lee-Kesler BWR

The Lee-Kesler BWR calculation method can be used for all pure components or fluid mixtures defined using the component lists. The fluid may be gas or liquid. If the fluid is in two phases, only the density for the specified fluid state will be displayed.

The flowing temperature and pressure for this window are taken from the flow calculation screen, and are not editable fields. However, the base condition temperature and pressure, whether entered in the flow calculation screen or not, are editable.

3.10.5 Thompson-Brobst-Hankinson

This method is also known as the COSTALD method. It was initially developed to correlate the density of liquid hydrocarbons. It can be used for all pure components or supported fluid mixtures for gas or liquid. It is not accurate for high asymmetric fluids at high pressure.

The flowing temperature and pressure for this window are taken from the flow calculation screen, and are not editable fields. However, the base condition temperature and pressure, whether entered in the flow calculation screen or not, are editable.

3.10.6 Modified Rackett

The Modified Rackett equation should only be used for saturated liquids.

The flowing temperature and pressure for this window are taken from the flow calculation screen, and are not editable fields. However, the base condition temperature and pressure, whether entered in the flow calculation screen or not, are editable.

3.10.7 AGA 8 (1985), Detailed

The AGA 8 (1985), detailed method can be used to calculate natural gas density by entering a detailed analysis of the composition. This method is not recommended for sour natural gas (see the next section).

Whenever possible, the AGA 8 (92) detailed method should be applied, since this method includes the most recent compressibility factor data, and an improved correlation methodology (AGA Report 8, p.1, 1992).

The flowing temperature and pressure for this window are taken from the flow calculation screen, and are not editable fields. However, the base condition temperature and pressure, whether entered in the flow calculation screen or not, are editable.

3.10.8 AGA 8 (1992), Detailed

The AGA 8 (1992), detailed method can be used to calculate natural gas density by entering a detailed analysis of the composition. It can be used for sweet as well as sour natural gas.

Whenever possible, the AGA 8 (92) detailed method should be applied, since this method includes the most recent compressibility factor data, and an improved correlation methodology (AGA Report 8, p.1, 1992).

The flowing temperature and pressure for this window are taken from the flow calculation screen, and are not editable fields. However, the base condition temperature and pressure, whether entered in the flow calculation screen or not, are editable.

3.10.9 Redlich-Kwong (Wichert-Aziz)

This method was developed for sour natural gas. It uses the Redlich-Kwong equation of state, with a corrected critical temperatures and pressures. If no H_2S or CO_2 is present, this method becomes the same as the Redlich-Kwong equation of state.

The flowing temperature and pressure for this window are taken from the flow calculation screen, and are not editable fields. However, the base condition temperature and pressure, whether entered in the flow calculation screen or not, are editable.

3.10.10 NX-19, Detailed

NX-19 detailed method can be used to calculate natural gas density by entering a detailed analysis of the composition. When possible, the AGA 8 (1992) detailed method should be used, since this method provides more accurate computation of compressibility factor over a larger range of temperature, pressure and compositions (AGA Report 8, p.1, 1992).

The flowing temperature and pressure for this window are taken from the flow calculation screen, and are not editable fields. However, the base condition temperature and pressure, whether entered in the flow calculation screen or not, are editable.

3.10.11 NBS/NRC Steam Equation

This method was developed by the US National Bureau of Standards and the national Research Council of Canada. NBS/NRC Steam equation of state is available in Flowel for calculating steam and water density. It can be used for both superheated steam and compressed water.

Flowel will automatically detect the phase condition according to the temperature and pressure regardless of the specified fluid state.

The flowing temperature and pressure for this window are taken from the flow calculation screen, and are not editable fields. However, the base condition temperature and pressure, whether entered in the flow calculation screen or not, are editable.

The H2O density calculator with NBS equation operates as follows.

3.10.11.1 Flowing Density

To calculate a flowing density you are presented with three options:

1. H2O saturated, use Temperature
2. H2O saturated, use Pressure
3. H2O not saturated, use Both Temp. and Press

If “H2O saturated, use Temperature” is selected, a saturated density at flowing temperature in the selected state (gas or liquid) is calculated. This state is selected in the Fluid Setting dialog box. The flowing pressure is changed to the pressure corresponding to the saturated temperature.

If “H2O saturated, use Pressure” is selected, a saturated density at flowing pressure in the selected state (gas or liquid) is calculated. This state is selected in the Fluid Setting dialog box. The flowing temperature is changed to the temperature corresponding to the saturated pressure.

If “H2O not saturated, use Both Temp. and Press.” is selected, a density at flowing temperature and flowing pressure is calculated. The density calculated may be either for a gas or a liquid depending on the temperature and pressure and may not correspond to the state selected in the Fluid Setting dialog box. Whether the calculated density is gas or liquid is determined by calculating the vapor pressure at the flowing temperature. If the flowing pressure is greater than the calculated vapor pressure, a liquid density is calculated. If the flowing pressure is less than the calculated vapor pressure then a gas density is calculated. Neither the flowing temperature or pressure are changed.

3.10.11.2 Base Density

The base density is always calculated using both the base temperature and base pressure (no matter what method option is selected for flowing density). The density calculated may be either for a gas or a liquid depending on the temperature and pressure and may not correspond to the state selected on the fluid setting window. Whether the calculated density is gas or liquid is determined by calculating a vapour pressure at the base temperature. If the base pressure is greater than the calculated vapour pressure, a liquid density is calculated. If the base pressure is less than the calculated vapour pressure, a gas density is calculated. Neither the base temperature or pressure are changed.

3.10.12 NBS Ammonia, NBS Nitrogen, NBS Argon, NBS Oxygen, IUPAC Carbon Dioxide, NBS Hydrogen, NBS Methane, NBS Ethane, NBS Ethylene, NBS Propane, NBS i-Butane, NBS n-Butane

Methods are available for each of these pure fluids. They are appropriate to both gas and liquid phases. Flowel will automatically detect the phase condition according to the temperature and pressure regardless of the specified fluid state.

The flowing temperature and pressure for this window are taken from the flow calculation screen, and are not editable fields. However, the base condition temperature and pressure, whether entered in the flow calculation screen or not, are editable.

3.10.13 AGA 8 (1985), SG, CO_2, N_2

This is an alternative gross characterization method for a fluid state of gas, and “Natural gas - AGA 8 (85) component list” or “None of the above” fluid types. This method requires specific gravity plus the mole fraction of CO_2 and N_2 for a natural gas.

Enter the values for the components on the left-hand-side of the window. Set the temperature and pressure as necessary.

Note: The entered specific gravity will be reset to null after any changes to the density occur. It will maintain the entered Specific Gravity until the density is changed, either by direct editing or re-calculation.

3.10.14 AGA 8 (1985), SG, HV, CO_2

This is a gross characterization method for a fluid state of gas, and “Natural gas - AGA 8 (85) component list” or “None of the above” fluid types. This method requires the heating value, specific gravity, and mole fraction of CO_2 for a natural gas.

Enter the values for the components on the left-hand-side of the window. Set the temperature and pressure as required.

You can set different base temperature and pressure values and units for the heating value and specific gravity.

Note: The entered specific gravity will be reset to null after any changes to the density occur. It will maintain the entered Specific Gravity until the density is changed, either by direct editing or re-calculation.

3.10.15 AGA 8 (1985), HV, CO_2, N_2

This is a gross characterization method for a fluid state of gas, and “Natural gas - AGA 8 (85) component list” or “None of the above” fluid types. This method requires the heating value and mole fractions of CO_2 and N_2 for a natural gas.

Enter the values for the components on the left-hand-side of the window. Set the temperature and pressure as required.

3.10.16 AGA 8 (1985), SG, CH_4, CO_2, N_2

This is a gross characterization method for a fluid state of gas, and “Natural gas - AGA 8 (85) component list” or “None of the above” fluid types. This method requires the specific gravity and mole fractions of Methane, CO_2 and N_2 are known for a natural gas.

Enter the values for the components on the left-hand-side of the window. Set the temperature and pressure as required.

Note: The entered specific gravity will be reset to null after any changes to the density occur. It will maintain the entered Specific Gravity until the density is changed, either by direct editing or re-calculation.

3.10.17 AGA 8 (1992), SG, HV, CO_2

This is a gross characterization method for a fluid state of gas, and “Natural gas - AGA 8 (85) component list”, “Natural gas - AGA 8 (92) component list”, or “None of the above” fluid types. This method requires the heating value and mole fractions of CO_2 for a natural gas. Enter the values for the components on the left-hand-side of the window. Set the temperature and pressure as required.

You can set different base temperature and pressure values and units for the heating value and specific gravity.

Note: The entered specific gravity will be reset to null after any changes to the density occur. It will maintain the entered Specific Gravity until the density is changed, either by direct editing or re-calculation.

3.10.18 AGA 8 (1992), SG, CO_2, N_2

This is a gross characterization method for a fluid state of gas, and “Natural gas - AGA 8 (85) component list”, “Natural gas - AGA 8 (92) component list”, or “None of the above” fluid types. This method requires the specific and mole fractions of CO_2 and N_2 for a natural gas.

Enter the values for the components on the left-hand-side of the window. Set the temperature and pressure as required.

Note: The entered specific gravity will be reset to null after any changes to the density occur. It will maintain the entered Specific Gravity until the density is changed, either by direct editing or re-calculation.

3.10.19 Ideal Gas Method, SGi, Zf

The Ideal Gas method is to be used to calculate density when the ideal specific gravity and compressibility factors (flowing and base) for a gas are known.

$$\text{Ideal Specific Gravity} = \frac{\text{Molecular weight of fluid}}{28.96247}$$

Enter the ideal specific gravity and compressibility into the popup dialog box.

3.10.20 Real Gas Method, SGr, Zair

The Real Specific Gravity method can be used to calculate density when the real specific gravity and the compressibility factor (flowing and base) of air are known.

$$\text{Real specific gravity} = \frac{\text{Molecular weight of fluid}}{28.96247} \times \frac{\text{air compressibility factor at flowing conditions}}{\text{fluid compressibility factor at flowing conditions}}$$

Enter the real specific gravity and compressibility into the popup dialog box. Flowel will fill in values for the compressibility of air.

3.10.21 Molecular Weight Method, MW, Zf

The Molecular Weight method can be used to calculate density when the molecular weight and compressibility (flowing and base) of a fluid are known.

Enter the molecular weight and compressibility into the popup dialog box.

3.10.22 Liquid Method, SG, Density H_2O

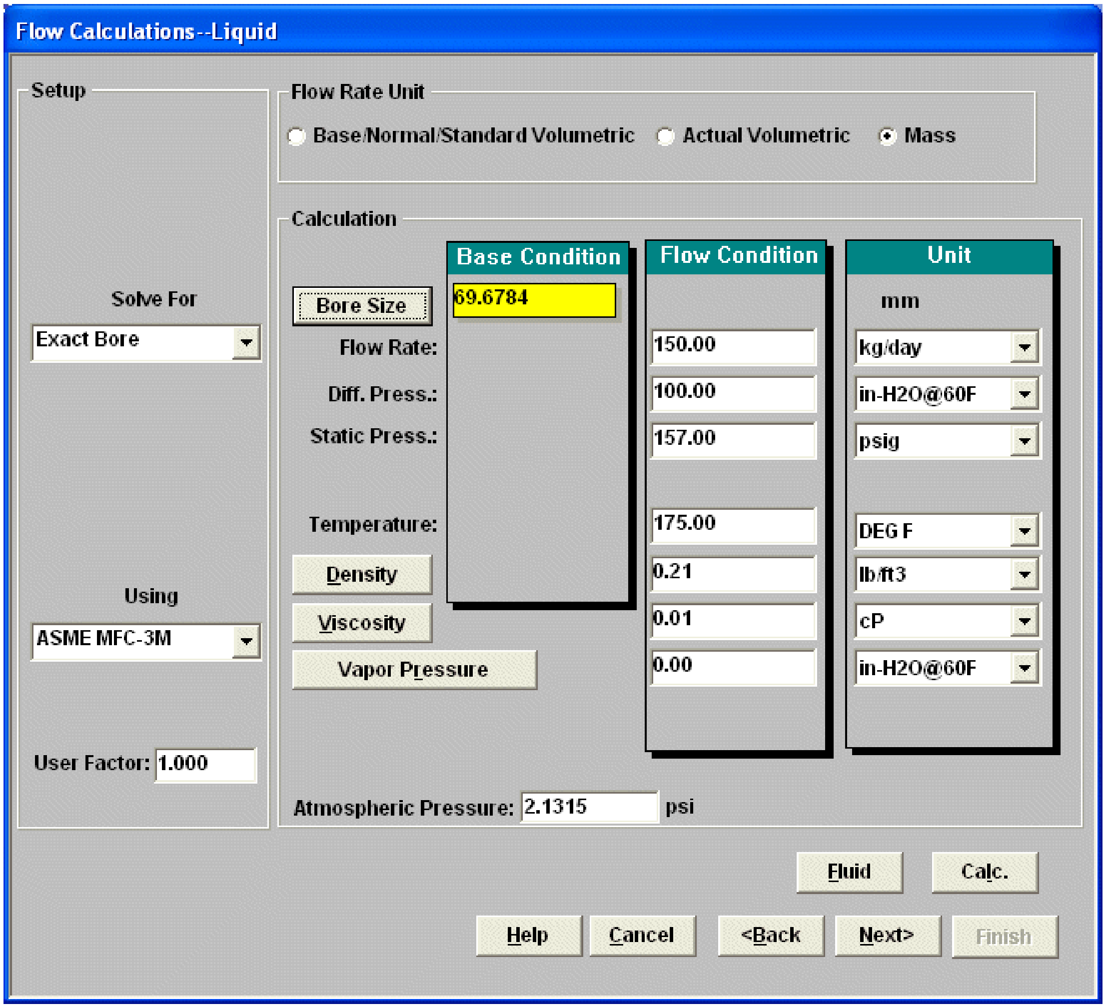
For liquids, the density can be calculated when the specific gravity is known. Enter the specific gravity and density of water at standard conditions into the popup dialog box.

The reference condition used for measuring specific gravity varies. A list of the most commonly used reference conditions is provided for convenience. You may select “Other”, and enter other values for the density of water.

3.11 Exact Bore Size

This function calculates an exact bore diameter based on maximum flow, maximum differential pressure, and other user-entered information.

Figure 3-8 Flow Calculation Window Solving for Exact Bore Size



Flow Rate Unit: ○ Base/Normal/Standard Volumetric ○ Actual Volumetric ● Mass

Solve For: Exact Bore

Using: ASME MFC-3M

User Factor: 1.000

	Base Condition	Flow Condition	Unit
Bore Size	69.6784		mm
Flow Rate:		150.00	kg/day
Diff. Press.:		100.00	in-H2O@60F
Static Press.:		157.00	psig
Temperature:		175.00	DEG F
Density		0.21	lb/ft3
Viscosity		0.01	cP
Vapor Pressure		0.00	in-H2O@60F

Atmospheric Pressure: 2.1315 psi

The methods available for use to solve for exact bore size are:

- AGA 3-1985
- AGA 3-1990
- ASME MFC-3M
- ASME MFC-7M 1987
- ASME MFC-14M-2003 (for small bore orifice only)
- ISO 5167-1980
- ISO 5167-1991
- ISO 5167-2003

The methods that are available for selection depend on fluid state, fluid type, element type and differential pressure tap location.

For this screen, the minimum data required to calculate the exact bore are:

- flow rate – flowing conditions, or base conditions if a standard or normal volumetric flow rate unit was selected
- differential pressure
- static pressure – flowing conditions
- temperature – flowing conditions
- density – flowing conditions
- viscosity
- isentropic exponent (this field will not appear if the fluid is in liquid state)

3.12 Exact Differential Pressure

This function calculates the exact differential pressure based on the flow rate, element bore, and other user-entered information.

The methods available for use to solve for exact differential pressure are:

- AGA 3 – 1985
- AGA 3 – 1990
- ASME MFC-3M
- ISO 5167-1980
- ISO 5167-1991
- ISO 5167-2003

The methods that are available for selection depend on fluid state, fluid type, element type, and differential pressure tap location. For this screen, the minimum data required to calculate the exact differential pressure are:

- beta ratio
- flow rate – flow conditions
- static pressure – flow conditions
- temperature – flow conditions
- density – flow conditions
- viscosity
- isentropic exponent (this field will not appear if the fluid is in liquid state)

Upon entry of the values for these fields, press the **Calc.** button to perform the calculation.

3.13 Exact Flow Rate

Exact Flow Rate causes the program to solve for the flow rate based on the element bore, differential pressure, and other user-entered information.

The methods available for use to solve for exact flow rate are:

- AGA 3 – 1985
- AGA 3 – 1990
- ASME MFC-3M
- ASME MFC-7M 1987
- ISO 5167-1980
- ISO 5167-1991
- ISO 5167-2003

The methods that are available for selection depend on fluid state, fluid type, element type and differential pressure tap location. For this screen, the minimum data fields required for calculation are:

- beta ratio
- differential pressure
- static pressure – flow condition
- temperature – flow condition
- density – flow condition
- viscosity
- isentropic exponent (this field will not appear if the fluid is in liquid state)

Upon entry of the values for these fields, click the **Calc.** button to perform the calculation.

3.14 Exit

To activate the Exit function, type Alt-F-X, or under the **File** menu, click **Exit**.

Use the Exit command to exit the FLOWEL 4.0 program. You will be prompted to confirm this choice. Press the **Enter** key or click **OK** to confirm.

Note: The program will not prompt you to save any changes because any changes are saved as each command or function is activated.

3.15 Export Fluid

To activate the Export Fluid function, type Alt-U-E, or from the **User Data** menu, click **Export Fluid**.

Description

This command allows Flowel to export existing fluids mixtures to .CSV (comma separated value) file format for use outside the Flowel program.

A mixture name can include any characters except commas. Each name can be up to 49 characters long. Valid fluid type names:

- All
- Common Fluids
- General Mixture
- Natural Gas, AGA 8 (85) Component List
- Natural Gas, AGA 8 (92) Component List
- Natural Gas, NX-19 Component List
- None of the Above (user-defined)

Unit must be either ‘Mole Fraction’ or ‘Mole Percent’.

The component name will be a valid fluid name from the list. Select a Fluid Type. A list of available fluids will appear. Select the fluid you wish to export, then click **OK**. The standard Windows file selection dialog will appear. Enter the new fluid name, then click **OK**. The program will perform the export.

3.16 Export Job

To activate the Export Job function, type Alt-F-J, or under the **File** menu, click **Export Job**.

Description

⚠ This command allows exporting of job information only (no tag information is included when exporting Jobs).

There are two cases when this function is important. First, there may be situations in the future when the Flowel database will be altered. Rather than force each user to re-enter each of the jobs created, this function will allow the data to be exported into a form that can be read by a future version.

Second, this function allows job information to be stored into another form for backup purposes. Using all of the export functions (Job, Tags, and Fluids) you can archive this information.

On the **File Menu**, select **Export Job**. You will be prompted to select or enter a filename for the export file. The program will automatically add the filename extension. Click **OK** to complete the process. The dialog box will disappear from the screen as the export process begins.

3.17 Export Tag

To activate the Export Tag function, type Alt-F-E, or under the **File** menu, click **Export Tag**.

Description

This command allows for the exporting of tags for use elsewhere. This function exports tags associated with the currently open job to a comma separated value (*.CSV) file format. This format is commonly used by both spreadsheet and database programs.

First, select the tags that are to be exported. Your options include selecting all tags, one tag or some tags.

To select all of the tags, click on the **Select All** option in the Export Tag dialog box. If you click on this option again, you will deselect all of the selected tags.

To select a single tag, scroll the list until it is visible, then click on the tag name to highlight it. Once highlighted, a tag is selected.

To select tags that do not appear contiguously in the list, click on the first tag, then use the mouse to click on the next tag to be selected. If tags you want are down the list beyond view, click on the scroll buttons on the list to bring the tags you want into view.

When you have made all of your selections, click **OK**. Once you have selected the tags that are to be exported, you must select a filename and location for that file. A standard Windows file selection dialog box will appear.

Enter an appropriate name in the File Name field, using the standard DOS eight-character naming convention. It is not necessary to add the three-character filename suffix, the program will add it for you.

Select the drive and directory onto which the file is to be saved.

When these steps are complete, click **OK**. Flowel will display a confirmation message indicating that the export is being performed. If an existing filename has been selected, a warning message will ask you to confirm an overwrite of the existing file.

3.18 File Menu

To activate the file menu, type Alt-F.

Description

This menu contains the commands needed to open and create new jobs and tags, import and export, and print.

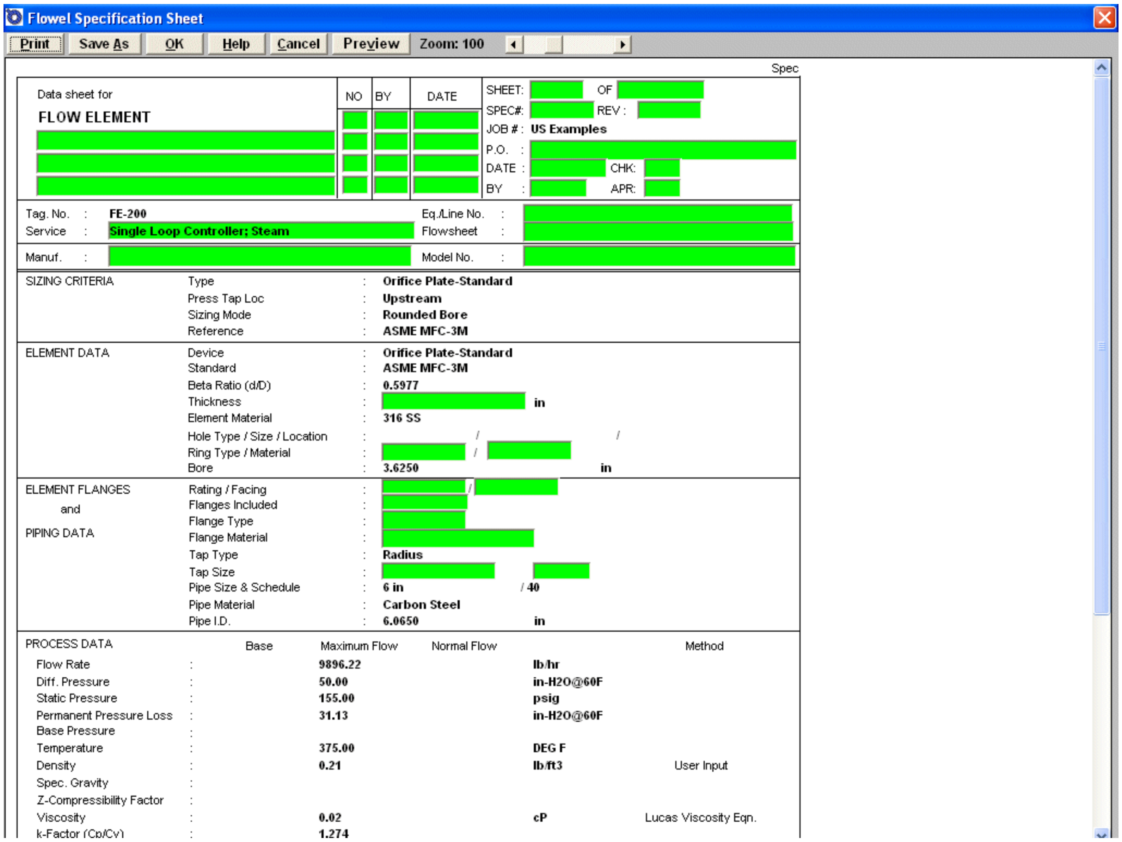
All of the menu items in Flowel are listed by name (alphabetically) in the reference section. Please look to the specific function name for information on that function.

3.19 Flowel Data Sheet

Description

This function aids in the production of a Flowel Data Sheet report. The Flowel form appears on screen, with as much information as possible filled in automatically by the program using already-entered data. You can fill in the remaining fields.

Figure 3-9 Flowel Data Sheet Window



Data sheet for

FLOW ELEMENT

JOB # : US Examples

Tag. No. : FE-200
Service : Single Loop Controller; Steam
Eq./Line No. :
Flowsheet :
Manuf. :
Model No. :

SIZING CRITERIA
Type : Orifice Plate-Standard
Press Tap Loc : Upstream
Sizing Mode : Rounded Bore
Reference : ASME MFC-3M

ELEMENT DATA
Device : Orifice Plate-Standard
Standard : ASME MFC-3M
Beta Ratio (d/D) : 0.5977
Thickness : in
Element Material : 316 SS
Hole Type / Size / Location : / /
Ring Type / Material : /
Bore : 3.6250 in

ELEMENT FLANGES and PIPING DATA
Rating / Facing : /
Flanges Included :
Flange Type :
Flange Material :
Tap Type : Radius
Tap Size :
Pipe Size & Schedule : 6 in / 40
Pipe Material : Carbon Steel
Pipe I.D. : 6.0650 in

PROCESS DATA

	Base	Maximum Flow	Normal Flow		Method
Flow Rate :		9896.22		lb/hr	
Diff. Pressure :		50.00		in-H2O@60F	
Static Pressure :		155.00		psig	
Permanent Pressure Loss :		31.13		in-H2O@60F	
Base Pressure :					
Temperature :		375.00		DEG F	
Density :		0.21		lb/ft3	User Input
Spec. Gravity :					
Z-Compressibility Factor :					
Viscosity :		0.02		cP	Lucas Viscosity Eqn.
k-Factor (Cp/Cv) :		1.274			

3.19.1 Entering Data

Data may be entered into this specification sheet. Use the Tab key to move between fields which allow user input. As you finish entering data into a field, press Tab to move to the next field.

All of the colored fields indicate that they are editable. Some of these fields are drop down selection list boxes which will activate as you click on them.

3.19.2 Zoom

The zoom control will allow the spec. sheet page to be zoomed from 60 to 200% in size. To change the zoom in 1% increments, click on the arrows which appear on the horizontal scroll bar to the right of the zoom display. To change the zoom in 5% increments, click on the scroll bar, on either side of the scroll button in the direction you wish to zoom. Use the button on the scroll bar to click and drag the zoom factor.

The scale you set for the specification sheet is saved for re-use, until you set it again. This allows scaling (normally 95%) for proper printing for European paper sizes.

3.19.3 Print

Print this sheet by clicking the **Print** button. A prompt will indicate printing status. You can change the printed sheet size by changing the zoom factor. The paper size is either A4 or letter, as selected under the **Options** menu and **Print Paper Format**.

3.19.4 Save

The data sheet can be saved to a portable document format (PDF) file. The paper size is either A4 or letter, as selected under the **Options** menu and **Print Paper Format**. PDF files can be printed on all Adobe Reader supported paper sizes.

3.19.5 Adding Your Logo to the Datasheet

You may add your logo to the datasheets through a simple process.

1. Create a bitmap (.BMP) file containing your logo. This file should be a maximum of 1.5 inches wide and 1 inch tall.
2. Name the file `LOGO.BMP`.
3. Copy the file into the directory which contains the Flowel program.

The logo will automatically be added to each of the datasheets. To remove the logo, either rename the logo to another filename, or move it from the Flowel directory.

3.20 Fluid

To activate the fluid function, type Alt-S-F, or under the **Worksheet** menu, click **Fluid**.

Description

The Fluid Setting dialog is the first window to use after the creation of a tag name. This function allows you to define the fluid state and fluid type associated with this tag.

3.20.1 Fluid State

Select the state from the dropdown list provided. Your choices are:

- Gas
- Gas, Critical Flow
- Liquid
- Liquid, Critical Flow
- Wet Gas

These selections affect how the program solves for each of the variables, as each of these states are solved for using different methods and formulas. You must make a fluid state selection. Critical Flow is the maximum.

3.21 Fluid Type

Next, select the fluid type from the provided list. The following options are available:

- All
- Common Fluids
- General Mixture
- Natural Gas, AGA 8 (85) Component List
- Natural Gas, AGA 8 (92) Component List
- Natural Gas, NX-19 Component List
- None of the above (you may type in a fluid name)

3.21.1.1 All

The All option allows you to select from all of the fluids available including Flowel's built-in database of pure components and any defined mixtures. Once you have selected All, you can select from the dropdown list. If you know the component's name, you can type in the first character into the name field. As you type, the program automatically searches for a match. For a pure component selection, you do not have to define the fluid further.

3.21.1.2 Common Fluids

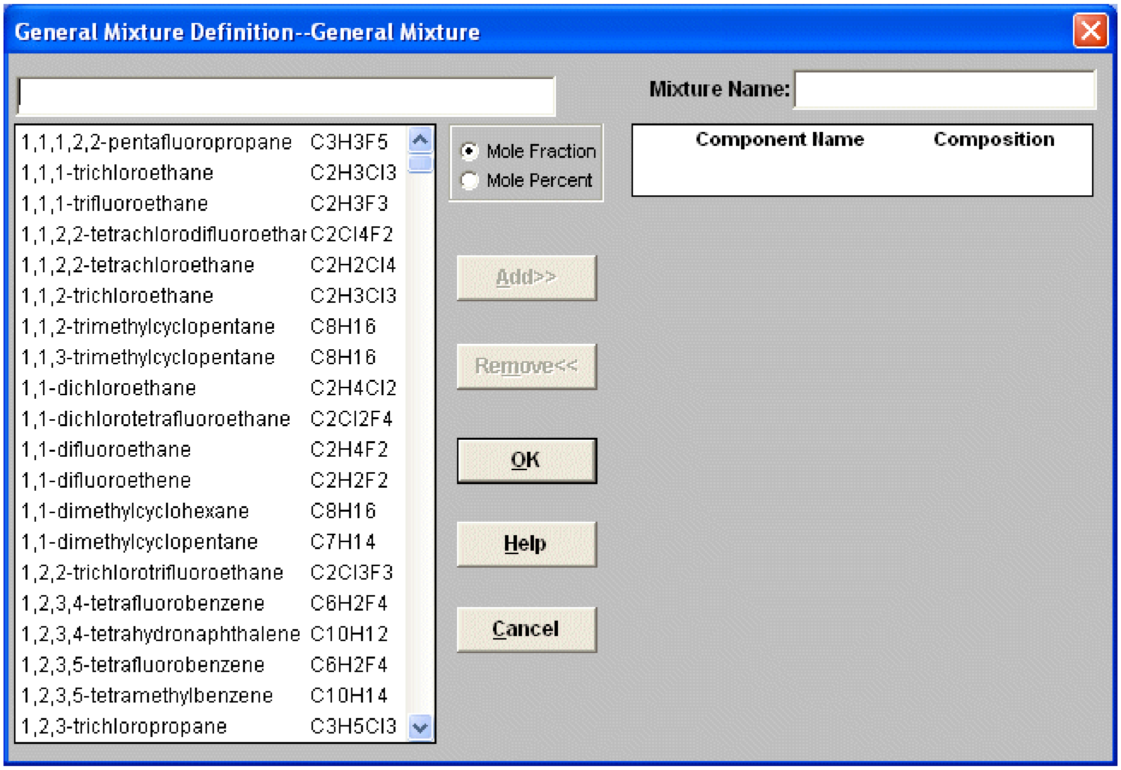
The Common Fluids option allows you to select a pure component from Flowel's built-in database. Once you have selected Common Fluids, you can select a pure component from the dropdown list. If you know the component's proper name, you can type in the first character into the name field. As you type, the program automatically searches for a match. For a pure component selection, you do not have to define the fluid further.

3.21.1.3 General Mixture

The General Mixture option provides the means to defining your own custom fluid mixture. To use this option, select General Mixture from the fluid types, then click the **Define Mixture** button. The Mixture Definition dialog box will appear.

Flowel is not necessarily able to determine if the phase is correct, or if there is any chemical reaction from mixing these fluids. It is up to the user to ensure that the fluids can be mixed, and to know the phase of the resulting fluid.

Figure 3-10 General Mixture Definition Dialog Box



General Mixture Definition--General Mixture

Mixture Name:

● Mole Fraction
○ Mole Percent

1,1,1,2,2-pentafluoropropane	C3H3F5
1,1,1-trichloroethane	C2H3Cl3
1,1,1-trifluoroethane	C2H3F3
1,1,2,2-tetrachlorodifluoroethar	C2Cl4F2
1,1,2,2-tetrachloroethane	C2H2Cl4
1,1,2-trichloroethane	C2H3Cl3
1,1,2-trimethylcyclopentane	C8H16
1,1,3-trimethylcyclopentane	C8H16
1,1-dichloroethane	C2H4Cl2
1,1-dichlorotetrafluoroethane	C2Cl2F4
1,1-difluoroethane	C2H4F2
1,1-difluoroethene	C2H2F2
1,1-dimethylcyclohexane	C8H16
1,1-dimethylcyclopentane	C7H14
1,2,2-trichlorotrifluoroethane	C2Cl3F3
1,2,3,4-tetrafluorobenzene	C6H2F4
1,2,3,4-tetrahydronaphthalene	C10H12
1,2,3,5-tetrafluorobenzene	C6H2F4
1,2,3,5-tetramethylbenzene	C10H14
1,2,3-trichloropropane	C3H5Cl3

Component Name	Composition

Enter a new mixture name. Select either Mole Fraction or Mole Percent, depending on your preference. Then use the buttons to add components to your mixture. As each component is added, enter either the mole value or fraction for that component. When you have completed adding components, click **OK**. For more information on defining mixtures, see Mixture Definition, Section 3.35.

3.21.1.4 Natural Gas

For any of the Natural Gas fluid types, you must define the mixture. The program automatically provides a short list of components for the Natural Gas fluid type selected. You select the desired components from this list and enter the mole values accordingly.

3.21.1.5 None of the Above

This option allows a fluid name to be entered into the Fluid field, but no mixture definition is possible. Unlike the other options whereby defining the fluid sets up the program to automatically draw information about a fluid from the built-in database, this option requires that you enter this information on the Calculate screen.

3.21.2 Define Mixture

The Define Mixture function is used in conjunction with the fluid types other than All (pure substances) or Unknown Fluid. See the reference topic Mixture Definition for a more detailed explanation on mixtures.

Once you have completed defining the fluid for this tag, click **OK**.

3.22 Fluid Maintenance

To activate the Fluid Maintenance function, type Alt-U-F, or under the **User Data** menu, click **Fluid Maintenance**.

Description

The Fluid Maintenance function permits some "housekeeping" to be done on the fluids defined in Flowel. Using this function you can copy a fluid to another name, delete an unused fluid, edit the mole values for the components of a fluid, and print the fluid composition.

The copy function is particularly useful when you already have a fluid defined which is close to your desired fluid. It allows you to copy the existing fluid and make changes to the mole values in the copy.

3.22.1 Copying a Fluid

On the Fluid Maintenance dialog box select the original fluid from the list. Click the **Copy** button. The copy window will appear.

The name of the original fluid will appear in the Copy From box. Type in the name of the new fluid in the To field. When the name is complete, click **OK**.

3.22.2 Deleting a Fluid

On the Fluid Maintenance dialog box, select the fluid to be deleted from the list. Click the **Delete** button.

The program will ask you for confirmation. Click **Yes** to complete the deletion.

3.22.3 Printing a Fluid

Click the **Print** button to print out a listing of the composition for the selected fluid.

3.23 Fluid Report

To activate the Fluid Report function, type Alt-S-S-F, or under the **Worksheet** menu, select **Spec Sheet**, and click **Fluid Report**. You can also select the function from printing dialog boxes.

Description

The Fluid Report is a datasheet detailing the fluid mixture which is attached to a tag. All of the components are listed with their formulas, and the mole percentage or mole fraction within the fluid.

Notes:

1. When this option is selected, the fluid report will print only if a fluid mixture is attached to the tag. If multiple tag printing has been selected, only those tags with a fluid mixture attached will have a fluid report printed for them.
2. Job and tag related information can be edited on the Calculate Data, ISA S-2, or Emerson datasheets.

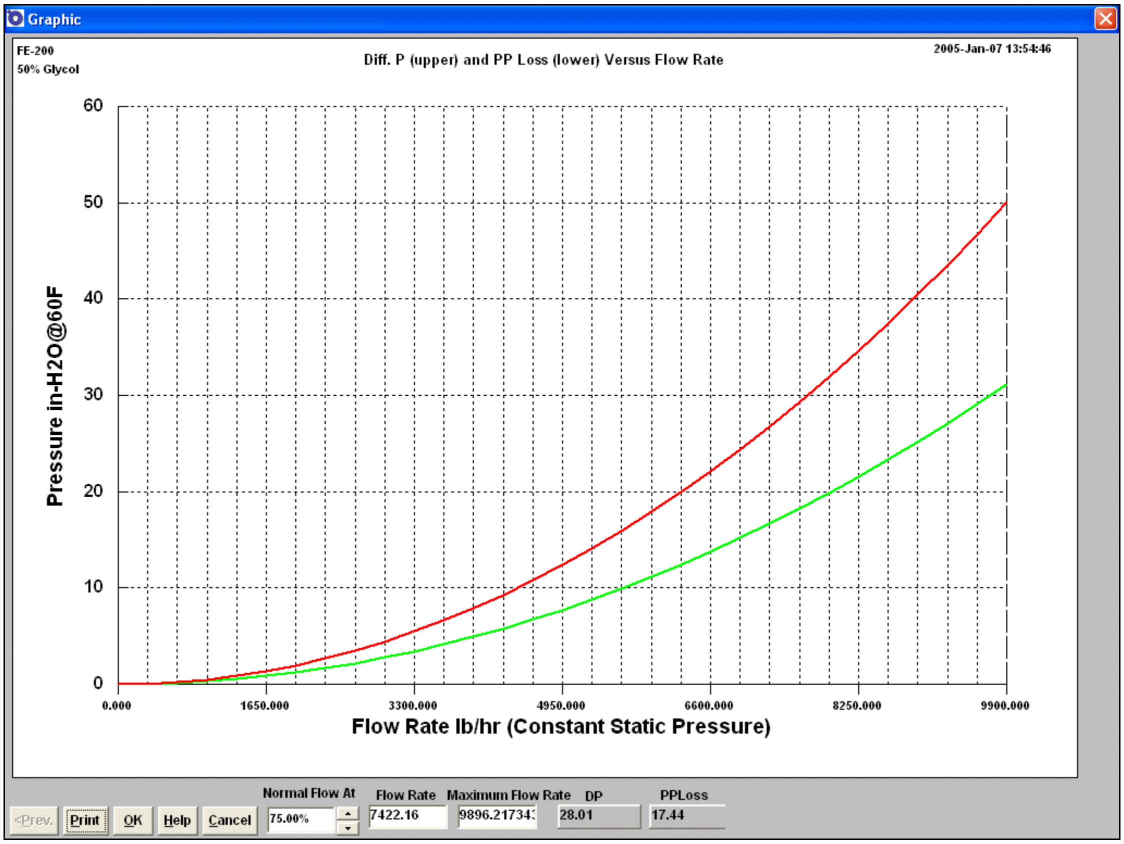
3.24 Graph

To activate the Graph function, type Alt-S-G, or under the **Worksheet** menu, click **Graph**.

Description

This displays a graph of the relationship between flow rate and both differential pressure and permanent pressure loss. To use this function, a flow calculation must have been performed for the tag.

Figure 3-11 Graph Window



Normal Flow At: 75.00%
Flow Rate: 7422.16
Maximum Flow Rate: 9896.21734
DP: 28.01
PPLoss: 17.44

This option displays a graph of the function in a scaleable window. The graph can be printed using the **Print** button.

You must set the scale on one of the specification sheets. The scale you set for the graph is saved for re-use, until you set it again. This allows scaling (normally 95%) for proper printing for European paper sizes.

You may adjust the percentage of normal flow by either entering a value in the entry field or by clicking on the up and down arrows. If you enter the Flow Rate you must click the mouse on Normal Flow to get the calculated percentage.

Flow rate, differential pressure, permanent pressure loss, and Reynolds number values are displayed. The flow rate value may be edited. The Reynolds number is automatically checked against the upper and lower limits. A message box will pop up if it is out of range.

When you have finished viewing or printing the currently displayed graph, press **OK** to return to the program.

Note: The graph is not available for critical flow.

3.25 Help Menu

To activate the Help Menu function, type Alt-H.

Description

Use this menu to find help about the operation of the software, and the use of the help system itself. The About option provides information about the program.

All of the menu items in Flowel are listed by name (alphabetically) in the reference section. Please look to the specific function name for information on that function.

3.25.1 Help Content

To activate the Help Content, type Shift+C or under the **Help** menu, click **Help Content**.

Description

Flowel help is a comprehensive on-line help system based on the reference section of the printed user manual.

Any underlined topic names are called “jumps”. They link the underlined words to information. To get help on a particular topic, click on the topic's “jump”. The help program will automatically bring up the help pages associated with that topic name.

3.25.2 Help Index

To activate the Help Index, type Shift+I, or under the **Help** menu, click **Help Index**.

Description

This option provides a general index into the help topics available in Flowel. Once Help Index has been selected, the Help Index window will appear.

3.25.3 How to Use Help

To activate the How to Use Help function, type Alt-H-U, under the **Help**, click **How to Use Help**.

Description

This is an explanation of WindowsTM style of help systems. This help information is the same as that provided with Windows. For complete instruction on the use of help within Windows, and the use of Windows itself, use the help tutorial provided with your Windows software package.

3.26 Import Fluid

To activate the Import Fluid function, type Alt-O-I, or under the **User Data** menu, click **Import Fluid**.

Description

This command allows Flowel to import fluid compositions from a file created outside of the Flowel program.

A mixture name can include any characters except commas. Each name can be up to 49 characters long. Valid fluid type names: "Natural Gas - AGA 8 (85) Component List"; "Natural Gas Liquid".

Unit must be either ‘Mole Fraction’ or ‘Mole Percent’.

The component name must be a valid fluid name from the fluid component list. To check a component, use Flowel's fluid definition function, select All from the fluid type, and scroll through the list to confirm the exact spelling for the composition.

3.27 Import Job

To activate the Import Job function, type Alt-F-M, or under the **File** menu, click **Import Job**.

Description

This command allows Flowel to import jobs which were archived using the Export job function. The program prompts with a standard Windows file open dialog. Select the file which was created using the Export Job function.

3.28 Import Tag

To activate the Import Tag function, type Alt-F-I, or under the **File** menu, click **Import Tag**.

Description

This command allows Flowel to import tags from files of your own creation. Flowel can import files stored in a .CSV (comma separated value) file format. Most database and spreadsheet programs, as well as many other software applications, can save information in this format.

The program imports the tag information into the currently open job.

Once the proper job is open, select the Import option. You will be prompted to select the desired file. Flowel uses the standard Windows file selection dialog box.

After locating the drive/directory containing your file, select the file and click **OK**. The program will begin to import the file.

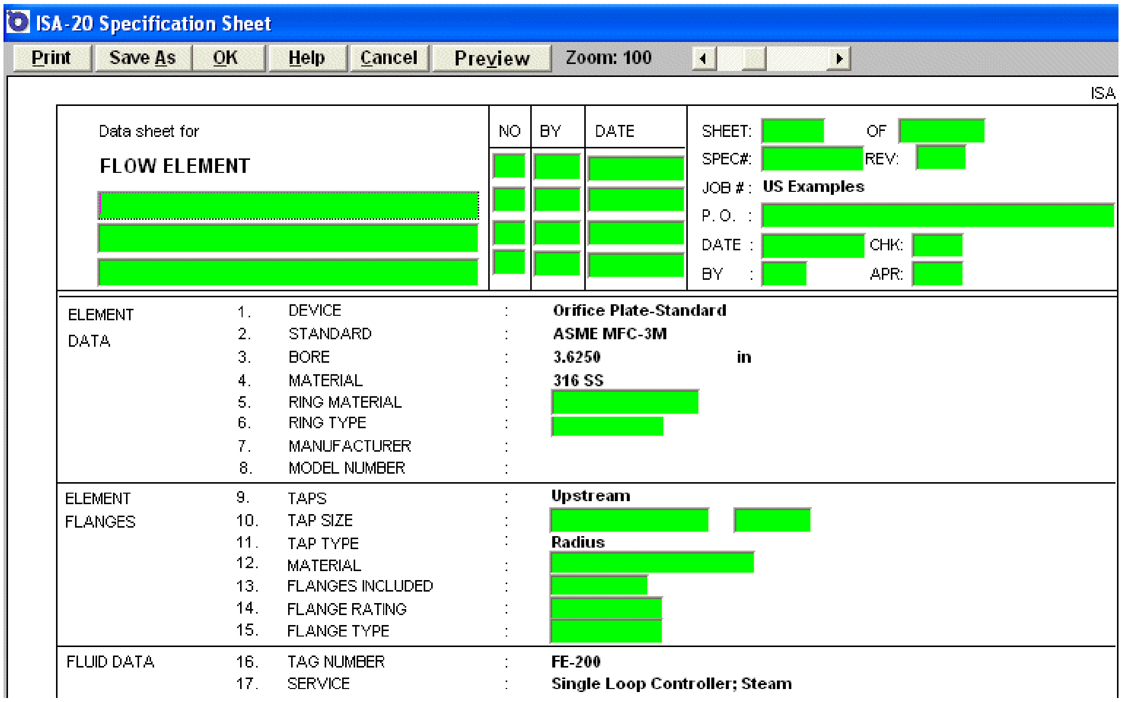
3.29 ISA S-20 Data Sheet

To activate the ISA S-20 Data Sheet, type Alt-S-S-I, or under the **Worksheet** menu, select **Spec Sheet**, and click **ISA S-20 Data Sheet**.

Description

This function produces an ISA S-20 Data Sheet report. The ISA S-20 form appears on screen, with as much information as possible filled in automatically by the program using already-entered data. You can fill in the remaining fields.

Figure 3-12 ISA S-20 Data Sheet Window



Data sheet for

FLOW ELEMENT

NO	BY	DATE	
SHEET:		OF	
SPEC#:		REV:	
JOB # :	US Examples		
P. O. :			
DATE :		CHK:	
BY :		APR:	

ELEMENT DATA	1.	DEVICE	:	Orifice Plate-Standard
	2.	STANDARD	:	ASME MFC-3M
	3.	BORE	:	3.6250 in
	4.	MATERIAL	:	316 SS
	5.	RING MATERIAL	:	
	6.	RING TYPE	:	
	7.	MANUFACTURER	:	
	8.	MODEL NUMBER	:	
ELEMENT FLANGES	9.	TAPS	:	Upstream
	10.	TAP SIZE	:	
	11.	TAP TYPE	:	Radius
	12.	MATERIAL	:	
	13.	FLANGES INCLUDED	:	
	14.	FLANGE RATING	:	
	15.	FLANGE TYPE	:	
FLUID DATA	16.	TAG NUMBER	:	FE-200
	17.	SERVICE	:	Single Loop Controller; Steam

3.29.1 Entering Data

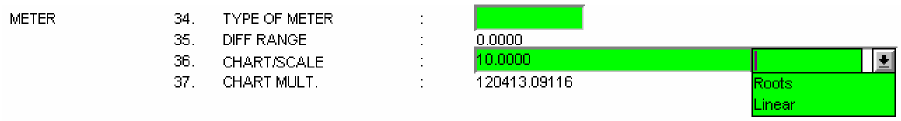
Data may be entered into this specification sheet. Use the Tab key to move between fields which allow user input. As you finish entering data into a field, press Tab to move to the next field.

In multi-line fields, such as the note field, use the Control-Enter keystroke combination to begin a new line. The program does not automatically wrap the text onto the next line, and pressing Enter does not go to the next line.

Some of the user-definable fields are actually selection lists, rather than entry fields. Click on the field. If a listbox appears, make your selection from the list. To set the Normal Flowrate use the Flow Curve graph.

The Meter section of the sheet includes a field for the chart/scale value, and an associated selection list for Roots or Linear. Once these values are entered, the Chart Mult. field is calculated automatically.

Figure 3-13 Chart/Scale Value



METER
34. TYPE OF METER :
35. DIFF RANGE : 0.0000
36. CHART/SCALE : 10.0000
37. CHART MULT. : 120413.09116

3.29.2 Zoom

The zoom control will allow the spec. sheet page to be zoomed from 60 to 200% in size. To change the zoom in 1% increments, click on the arrows which appear on the horizontal scroll bar to the right of the zoom display. To change the zoom in 5% increments, click on the scroll bar, on either side of the scroll button in the direction you wish to zoom. You may use the button on the scroll bar to click and drag the zoom factor.

The scale you set for the specification sheet is saved for re-use, until you set it again. This allows scaling (normally 95%) for proper printing for European paper sizes.

3.29.3 Print

Print this sheet by clicking the **Print** button. A prompt will indicate printing status. You can change the printed sheet size by changing the zoom factor. The paper size is either A4 or letter, as selected under the **Options** menu and **Print Paper Format**.

3.29.4 Save

The data sheet can be saved to a PDF file. The paper size is either A4 or letter, as selected under the **Options** menu and **Print Paper Format**.

3.29.5 Adding Your Logo to the Datasheet

You may add your logo to the datasheets through a simple process. Do the following:

1. Create a bitmap (.BMP) file containing your logo. This file should be a maximum of 1.5 inches wide and 1 inch tall.
2. Name the file `LOGO.BMP`.
3. Copy the file into the directory which contains the Flowel program.

The logo will automatically be added to each of the datasheets. To remove the logo, either rename the logo filename, or move it from the Flowel directory.

3.30 Isentropic Exponent

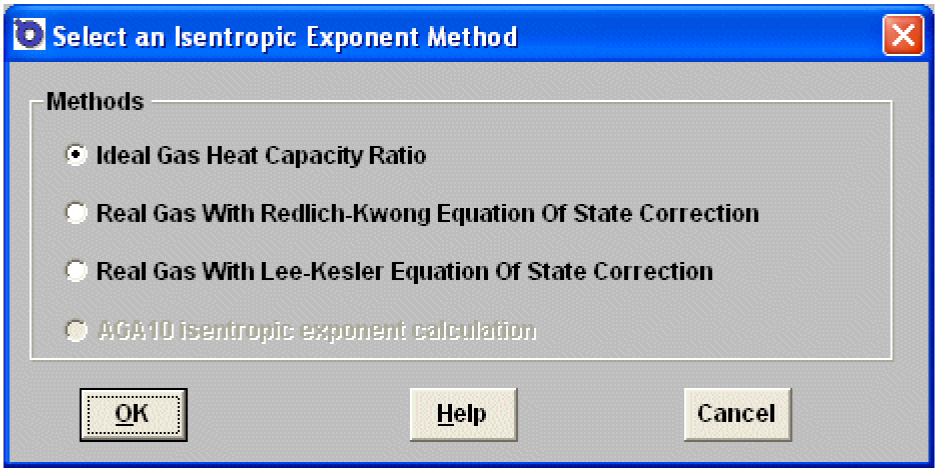
To activate the Isentropic Exponent function, click the **Isentropic Exponent** button on the Calculate dialog box.

Description

The isentropic exponent for a fluid can be calculated automatically in Flowel's flow calculation area, based upon the fluid defined. An exception to this is when "Unknown Fluid" is selected as a fluid. In this case, you must calculate and enter the isentropic exponent manually.

Note: Flowel provides three methods for calculating Isentropic Exponent. For help on these options, see the online help topic “Selecting an Isentropic Exponent Method.”

Figure 3-14 Isentropic Exponent Calculation Method Selection



Three methods of calculation are possible using the isentropic exponent function:

- Ideal Gas Heat Capacity Ratio
- Real Gas with Redlich-Kwong Equation of State Correction
- Real Gas with Lee-Kesler Equation of State Correction
- AGA-10 isentropic exponent calculation

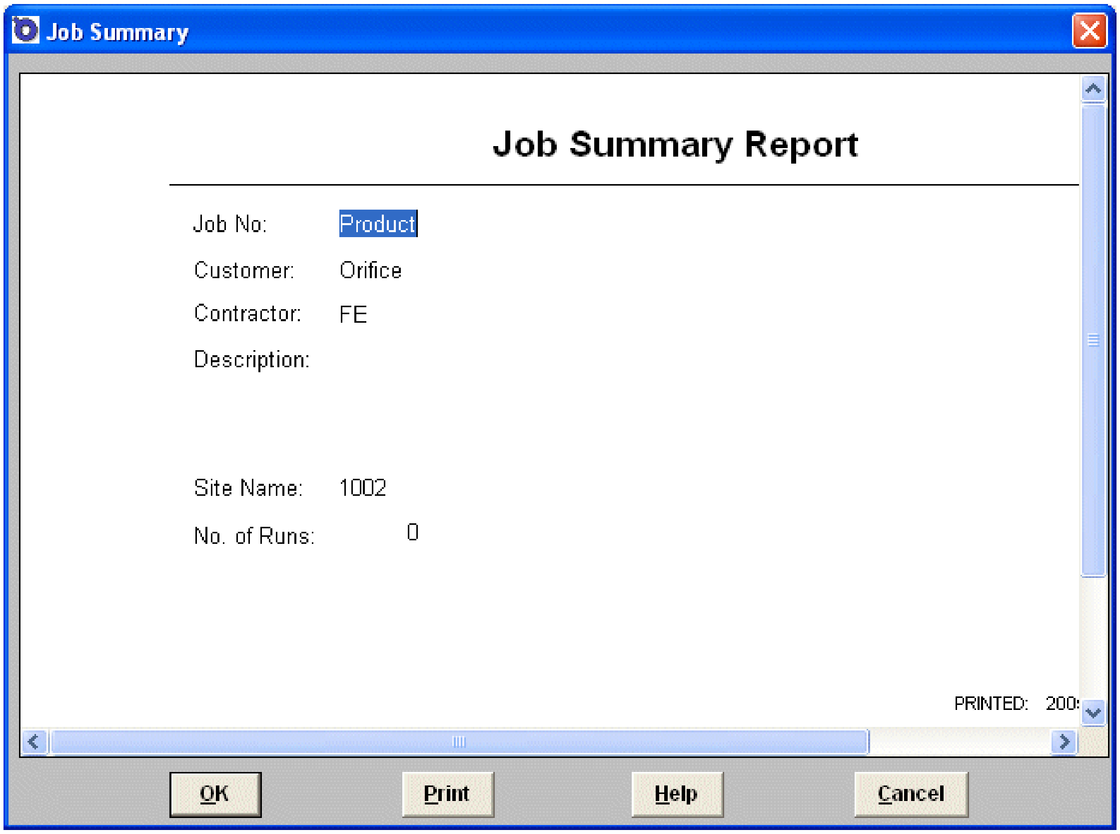
Click on one of these methods, then click **OK** to complete the calculation. The program will automatically place the results of this calculation in the Isentropic Exponent entry field on the Calculate dialog box.

The AGA-10 isentropic exponent calculation is only available on natural gas with a full gas composition (AGA-8 1985 or AGA-8 1992).

3.31 Jobs Summary

To activate the Jobs Summary function, type Alt-U-J, under the **User Data** menu, click **Jobs Summary**.

Figure 3-15 Job Summary Report



Job Summary Report

Job No: Product

Customer: Orifice

Contractor: FE

Description:

Site Name: 1002

No. of Runs: 0

PRINTED: 200:

Description

This function produces a report listing all of the jobs in the Flowel database, the associated job information, the number of tags, and the total number of times any of the tags with that job number have had calculations performed on them (number of Runs). Use the arrows on the page to scroll up and down or from right to left to view the information in the report. To print the report click on the **Print** button. This is particularly important for users who have purchased Flowel on a run-calculated basis, and users who wish to charge the use of Flowel to their end customers.

For users who have limited run versions of the program, and wish to reorder or extend their Flowel license, please see the reference topic “Options Ordering” for more information.

Related topics include:

- Option Ordering

3.32 Main Menu

The main menu is Flowel's main program menu. Use this menu, in combination with the toolbar, to make the most efficient use of the program and its functions.

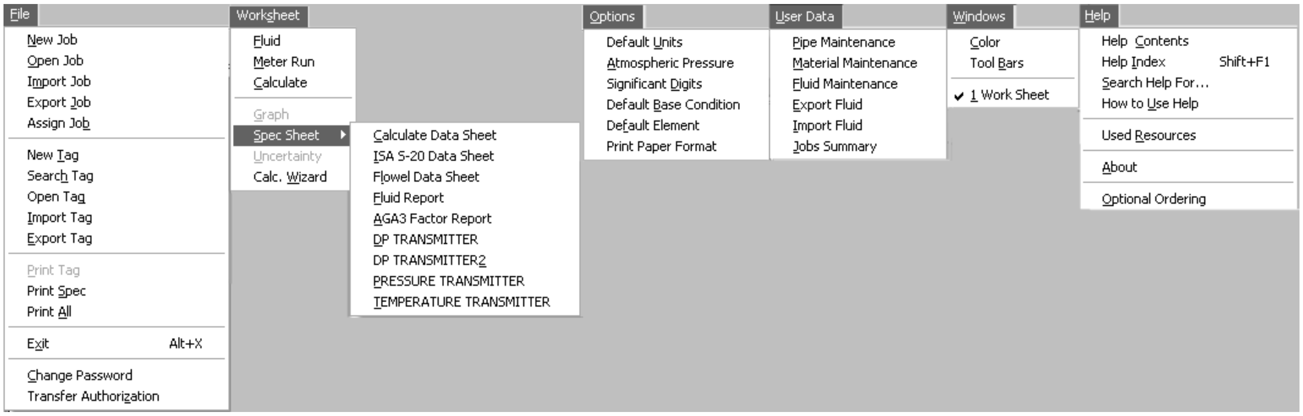
Figure 3-16 Main Menu

The main menu options include:

- File – the main create, open, import/export and print menu
- Worksheet – where the calculations are performed
- Options – allows user to set up the site-specific information
- User Data – allows users to set up the user-specific information.
- Windows – allows users set some of the Windows options
- Help – allows users access to all levels of on-line help information

The following menu diagram shows the main menu options and the commands which are available under each option. Please consult each.

Figure 3-17 Menu Diagram



3.33 Material Maintenance

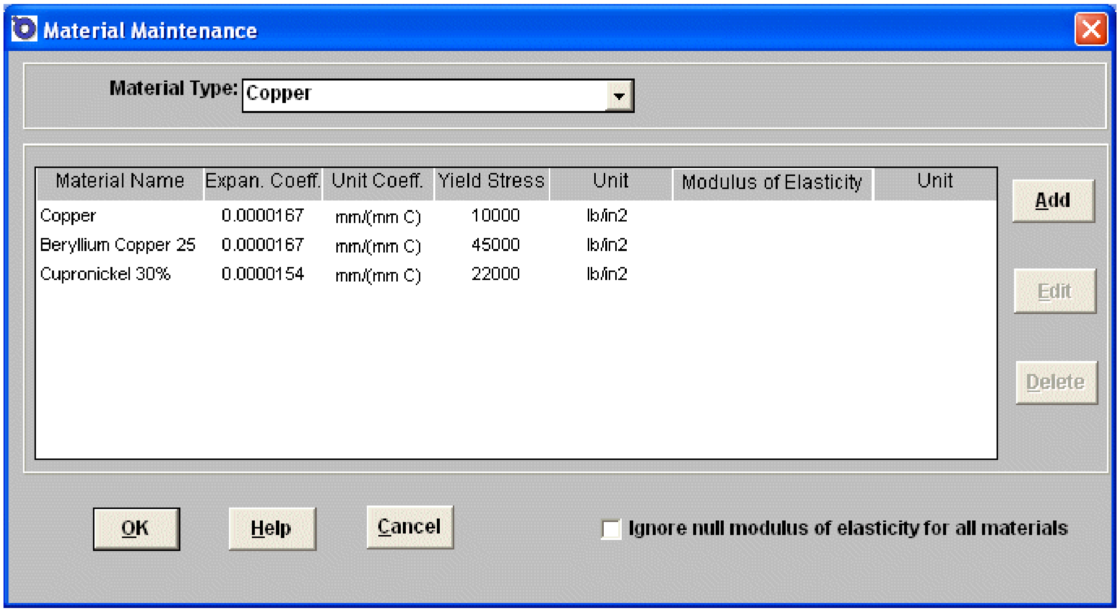
To activate the Material Maintenance function, type Alt-U-M, or under the **User Data** menu, click **Material Maintenance**.

Description

The Material Maintenance option is the function used to add, delete, and maintain Flowel's list of materials used in defining pipe and flow elements.

To display the list of materials available, click the material dropdown list.

Figure 3-18 Material Maintenance Dialog Box



Material Maintenance

Material Type: Copper

Material Name	Expan. Coeff.	Unit Coeff.	Yield Stress	Unit	Modulus of Elasticity	Unit
Copper	0.0000167	mm/(mm C)	10000	lb/in2		
Beryllium Copper 25	0.0000167	mm/(mm C)	45000	lb/in2		
Cupronickel 30%	0.0000154	mm/(mm C)	22000	lb/in2		

☐ Ignore null modulus of elasticity for all materials

3.33.1 Add Materials

On the Material Maintenance dialog box, click the **Add** button. The Add/Edit Material dialog box will appear. Type in the material name (up to 27 characters long). Select the units for the expansion coefficient, then enter the value for this material.

Next, select the units for the yield stress, then enter the value for the yield. Click **OK** to complete the addition of a material.

Note: The new material name must be unique.

3.33.2 Edit Materials

Flowel permits editing of user-defined materials only. Flowel keeps the pre-defined materials safe from any changes.

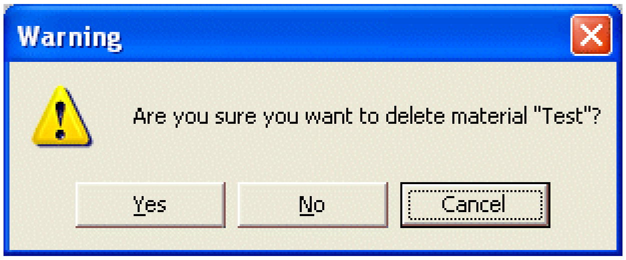
To edit a material, select the material from the Material Maintenance dialog box, then click the **Edit** button. Make the necessary changes and click **OK** to save the changes.

3.33.3 Delete Materials

Flowel permits the deletion of user-defined materials. Pre-defined materials included with Flowel cannot be deleted.

To delete a material, select the material from the Material Maintenance dialog box, then click the **Delete** button. A warning message appears.

Figure 3-19 Delete Material Warning Message



Warning

Are you sure you want to delete material "Test"?

Click **Yes** to confirm and complete the deletion.

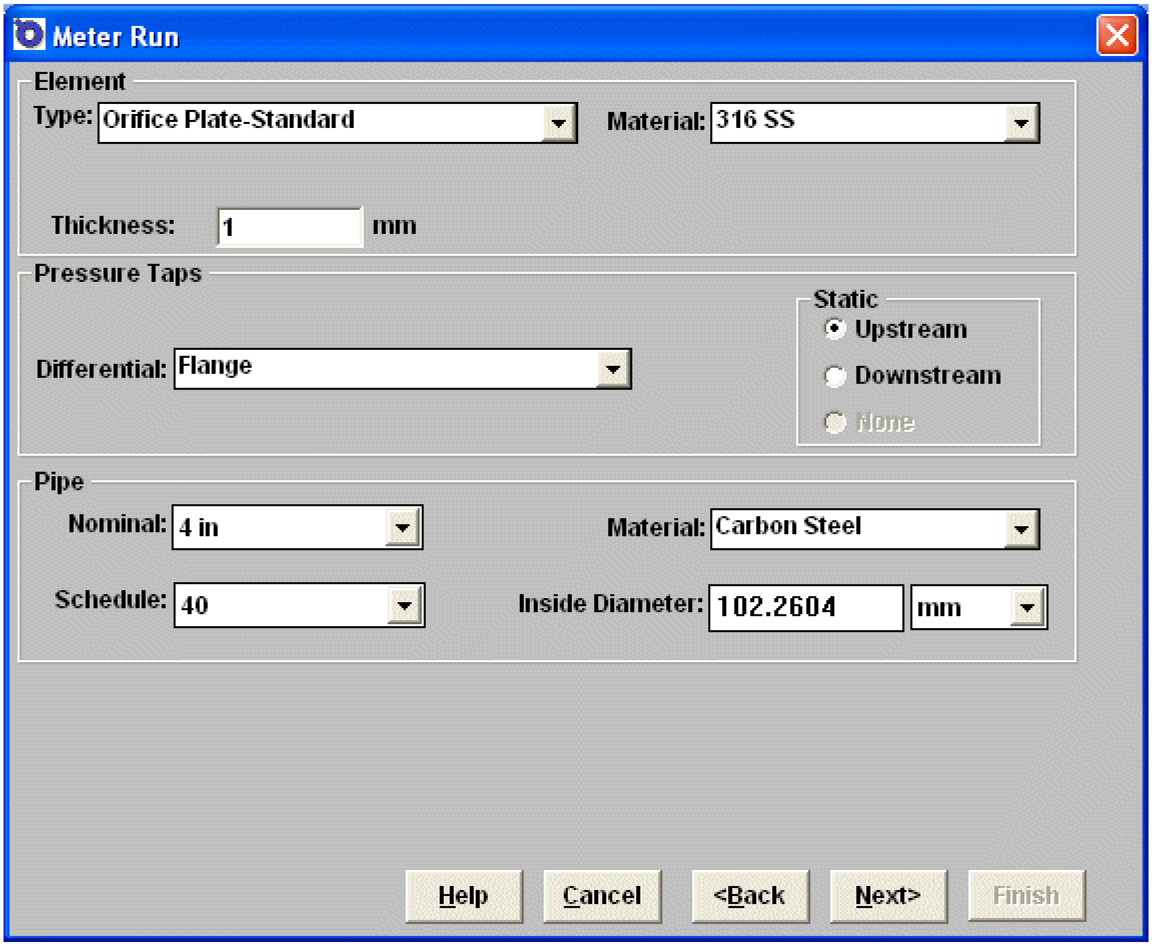
3.34 Meter Run

To activate the Meter Run function, type Alt-S-M, or under the **Worksheet** menu, click **Meter Run**.

Description

This option allows you to set up the meter information.

Figure 3-20 Meter Run Dialog Box



Meter Run

Element

Type: Orifice Plate-Standard

Material: 316 SS

Thickness: 1 mm

Pressure Taps

Differential: Flange

Static

● Upstream

○ Downstream

○ None

Pipe

Nominal: 4 in

Material: Carbon Steel

Schedule: 40

Inside Diameter: 102.2604 mm

The Meter Run dialog box is divided into three sections: Element, Pressure Taps, and Pipe. In each of these sections, the options pertaining to this specific tag must be set.

If you make a change to the Meter Run of an existing tag, when you click **Next** the program automatically moves you to the calculation screen.

3.34.1 Element

Flowel supports many different pressure element types. Select the element type from the dropdown selection list. Included are many types of orifice plates, venturi & nozzles. For venturi, you will have to enter an exit angle. For elements with a drain/vent, you will have to set a hole size and shape. All elements require that you select a material.

3.34.2 Pressure Taps

The options available change automatically with the selection of an element type. All options associated with an element are shown in the dropdown selection list. As a Differential option is selected, the selections available under Static will change. Most of the time the Upstream and Downstream static pressure taps will be available. The Upstream tap option will be the default in most instances.

3.34.3 Pipe

The Pipe section is where the nominal pipe size, schedule, and material are set.

First, select a pipe nominal.

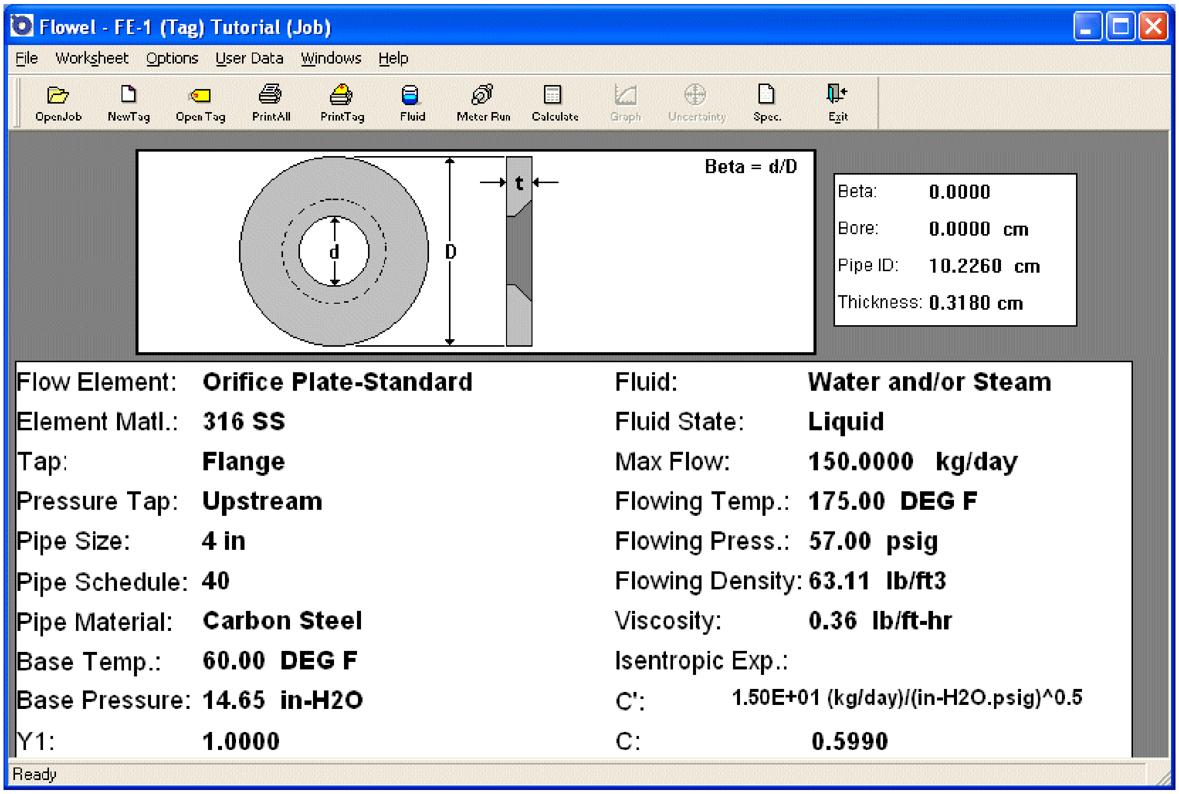
Next, based upon the nominal selected, there will be a number of schedules available for selection. Choose a schedule from the dropdown list. The inside diameter will be automatically set based upon the chosen nominal and schedule. You can also directly type in an inside pipe diameter. The inside pipe diameter units may be changed using the dropdown list box to the right of the diameter value.

Select a pipe material from the dropdown selection list. You may also type in the inside diameter directly. In this case, the fields for Nominal and Schedule will be set to a null (blank) once you click **Next**.

Note: If the desired pipe nominal/schedule/material for this tag does not exist in the pre-configured Flowel lists, see Pipe Maintenance, Section 3.42 for the proper way to add information.

Once all of the meter run information has been entered, click **Next** to save the information and move on to the next window.

Figure 3-21 Flowel Main Screen with Flow Element Displayed



Beta: 0.0000
Bore: 0.0000 cm
Pipe ID: 10.2260 cm
Thickness: 0.3180 cm

Flow Element: Orifice Plate-Standard
Element Matl.: 316 SS
Tap: Flange
Pressure Tap: Upstream
Pipe Size: 4 in
Pipe Schedule: 40
Pipe Material: Carbon Steel
Base Temp.: 60.00 DEG F
Base Pressure: 14.65 in-H2O
Y1: 1.0000

Fluid: Water and/or Steam
Fluid State: Liquid
Max Flow: 150.0000 kg/day
Flowing Temp.: 175.00 DEG F
Flowing Press.: 57.00 psig
Flowing Density: 63.11 lb/ft3
Viscosity: 0.36 lb/ft-hr
Isentropic Exp.:
C': 1.50E+01 (kg/day)/(in-H2O.psig)^0.5
C: 0.5990

You will notice that the main Flowel window has changed. Near the top of the window is an illustration of the flow element you selected. Also on the screen are the parameters you defined regarding element, pipe, fluid, etc.

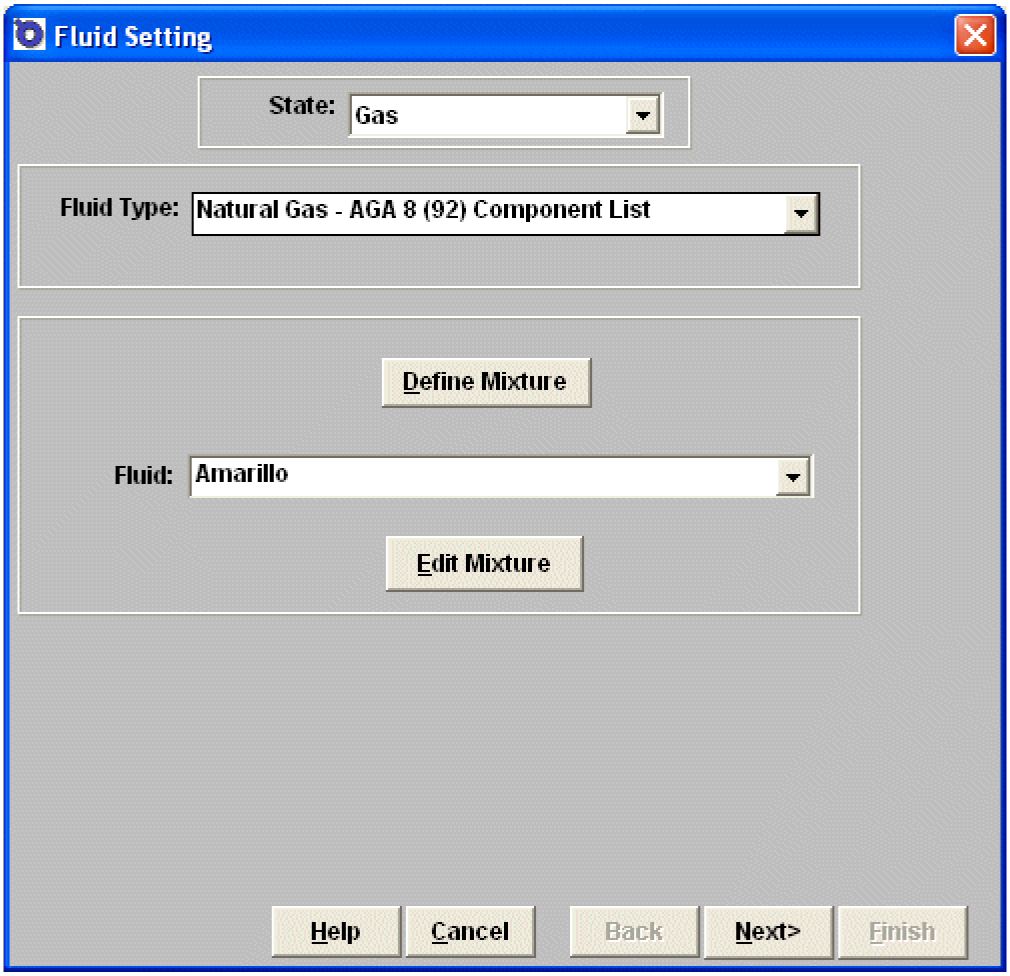
Related reference topics include:

- Material Maintenance
- Pipe Maintenance

3.35 Mixture Definition

To activate the mixture definition, click on the **Define Mixture** button on the Fluid Setting dialog box.

Figure 3-22 Fluid Setting Dialog Box



State: Gas

Fluid Type: Natural Gas - AGA 8 (92) Component List

Fluid: Amarillo

Description

A mixture is any fluid other than a pure substance or an "unknown fluid". For pre-defined fluids such as natural gas, the list of pure components that can be included in the mixture is restricted to only those that are applicable.

For a general mixture fluid type, however, you may select components from the complete Flowel pure component listing.

3.35.1 To Define a Mixture

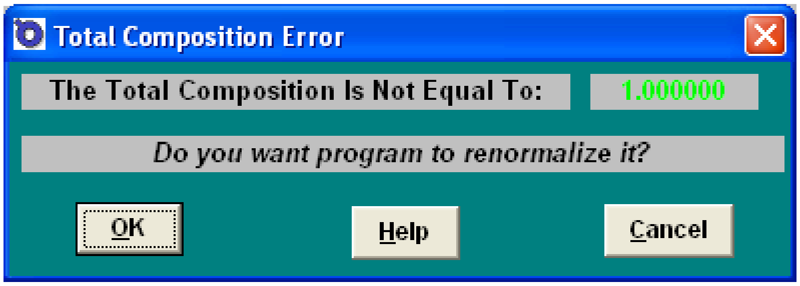
On the mixture definition dialog box, type in the mixture name. Select your preference of mole fraction or mole percentage.

Select the components to be included in this mixture, one by one, selecting from the component list using the **Add** button or by double-clicking on the selection to insert it into the list.

For each component, enter the mole value. For percentage, each value must be in the range of 0 to 100. For fraction, this value must be between 0 and 1.

If the total mole fraction does not add up to 1 or the total percentage does not add up to 100, and **OK** is clicked, Flowel will display the following message.

Figure 3-23 Total Composition Error Dialog Box



The Total Composition Is Not Equal To: 1.000000

Do you want program to renormalize it?

Click **OK** again to renormalize these values. The program will adjust each value proportionally to its weight, until the sum of the components equals 1 in the case of fraction and 100 in the case of percentage.

Note: On Flowel's selection lists; many of the selection lists within Flowel allow for item selection in more than one fashion. In this example we want to select Gas as a fluid state. We have two methods of making the selection.

The first method is the standard selection method. Press on the arrow button on the top-right hand of the State field. A dropdown list will appear. Select from the selection list by clicking on the desired item.

The alternate method is to type the first letter of the desired item, in this case the letter `G`. If there are more than one item which begins with the letter G, the first will be brought up. Press `G` again to get to the second one, and so on.

These methods apply to many areas of the program. In particular, when selecting pure fluids on the mixture definition function, the letter-selection method allows quick access to a component which might otherwise take a lot of time to scroll to in a list.

3.36 New Job

To activate the New Job function, type Alt-F-N, or under the **File** menu, click **New Job**.

Description

Use this function to start a new job.

Job No., Customer, Contractor, and Site Name fields can hold up to a 40 character description each. The Description field can hold up to 254 characters.

The job number is the most important information needed here. At a minimum you must enter a job number to continue. Your organization may have standards for job naming and tracking.

3.36.1 Define New Job

You must click the **Define New Job** button before entering a job number and information. If the **Delete Job** button is used, you must click the **Define New Job** button before creating a new job.

3.36.2 Delete Job

Use this function to delete an existing job and all of the associated tags. A warning prompt will ask for confirmation before this action is completed.

Note: You cannot delete a job if it is the currently open job. You must open a different job to be able to delete the desired job from the database.

3.36.3 New Tag Button

Use this button to go directly to the New Tag screen.

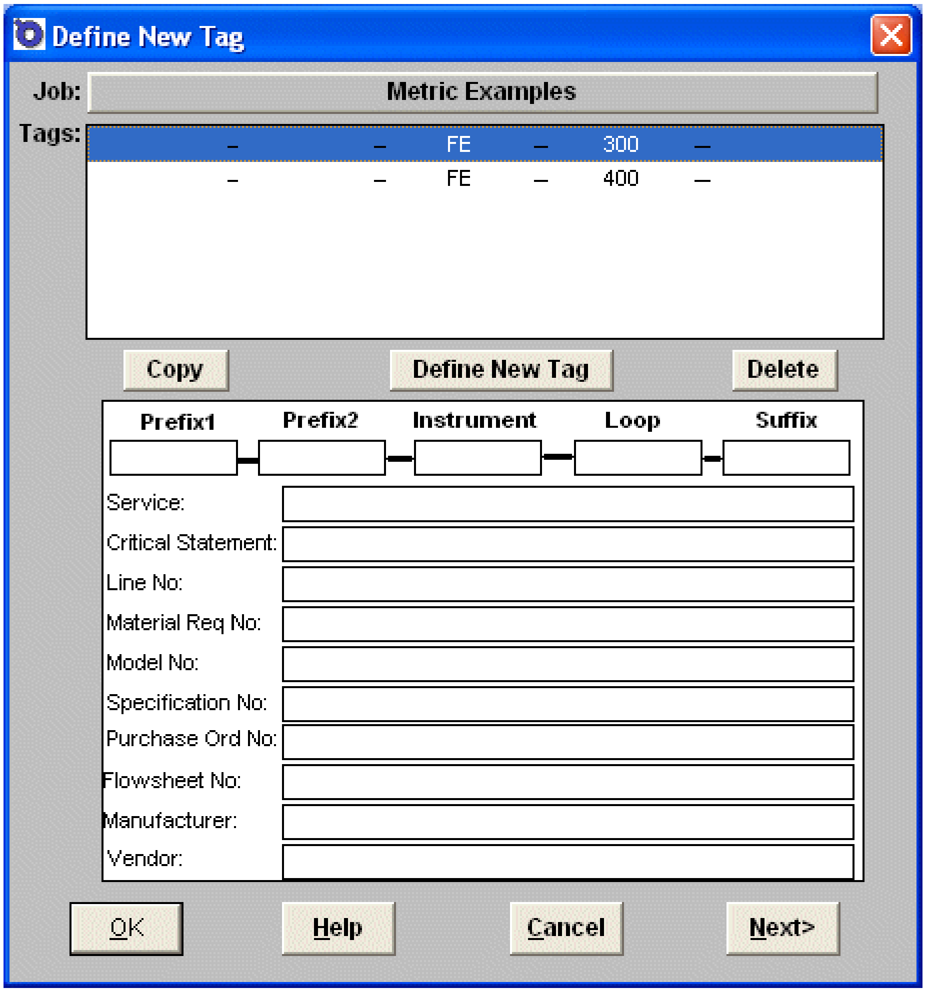
3.37 New Tag

To activate the New Tag function, type Alt-F-T, or under the **File** menu, click **New Tag**.

Description

This command creates a new tag within the currently open job. Each tag is associated with a real world device in the field.

Figure 3-24 New Tag Dialog Box



Job: Metric Examples

Tags:

```
 –    –  FE  –  300  –
 –    –  FE  –  400  –
```

The New Tag dialog box displays the current job (to which this new tag will be saved), and any existing tags under this job.

3.37.1 Define New Tag

Click the **Define New Tag** button to accept information on a new tag. Begin by entering the full tag name. Flowel is designed to use a five-part tag thereby conforming to the ISA-standard tag naming convention.

Here is a brief review of the ISA tag naming convention:

- Prefix1 – an optional general location identifier
- Prefix2 – an optional, more specific location identifier
- Instrument ID – a required field which classifies the function of the device

- Loop number – a required field, usually a grouping of instruments working together toward a common function
- Suffix – additional optional identifier to distinguish between instances of a device in a loop

The minimum information required fields to complete when creating a new tag are the Instrument ID and Loop fields. However, we do not recommend creating tags with only this minimum information. Be thorough here and you will likely save considerable time and effort later.

The following fields are available for use:

Field	Characters
Critical Statement	25
Line No.	20
Service	40
Model No.	40
Specification No.	8
Material Req. No.	40
Purchase Order No.	40
Part ID No.	40
Manufacturer	32
Vendor	32

When you have completed filling in the information on this dialog box, click **OK** to save the tag information, or if you are following Flowel's recommended program flow (see Flowel's Method, Section 3.37.4), click the **Next** button to get to the next function.

3.37.2 Copy

Select an existing tag from the list available, then click the **Copy** button. The information from the original tag will be copied into the fields of the new tag. You may then edit the information which appears in this dialog box to complete the creation of this new tag.

3.37.3 Delete

A delete command is available here for your convenience. This is the only way to remove tags from a job.

Select the tag to be deleted, then click the **Delete** button.

Note: The currently open tag may not be deleted. Open another tag before deleting a tag from the database.

3.37.4 Flowel's Method

Flowel 4.0 was designed with a certain method or approach in mind. As a result, we have built into the program a way of following this method easily and quickly.

A **Next** button appears at the bottom of the New Tag dialog box. Each subsequent dialog box in the recommended program flow provides a **Next** button, and most provide a **Back** button (to go back and change or fix something). When the process is completed you will have followed all of the steps necessary to add and configure a new tag. Any of the parameters that you set in this process can be modified after-the-fact by recalling the particular function using the menus.

If you are creating a new tag, the **Next** button calls up the next screen in the recommended program flow.

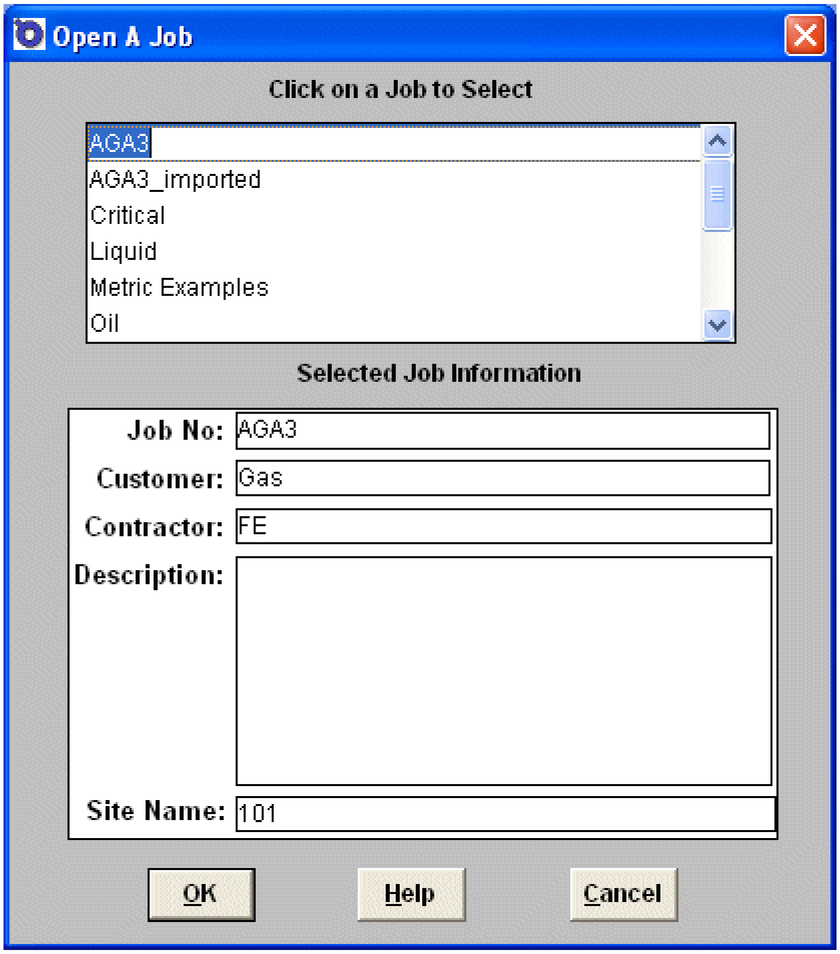
3.38 Open Job

To activate the Open Job function, type Alt-F-O, or under the **File** menu, click **Open Job**.

Description

The Open Job command is used to recall or resume work on a job that has already been created.

Figure 3-25 Open Job Dialog Box



Job No: AGA3
Customer: Gas
Contractor: FE
Description:
Site Name: 101

As you move between selections, the information associated with each job is displayed. This makes it easier to identify the job.

Select the job's name from the window, then click **OK**.

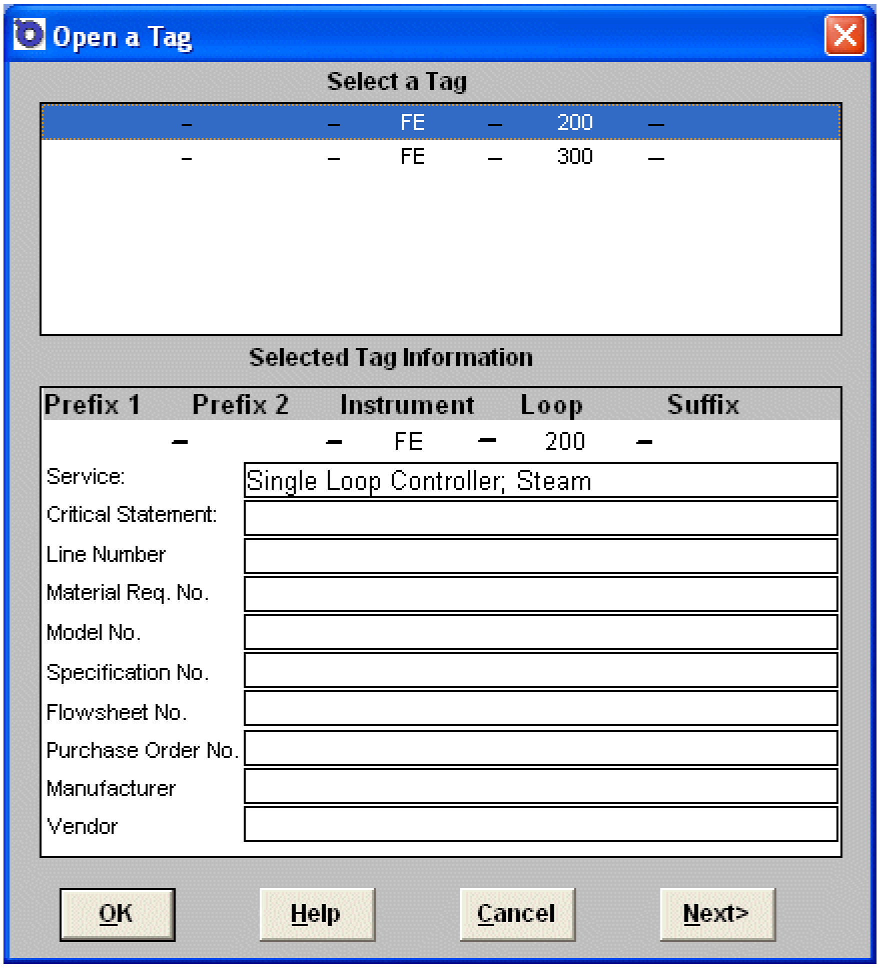
3.39 Open Tag

To activate the Open Tag function, type Alt-F-G, or under the **File** menu, click **Open Tag**.

Description

This command opens an existing tag. Select the tag from the list by double clicking on it, or use the cursor keys to select the tag then press Enter or click **OK**.

Figure 3-26 Open Tag Dialog Box



Select a Tag

	–		–	FE	–	200	–	
	–		–	FE	–	300	–	

Selected Tag Information

Prefix 1	Prefix 2	Instrument	Loop	Suffix
–	–	FE –	200 –	

Service: Single Loop Controller; Steam

Critical Statement:

Line Number

Material Req. No.

Model No.

Specification No.

Flowsheet No.

Purchase Order No.

Manufacturer

Vendor

Information specific to each tag will appear as you select between tags, making it easier to identify each tag exactly.

3.40 Optional Ordering

To activate the Optional Ordering function, type Alt-H-O, or under the **Help** menu, click **Optional Ordering**.

Description

If your version of Flowel was purchased without the optional Fluid Property package, or you have a limited run version of the program and you want to order more days/runs, you can use this option to place your order.

If you have a run-limited version of the program, the dialog box which appears indicates how many days or runs are remaining on the current installation.

These are the steps you need to perform:

1. Obtain a purchase order and/or authorization to purchase the upgrade.
2. Activate this option (under the **Help** menu, click **Optional Ordering**), enter your company information, then make the selection regarding the type of installation. Your choices are: stand alone and network.
    - Stand Alone: A stand alone installation means that you will be running Flowel on one PC only (not from a server or over a network). Most installations will be of this type.
    - Network: If you will be running Flowel from a network server, or if you are installing Flowel on one computer but occasionally running it from another networked computer, you should select the network option.
3. Click the **Order** button.
4. A form will be printed on your printer. Fax this form to Hydrocarbon and Energy, at the number which appears on the form.
5. Hydrocarbon and Energy will fax back a site key. This key is used to enable the Fluid Properties package, or add additional runs/days.
6. Re-run this Optional Ordering function. On the screen where you entered the ordering information, enter the Site Key, then click **OK**.
7. Exit the program. When you restart Flowel, the Fluid Properties package, or the new number of days/runs will be enabled. In the case of the fluid properties option, all of the options will now be available to you.

3.41 Options Menu

To activate the **Options** menu, type Alt-O.

Description

The Options Menu contains functions to set the default units for the program, and for setting atmospheric pressure for each tag site.

All of the menu items in Flowel are listed by name (alphabetically) in the reference section. Please look to the specific function name for information on that function.

3.42 Pipe Maintenance

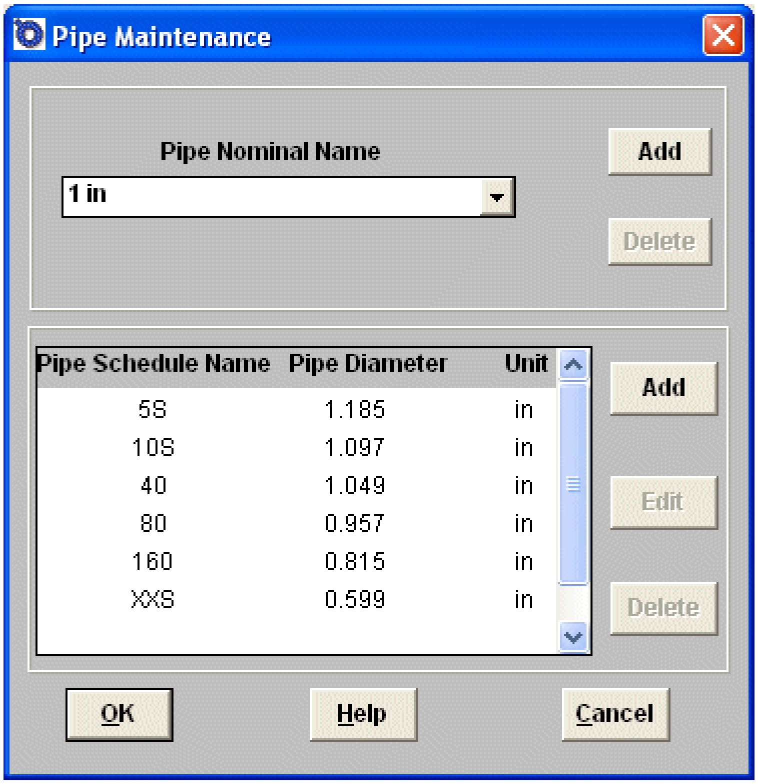
To activate the Pipe Maintenance function, type Alt-U-P, or under the **User Data** menu, click **Pipe Maintenance**.

Description

The Pipe Maintenance function allows new pipe information to be added to the pipe database included with Flowel.

For each nominal pipe size, there may be many pipe schedules defined. You may add to both the nominals as well as schedules for each nominal.

Figure 3-27 Pipe Maintenance Dialog Box



Pipe Nominal Name: 1 in

Pipe Schedule Name	Pipe Diameter	Unit
5S	1.185	in
10S	1.097	in
40	1.049	in
80	0.957	in
160	0.815	in
XXS	0.599	in

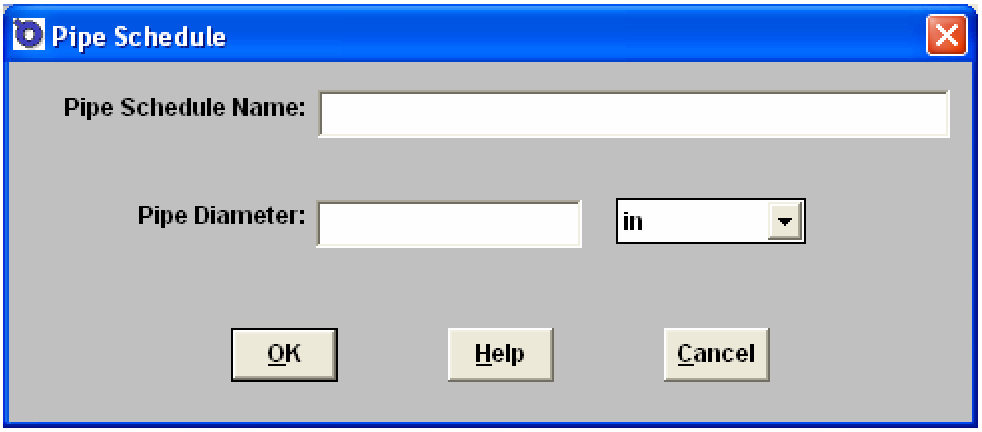
3.42.1 Add a Nominal Diameter

Click the **Add** button which appears to the right of the pipe nominal field.
The Pipe Nominal Name dialog box appears. Enter a name for this new pipe. The name may be up to 15 characters long. Click **OK** to continue.

3.42.2 Add a Pipe Schedule

After entering a pipe name, click the **Add** button which appears to the right of the schedule information field.

Figure 3-28 Pipe Schedule Dialog Box



The Pipe Schedule dialog box appears. Enter the schedule name. You may use up to 24 characters for the name. Next, set the units for the measurement and then enter a pipe diameter (ID).

When all of this information has been entered, click **OK**.

Note: You may add schedules to the nominals supplied by Flowel. These new schedules may be edited and deleted since they are user-defined. Any changes made here will not affect the Flowel-supplied nominals/schedules.

3.42.3 Edit a Pipe Schedule

Select the schedule to be changed from the Pipe Maintenance dialog box. Click the **Edit** button. The Pipe Schedule dialog box appears with the schedule name, diameter and units displayed in the fields. Make changes to any of these fields as necessary. Click **OK** when your changes are complete.

Note: You cannot edit the schedules provided by Flowel. Only the user-defined nominals and schedules may be edited or deleted.

3.42.4 Delete a Nominal Diameter

Only nominal diameter that you have added may be deleted. Flowel does not allow the nominal diameters and pipe schedules with which it was supplied to be altered or deleted.

To delete a user-defined nominal diameter, select the nominal from the Pipe Maintenance dialog box, then click the **Delete** button. A warning prompt will appear requesting confirmation of this action. Click **Yes** to complete the operation.

Note: All pipe schedules defined under this nominal diameter must be deleted before the nominal can be deleted.

3.42.5 Delete a Pipe Schedule

Only pipe schedules that you have added may be deleted. Flowel does not allow the nominal diameters or pipe schedules with which it was supplied to be altered or deleted.

To delete a user-defined pipe schedule, select the schedule from the Pipe Maintenance dialog box, then click the **Delete** button.

A warning prompt will appear requesting confirmation of this action. Click **Yes** to complete.

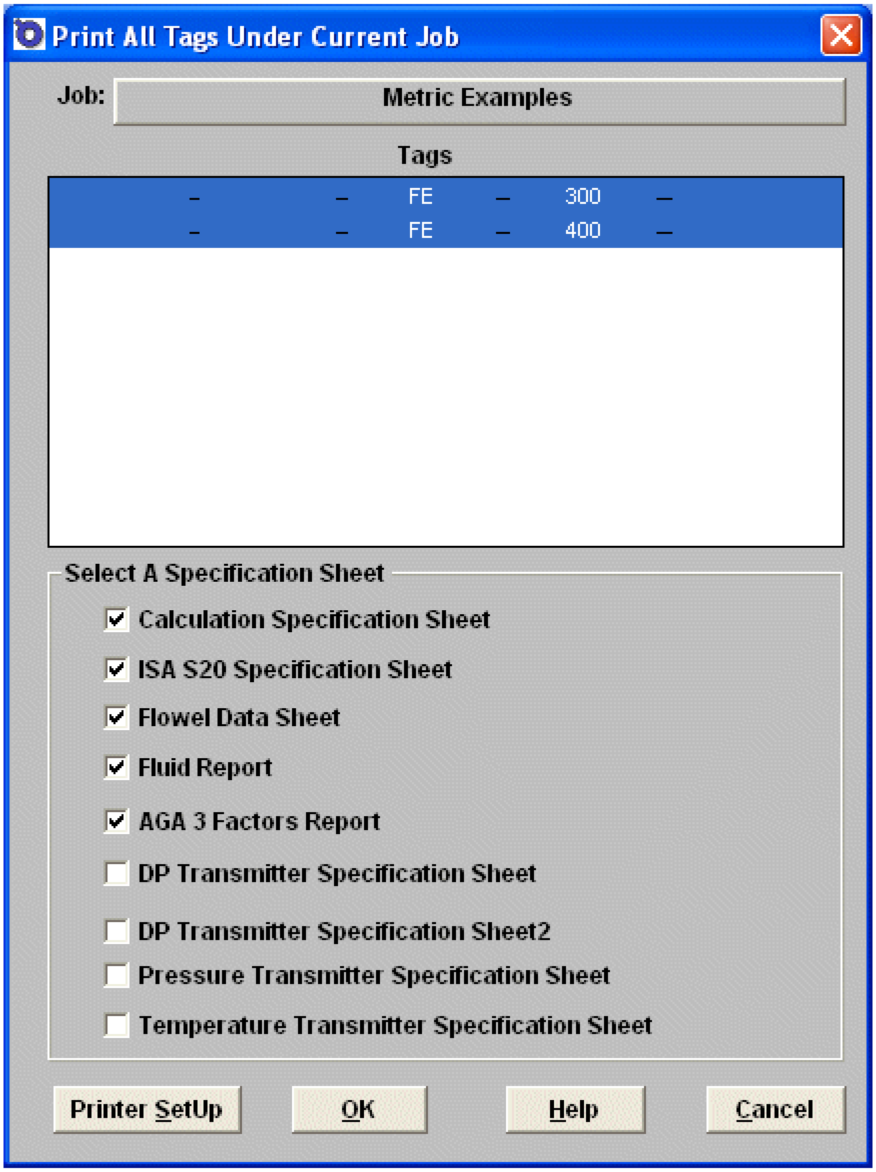
3.43 Print All

To activate the Print All function, type Alt-F-A, or under the **File** menu, click **Print All**.

Description

This command prints all tags which are associated with the current job.

Figure 3-29 Print All Dialog Box



Print All Tags Under Current Job

Job: Metric Examples

Tags

–	–	FE	–	300	–
–	–	FE	–	400	–

Select A Specification Sheet

☑ Calculation Specification Sheet
☑ ISA S20 Specification Sheet
☑ Flowel Data Sheet
☑ Fluid Report
☑ AGA 3 Factors Report
☐ DP Transmitter Specification Sheet
☐ DP Transmitter Specification Sheet2
☐ Pressure Transmitter Specification Sheet
☐ Temperature Transmitter Specification Sheet

The Print All dialog box appears, displaying the current job name. Underneath the name is a list of tags which will be printed.

Select a specification sheet format from those available. Click on the checkboxes for the options you want.

Note: Only those reports which are appropriate for each tag will be printed. For example, a tag which does not use the AGA 3 method will not have an AGA 3 factors report printed for it.

3.43.1 Print Paper Format

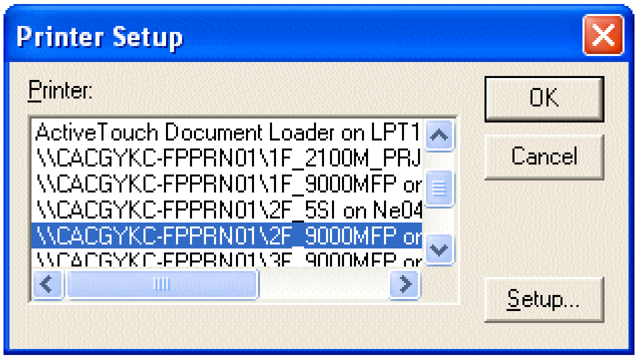
The Print Paper Format option allows the user to select Letter or A4 paper size. This will affect the print and save functions of the specification sheets.

To activate click the **Options** menu and select **Print Paper Format**.

3.43.2 Printer Setup

The program uses the standard Windows printer setup dialog. You will be familiar with this dialog box if you have operated other Windows applications.

Figure 3-30 Printer Setup Dialog Box



The printers which have been set up on your computer will appear in this list. Select the desired printer for your print job. Use the Setup option from this dialog box to make last-minute changes to your selected printer's configuration.

Once all of the selections have been made, click **OK** to start the printing process. A message on the screen will indicate the progress of the printing function.

3.44 Print Preview

To activate the Print Preview function, click the **Print Preview** button.

Description

The Preview function provides you with a method of proofing the look of your document before it is printed.

On the Print Preview dialog box, select the zoom factor for previewing, then click **OK**.

3.45 Print Spec.

To activate the Print Spec. function, type Alt-F-S, or under the **File** menu, click **Print Spec**.

Description

Use the Print Spec. function to print all of the specification sheets which have the same specification number defined as part of a tag's information. This number is defined on a tag by tag basis.

The Print Spec. dialog box displays the current job name. Select a specification number from the dropdown list provided. Once this has been done, the program will create a list of tags which will be printed. This list is displayed for you.

Select a specification sheet format from those available. Click on the checkboxes for the options you want.

Note: Only those reports which are appropriate for each tag will be printed. For example, a tag which does not use the AGA 3 method will not have an AGA 3 factors report printed for it.

For print paper format options, refer to Print Paper Format, Section 3.43.1. For printer setup and preview options refer to Printer Setup, Section 3.43.2 and Print Preview, Section 3.44.

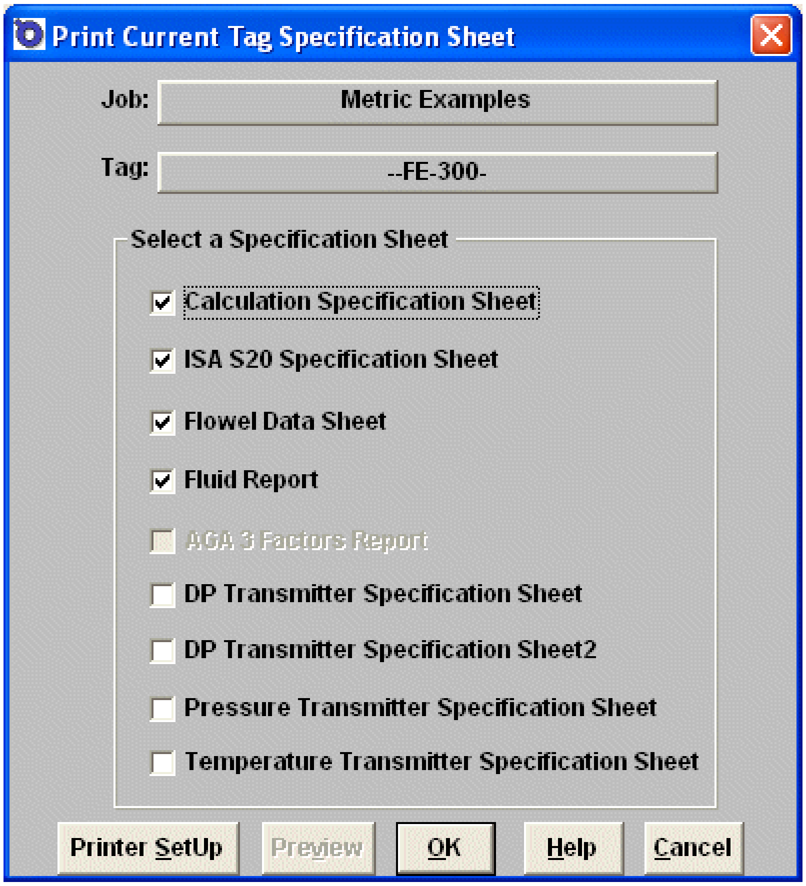
3.46 Print Tag

To activate the Print Tag function, type Alt-F-P, or under the **File** menu, click **Print Tag**.

Description

The Print Tag option prints the specification sheets for the current tag using the format selected on this print dialog box.

Figure 3-31 Print Tag Dialog Box



Print Current Tag Specification Sheet

Job: Metric Examples

Tag: --FE-300-

Select a Specification Sheet

- ☑ Calculation Specification Sheet
- ☑ ISA S20 Specification Sheet
- ☑ Flowel Data Sheet
- ☑ Fluid Report
- ☐ AGA 3 Factors Report
- ☐ DP Transmitter Specification Sheet
- ☐ DP Transmitter Specification Sheet2
- ☐ Pressure Transmitter Specification Sheet
- ☐ Temperature Transmitter Specification Sheet

The Print Tag dialog box displays the current job and tag name.

Select a specification sheet format from those available. Click on the checkboxes for the options you want. The preview button will be enabled if only one type of specification sheet is selected.

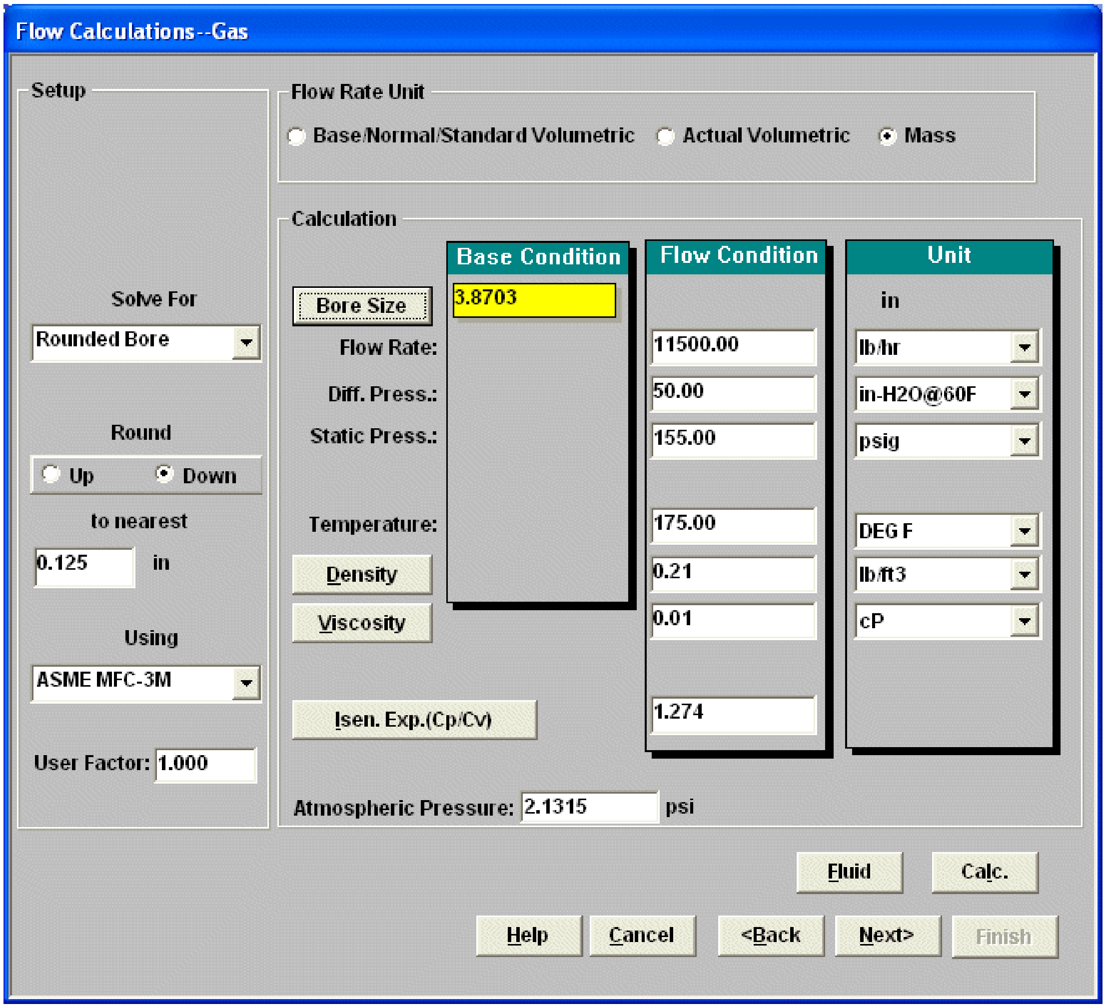
Note: Only those reports which are appropriate for each tag will be printed. For example, a tag which does not use the AGA 3 method will not have an AGA 3 factors report printed for it.

For print paper format options, refer to Print Paper Format, Section 3.43.1. For printer setup and preview options refer to Printer Setup, Section 3.43.2 and Print Preview, Section 3.44.

3.47 Rounded Bore Size

The Rounded Bore Size option applies to concentric orifice plates. When this option is selected, you can specify whether you want to round up or down to the specified increment.

Figure 3-32 Flow Calculation Dialog Box – Solving for Rounded Bore



Solve For: Rounded Bore

Round: ○ Up ● Down

to nearest 0.125 in

Using: ASME MFC-3M

User Factor: 1.000

Flow Rate Unit: ○ Base/Normal/Standard Volumetric ○ Actual Volumetric ● Mass

	Base Condition	Flow Condition	Unit
Bore Size	3.8703		in
Flow Rate:		11500.00	lb/hr
Diff. Press.:		50.00	in-H2O@60F
Static Press.:		155.00	psig
Temperature:		175.00	DEG F
Density		0.21	lb/ft3
Viscosity		0.01	cP
Isen. Exp.(Cp/Cv)		1.274	

Atmospheric Pressure: 2.1315 psi

The minimum information fields that are required to calculate the rounded bore are:

Flow Rate	flowing conditions, or base condition if a normal or standard volumetric flow rate is selected
Differential Pressure	
Static Pressure	flowing conditions, or base condition if a normal or standard volumetric flow rate is selected

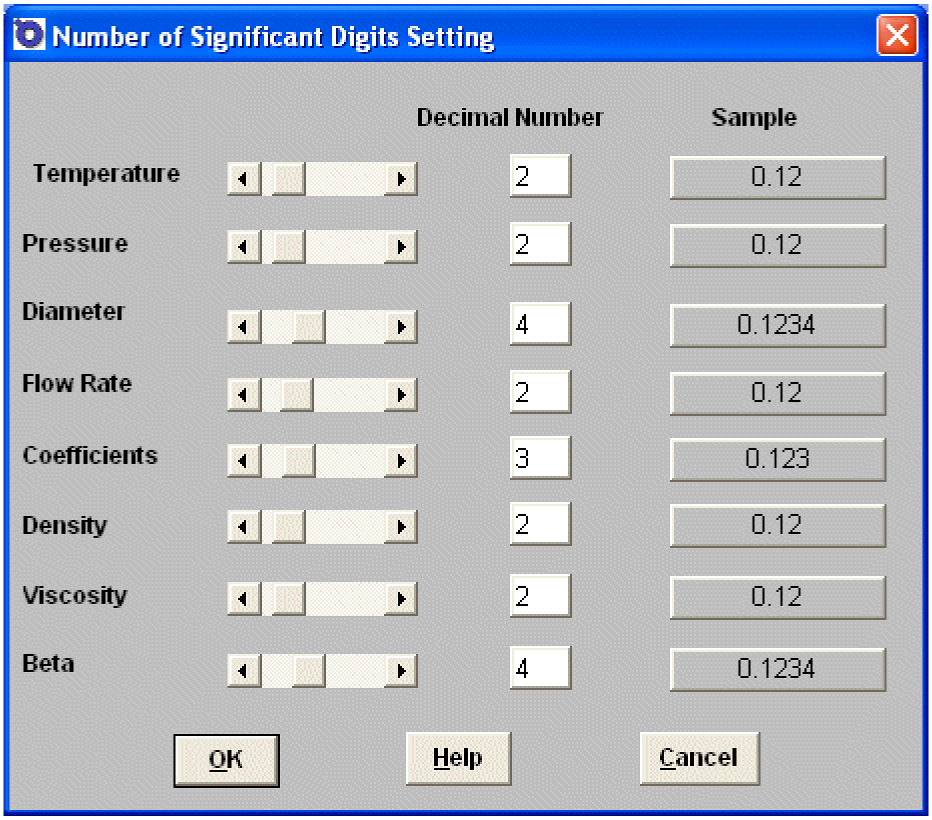
Temperature	flowing conditions, or base condition if a normal or standard volumetric flow rate is selected
Density	flowing conditions, or base condition if a normal or standard volumetric flow rate is selected
Viscosity	
Isentropic Exponent	(this field will not appear if the fluid is in liquid state)
Round Direction	Round to the nearest value and unit. The unit will be set to the pipe diameter unit automatically.

The program will calculate the beta ratio first, then adjust bore diameter according to the round setting. The program then uses the adjusted bore diameter to recalculate the flow rate.

3.48 Significant Digits

To activate the Significant Digits function, type Alt-O-D, or under the **Options** menu, click **Significant Digits**.

Figure 3-33 Significant Digits Setting Dialog Box



	Decimal Number	Sample
Temperature	2	0.12
Pressure	2	0.12
Diameter	4	0.1234
Flow Rate	2	0.12
Coefficients	3	0.123
Density	2	0.12
Viscosity	2	0.12
Beta	4	0.1234

Use this option to set the number of decimal places for the following variables:

- temperature
- pressure
- diameter
- flow rate
- compressibility
- density
- viscosity
- beta

Each of these fields can be set to display from 1 to 10 digits after the decimal (the exception is a range of 0 to 10 for flow rate). Either use the horizontal scroll bar to change the value, or enter the number of digits directly into the corresponding field. This will affect the number of decimal places displayed on a spec. sheet printout and the calculation screen. It does not affect the number of decimal places used in the calculations.

3.49 Spec. Sheet

To activate the Spec. Sheet function, type Alt-S-S, or under the **Worksheet** menu, click **Spec. Sheet**.

Description

The Spec Sheet option is used to create specification sheets for a tag. By selecting one of the three formats, you activate an entry screen which will include data filled in by the program for you. The remaining fields may be filled in as required. Each of the spec sheet types will have data fields unique to that type.

The scale you set for the specification sheet is saved for re-use, until you set it again. This allows scaling (normally 95%) for proper printing for European paper sizes. You may print each of the specification sheets from this display, including:

- Calculate Data Sheet
- ISA S-20 Data Sheet
- Flowel Data Sheet
- Fluid Report
- AGA 3 Factor Report
- DP Transmitter
- DP Transmitter 2
- Pressure Transmitter
- Temperature Transmitter

Create specification sheets of the selected type for viewing or printing of the current tag.

3.50 Toolbars

To activate the Toolbars function, type Alt-W-B, or under the **Windows** menu, click **Tool Bars**.

Description

The Toolbars prompt allows for the convenient positioning of tools within the window area. Options include standard toolbars, a floating toolbar, toolbars with text titles, and the ability to hide toolbars completely.

3.50.1 Use

The Toolbar provides a recommended method of program flow when each of the options are activated in order from left to right. This is the same process described in the New Tag topic but instead of using the **Next** button, the toolbar items are used.

Figure 3-34 Toolbars Dialog Box

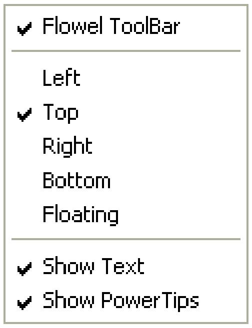
Customize Toolbars

Move
○ Left
○ Right
● Top
○ Bottom
○ Floating

☑ Show Text

An alternate method of activating the toolbar commands is to click anywhere on the toolbar using the right mouse button. This activates the following menu, shown in Figure 3-35.

Figure 3-35 Toolbar Menu

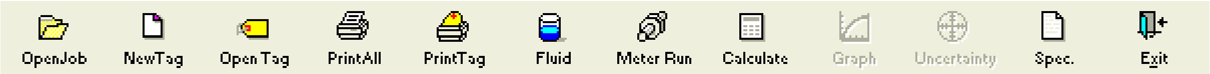


Checkmarks indicate the currently active options. You can select any option here as you would from the Toolbars popup dialog box. The Left, Right, Top and Bottom options move the toolbar to the outer edge of the screen in the position selected.

Figure 3-36 Floating Toolbar

The Floating option (Figure 3-36 above) allows the toolbar to be dragged anywhere in the window.

Figure 3-37 Toolbar with Show Text Selected



The "Show Text" option may be toggled on or off by clicking on the checkbox next to the option. This will display a text title underneath each toolbar option making it easier to remember each button's function, as shown in Figure 3-37.

To remove the toolbar from the window completely, press the Hide button. The toolbar will not appear at any time unless the toolbar function is reactivated and the Show button selected.

Once all of the options have been set, click **OK**.

3.51 Transfer Authorization

To activate the Transfer Authorization function, type Alt-F-Z, or under the **File** menu, click **Transfer Authorization**.

Description

This option is used to transfer the CrypKey copy protection when moving the program from one computer to another. You will not be able to transfer the site key from a 16 bit operating system to a 32 bit.

The transfer of your site key from one PC to another is a four step process. This process is required if you are moving Flowel from one computer to another. A new site key will not be generated for the new computer.

1. Install Flowel on the destination computer.
   Note: You must install. It is not sufficient to copy.
2. Prepare a blank floppy disk for the transfer by the destination computer.
3. Insert the floppy into the computer on which Flowel currently resides, and the transfer is initiated.
4. Place the completed floppy into the destination computer and the site key is transferred onto it.

The details for the site key transfer are as follows:

1. Prepare by having a blank, formatted floppy disk ready.
2. After Flowel has been installed on the destination computer, run the program (double-click on the Flowel icon from the Windows Program Manager.)
3. An Authorization Warning Message will appear. Click **OK**.
4. A Request for Authorization dialog will appear. Since this is not a new installation, select **Transfer from floppy**.
5. Click **OK**. The program will now prompt you to insert the floppy in to your floppy disk drive and select the drive letter from the selection box. Once the floppy is inserted in the drive, and the correct drive letter has been selected, click the **Register Transfer** button.
6. The program will prepare the floppy and an information message will appear. Click **OK**.
7. Now, bring the prepared floppy disk to the computer onto which Flowel is currently installed. Run Flowel.
8. On the **File** menu, select **Transfer Authorization**.
9. The program will prompt you to place the prepared floppy disk into this computer and select the floppy drive letter. Do so and click **OK**.
10. Move the floppy to the destination computer. Start Flowel.
11. A warning message may appear, if so, click **OK**.
12. The Request for Authorization screen appears. Select **Transfer from floppy**, and click **OK**.

13. The Transfer In Authorization screen appears. Select the drive.
14. Click **Transfer In**.
15. Once the transfer of the site key is complete, the prompt will disappear. Remove the floppy disk from this computer.
16. Once the site key has been successfully transferred from the floppy disk, Flowel will start.

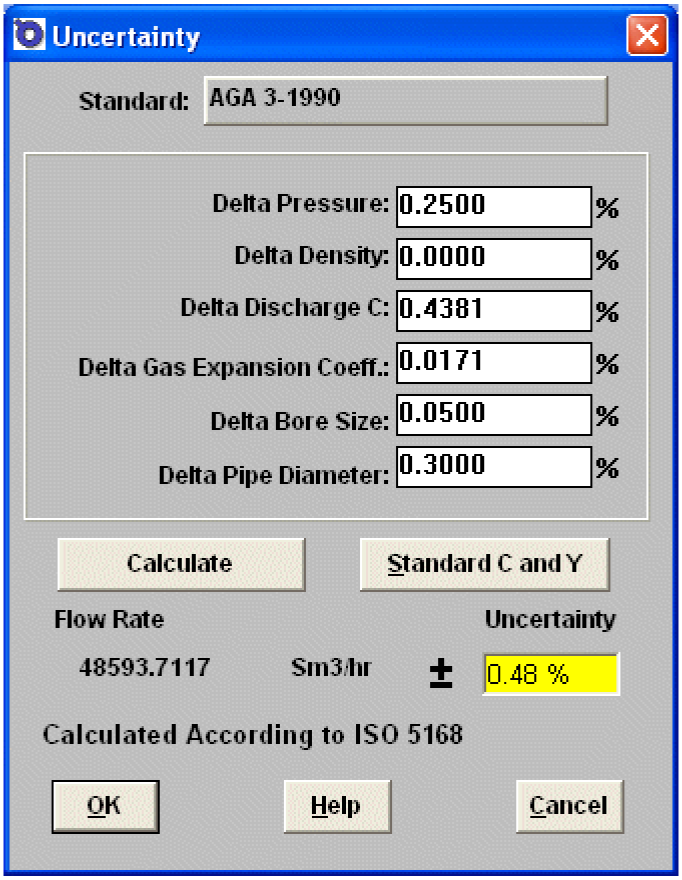
3.52 Uncertainty

To activate the Uncertainty function, type Alt-S-U, or under the **Worksheet** menu, click **Uncertainty**.

Description

Use this option to enter the uncertainty values for some of the variables used in ISO 5168 flow rate uncertainty calculations.

Figure 3-38 Uncertainty Dialog Box



Standard: AGA 3-1990

Delta Pressure: 0.2500 %
Delta Density: 0.0000 %
Delta Discharge C: 0.4381 %
Delta Gas Expansion Coeff.: 0.0171 %
Delta Bore Size: 0.0500 %
Delta Pipe Diameter: 0.3000 %

Flow Rate			Uncertainty
48593.7117	Sm3/hr	±	0.48 %

Calculated According to ISO 5168

Uncertainties in discharge coefficient and gas expansion coefficient as provided by the displayed standard (e.g. AGA 3-1985). These values are calculated based upon standards and flow conditions. These two values cannot be changed. Uncertainties in bore size and pipe inside diameter are also provided by Flowel according to the standard specified, however, you may overwrite these values.

It is recommended that you provide uncertainties in pressure and density. The program will use 0 (zero) for these values if they are not provided.

Once each of the values has been entered, click on the **Calculate** button and Flowel will calculate the flow rate uncertainty. Click **OK** to return to the main screen.

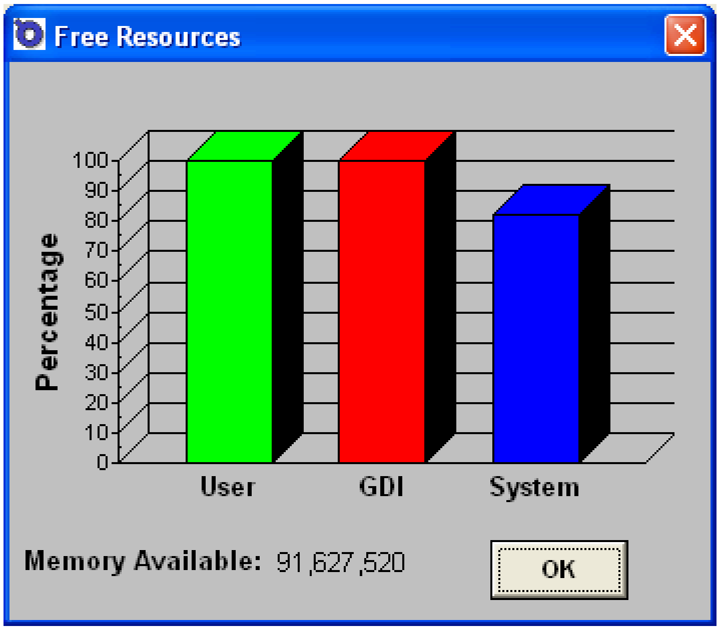
3.53 Used Resources

To activate the Used Resources function, type Alt-H-R, or under the **Help** menu, click **Used Resources**.

Description

This function displays a graph of the percentage of free resources available while you are running Flowel. This can be a useful indicator if you find your system is running slow or incorrectly. Check to see that there are adequate resources available. If not, try running fewer applications at one time.

Figure 3-39 Free Resources Dialog Box



Memory Available: 91,627,520

3.54 User Data Menu

To activate the User Data menu, type Alt-U.

Description

Use this menu to set the user-specific parameters for the program.

3.54.1 Pipe Maintenance

Allows new pipe nominal diameters and schedules to be added and maintained.

3.54.2 Material Maintenance

Allows new pipe and flow element materials to be added and maintained.

3.54.3 Fluid Maintenance

Allows fluids to be copied, user-defined fluids to be deleted, and mole fractions to be adjusted.

3.55 User Factor

The User Factor is an independent factor for the user to modify the flow equation. In most situations the User Factor will be 1.0.

3.56 Vapor Pressure/Bubblepoint

To activate the Vapor Pressure function, click the **Vapor Pressure** button on the Flow Calculation window (the **Bubblepoint** button if the current fluid is a mixture).

Description

This function calculates the vapor pressure or bubblepoint of fluids.

This calculation is not used in the calculation of flow rate, however, you can use the result to check for possible cavitation or flashing. If the bubblepoint is close to the downstream pressure, you can expect vaporization to occur.

3.56.1 Bubblepoint

The **Bubblepoint** button, when clicked, produces a dialog box that prompts the user to select a calculation method. The following methods are available: Soave-Redlich-Kwong and Peng-Robinson.

These methods provide comparable bubblepoint calculations. The results should be very close for most hydrocarbon systems. Please be aware that neither method will provide reliable results for polar systems.

3.57 Viscosity

To activate the Viscosity function, click the **Viscosity** button on the Flow Calculation dialog box.

Description

Use this function to calculate the viscosity of a gas (pure or defined mixture) and water or steam. Static pressure and temperature must be entered on the flow calculation screen for this operation to be successful.

3.58 Windows Menu

To activate the Windows menu, type Alt-W.

Description

This is a Windows housekeeping menu which allows you to make changes to the specific configuration of the program. The options available under this menu include Color and Tool Bars.

3.59 Worksheet Menu

To activate the Worksheet menu, type Alt-S.

Description

It is under this menu that the important calculations within Flowel are made, including Fluid, Meter Run, Calculate, Graph, Specification Sheets, and Uncertainty calculations.

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A Nomenclature – Glossary of Terms

Variable names and meanings for the purposes in the Flowel program are shown below.

B	AGA 3 simplification term
C	Flow element discharge coefficient
C'	Meter coefficient
d	Flow element actual or effective diameter (m) at flowing conditions
d_{meas}	Flow element actual or effective diameter (m) at 20°C
D	Pipe inside diameter (m) at flowing conditions
D_{meas}	Pipe inside diameter (m) at 20°C
D_{dh}	Drain or vent hole diameter (m)
ΔP	Differential pressure = P1-P2 (kPa)
E	Velocity of approach factor & AGA 3 simplification term
F_a	Material temperature correction factor
F_{ae}	Pipe temperature correction factor used in ISO
F_{ap}	Element temperature correction factor used in ISO
F_b	Basic orifice factor (AGA 3)
F_{dh}	Drain hole correction factor
F_{gr}	Specific gravity correction factor
F_{pb}	Base pressure correction factor
F_{pv}	Super compressibility factor
F_r	AGA 3 Reynolds number factor
F_{tb}	Base temperature correction factor
F_{tf}	Flowing temperature correction factor
F_{Tp}	Static total pressure correction factor
F_x	Two-phase flow correction factor
F_{usr}	User factor
h_w	Differential pressure
K	AGA 3 flow coefficient
K_e	AGA 3 flow coefficient when Rd=d(106)/15
K_o	AGA 3 flow coefficient when Rd is infinite
L_1	ISO relative pressure tap spacing upstream
l_1	Pressure tap spacing upstream
L_2	Relative pressure tap spacing downstream
l_2	Pressure tap spacing downstream

M_w	Molecular weight of flowing fluid (kg/kmol)
P	Static
P_1	Upstream flowing pressure (kPa-a)
P_2	Downstream flowing pressure (kPa-a)
P_b	Pressure of base reference flowing conditions (kPa-a)
P_f	Flowing pressure - same as P1 (kPa-a)
Q_m	Mass flow rate (kg/s)
Q_v	Volumetric flow rate
R	Universal Gas Constant
R_d	Reynolds number at the bore diameter
R_D	Reynolds number upstream in the pipe
S_G	Ideal specific gravity of flowing fluid
S_{Gr}	Real specific gravity of flowing fluid
T	Flowing temperature (Kelvin)
T_b	Temperature at base conditions (Kelvin)
T_f	Same as T
W	Speed of sound
x	Vapor quality
X	Mass of gas/total mass of mixture
Y	Expansion coefficient – this is the ε term in the ISO 5167 standard documentation. Y is used here for the sake of similarity with AGA 3 and Flowel version 1.3
Y_1	Expansion coefficient referenced to upstream tap
Y_2	Expansion coefficient referenced to downstream tap
Y_{cr}	Expansion coefficient at critical flow conditions
Z	Compressibility at flowing conditions
Z_{air}	Compressibility of air at flowing conditions
Z_b	Compressibility of flowing fluid at base conditions
α_1	Thermal expansion coefficient of pipe material
α_2	Thermal expansion coefficient of element material
β	Bore to diameter ratio = d/D
ϕ	Divergent angle of venturi
κ	Operating isentropic expansion coefficient (Cp/Cv)
κ_i	Ideal isentropic expansion coefficient
μ	Viscosity of flowing fluid at flowing conditions
π	PI with a value = 3.1415927654
ρ	Density of flowing fluid
ρ_f	Density of liquid component in wet vapor
ρ_g	Density of gas component in wet vapor
τ	Pressure ratio of P1/P2

ϖ	Permanent pressure loss
x_1	$\Delta P/P1$
x_2	$\Delta P/P2$

§

B Fluid Property Calculation Methods

B.1 Introduction

The purpose of this chapter is to describe the equations used by Flowel to calculate density, viscosity, vapor pressure, and isentropic exponent.

B.1.1 PVT Properties

The pressure-volume-temperature (PVT) relationship is one of the most important properties for fluid flow measurement. Density and specific gravity are calculated from PVT data.

For example, density $\rho = \frac{1}{V} = \frac{P}{ZRT}$

For most applications, temperature and pressure are known conditions. However, most equations of state use temperature and volume as independent variables. Therefore, an iteration is required for complicated equations of state, which is simple for those equations of state that are cubic in volume. An analytical solution can be obtained for those so-called cubic equations of state.

The PVT property methods are divided into two parts. The first is the generalized methods. These methods are expected to be useful for most systems and T, P, and composition conditions. The second is the more specialized methods. These methods are more accurate within the systems and conditions specified. However, these methods should not be used beyond the specified systems and conditions.

B.1.1.1 Generalized Methods

The generalized method can be used to calculate the properties of most substances over a wide range of conditions.

The generalized equations of state include:

- Redlich-Kwong equation
- Soave-Redlich-Kwong (SRK) equation with volume translation
- Peng-Robinson (PR) equation with volume translation
- Lee-Kesler BWR equation
- Thomson-Brobst-Hankinson and Modified Rackett equations

B.1.1.1.1 Redlich-Kwong and Soave-Redlich-Kwong

The Redlich-Kwong (RK) equation of state was proposed to give a better description of PVT over the van der Waals equation. The corresponding state principle was applied to obtain Redlich-Kwong equation parameters. Therefore, the two parameters of the RK equation can be calculated from the critical temperature and pressure. Redlich-Kwong equation of state is only applicable to the gas phase, with limited accuracy.

The Soave-Redlich-Kwong (SRK) equation was proposed by Soave in 1972. It is the first cubic equation of state with the capability of describing both liquid and vapor phases. With Peneloux's volume translation technique, the SRK equation will give more accurate liquid volumes. Besides the critical properties for SRK equation parameters, an acentric factor is needed. For Peneloux's volume translation form, an additional parameter, Rackett volume constant Z_{RA}, is needed. The details of the SRK equation are provided later in the appendix.

The correlation of binary interaction parameter for the SRK equation is used here, although the binary parameter is not important for volumetric calculations.

B.1.1.1.2 Peng-Robinson

The Peng-Robinson (PR) equation was proposed in 1976. It gives a better description of liquid density over the original SRK equation. With Peneloux's volume translation technique, the PR equation is essentially equivalent to the SRK equation. However, the PR equation is widely used in North America, while the SRK equation is preferred by European engineers.

Yu's volume translated PR equation is used here. Only critical temperature, pressure, and acentric factor are needed to obtain the parameters of volume translated PR equation.

B.1.1.1.3 Lee-Kesler BWR

As recommended by Reid et al., the Lee-Kesler BWR equation should be used for an expanded range of temperature and pressure, although the simple SRK and PR equations give a reasonable description of liquid density for non-polar molecules near saturated conditions. The Lee-Kesler BWR equation will also be used to provide an isentropic exponent (together with ideal gas heat capacity).

The Lee-Kesler BWR equation is highly nonlinear in volume. An Newton-Raphson iteration method is needed to solve volume for given temperatures and pressures. Although Lee-Kesler BWR may give several volume roots for given temperatures and pressures, only three of them will be within a physically meaningful range.

B.1.1.1.4 Thomson-Brobst-Hankinson and Modified Rackett

The correlation's for liquid density are:

- Thomson-Brobst-Hankinson equation
- Modified Rackett equation

The Thomson-Brobst-Hankinson equation is also known as the COSTALD (COrresponding STAtes Liquid Density) equation. The COSTALD equation extended the Tait equation to a generalized form with corresponding states formulation for the parameters. It is applicable to saturated liquid density and compressed liquid density, to pure fluid and fluid mixtures, and to non-polar and polar substances. This equation was developed from 6,338 density points for pure, non-polar liquids, 1,352 points for polar and quantum liquids, and 6,926 mixture density points including 319 points for LNG/LPG mixtures. Average absolute errors in densities calculated using this equation were 0.446% and 2.57% for pure non-polar and polar liquids respectively. It gave 0.3669% and 1.6% average absolute error for LNG/LPG mixtures and for all mixtures.

This equation needs critical pressure, critical temperature, and two additional characteristic parameters as inputs. These two characteristic parameters are available for about 400 substances.

The Spencer and Danner modified Rackett equation will be used here. The Rackett equation can only be used to calculate the saturated liquid volume (density). It is very simple and only needs critical temperature, critical pressure, and Z_{RA} as input. When Z_{RA} is not available, it can be estimated from the acentric factor.

In addition to the equation specific parameters, the above generalized equations need substances dependent on critical properties and acentric factors. Flowel provides these parameters for more than 600 substances. Two additional parameters are required for the Thomson-Brobst-Hankinson and the Modified Rackett equations, respectively. These two parameters are listed in the Table 3-10 of the book *"The Properties of Gases and Liquids"*[1] for more than 300 substances. There are also rules to estimate these two parameters when they are not available in the table.

Proper mixing rules are applied to extend the above equations to gas or liquid mixtures.

B.1.1.2 Specialized Method

The generalized methods are well known and have been extensively tested by many researchers. These methods usually provide reasonable accuracy, in most cases. However, more accurate methods are also necessary when you are more concerned with accuracy.

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[1] Walas, “Phase Equilibrium in Chemical Engineering”. Butterworth Publisher, Boston, 1985.

The specialized methods include:

- AGA 8 (versions 1985 and 1992).
- Redlich-Kwong equation with Wichert-Aziz correction for sour natural gases
- NX-19
- NBS/NRC Steam equation
- Ammonia equation
- Carbon Dioxide equation
- Nitrogen equation
- Oxygen equation
- Hydrogen equation
- Argon equation
- Methane equation
- Ethane equation
- Ethlyene equation
- Propane equation
- i-Butane and n-Butane equation
- Air

There are two versions of the AGA 8 equation. One was proposed in 1985 and the other in 1992. The new data available between 1985-1990 was included to obtain the new version of the AGA equation. The new version of the AGA 8 equation can replace the old version AGA 8 equation. However, in consideration for those users of the previous versions of Flowel, both versions of the AGA 8 equations are included in this property library.

AGA 8 equations can be used over a wide range of temperature and pressure for natural gas systems. However, the AGA 8 compressibility equation is only applicable for the gas phase.

Wichert-Aziz proposed an empirically modified Redlich-Kwong equation for sour natural gases. They proposed a set of pseudo-critical temperatures and pressures for the Redlich-Kwong equation. Therefore, the original Redlich-Kwong equation program can be directly used here with the special pseudo-critical pressure and pseudo-critical temperature.

NX-19 is the first effort to represent natural gas data in an equation of state form. It is old but still popular in the natural gas industry. Therefore, this equation is included as an additional option for users.

The U.S. National Bureau of Standards under the auspices of the Office of Standard Reference Data, and in collaboration with the National Research Council of Canada, undertook the task of correlating the large body of thermodynamic measurements for water and steam. The result of that program is a new formulation that is more accurate and has a much wider range of validity than previously existing formulations. The International Association for the Properties of Steam (IAPS) granted this formulation provisional acceptance in September 1982.

In this formulation, all of the thermodynamic properties are derived from the analytic Helmholtz function: $A = A(\rho, T)$

An analytical equation of state derived from the Helmholtz function is used for our PVT calculation. The vapor pressure equation of steam provided in the NBS/NRC steam table is used for steam phase status checking purposes.

ASME/ANSI MFC-7M-1987 recommended equations of state for the thermodynamic properties of Nitrogen, Oxygen, and Ammonia are used. The NBS monograph on thermophysical properties of Ethane and Propane, and the recently published results on Methane, i-Butane, and n-Butane are used as well. The IUPAC international thermodynamic tables of fluids for Carbon Dioxide and Argon are used.

B.1.2 Bubblepoint

Bubblepoint is necessary to check the phase status of a fluid at certain conditions. The two phase regions are avoided in normal metering operations. It is important to predict the cavitation conditions for liquid flow metering.

B.1.2.1 Pure Substances

For pure substances, it is easy to check the phase status by comparing system pressure (operation pressure) with vapor pressure. The modified Antoine equation is used for this purpose. The coefficients for modified Antoine equations for more than 500 substances are available in the book *"The Properties of Gases and Liquids."*

B.1.2.2 Mixtures

Equations of state are used to check the phase status of fluid mixtures. As Peng-Robinson and Soave-Redlich-Kwong equations of state are cubic in volume, they are relatively easy to use. These two equations of state are among the most extensively tested simple equations for phase behavior calculation. It also should be noted that these two simple equations perform equally or better than complicated Lee-Kesler BWR and BWRS equations for phase behavior purposes.

The binary interaction parameter is very important for phase behavior calculation. There are also extensive compilations of binary interaction parameters for both Peng-Robinson and Soave-Redlich-Kwong equations. The correlated form of binary interaction parameters is used in the program.

The phase equilibrium calculation methods include a constant temperature and pressure flash calculation, dew-point calculation, and bubble-point calculation.

The phase status checking is done automatically or as an option the user can select.

B.1.3 Viscosity

Viscosity is also an important property for Flowel calculations. The low pressure gas viscosity can be estimated within about 1% error for most substances. There are several correlation's available for calculating the temperature and pressure dependence of viscosity. Among them, the Lucas method can be used to calculate the viscosity of non-polar and polar substances over a wide range of temperatures and pressures. The Lucas method is also tested for gas mixtures, and the Lucas method only needs critical properties as input for substance dependent parameters.

IAPS approved (1975) viscosity equations for steam will be adopted here for pure water viscosity calculations.

B.1.4 The Isentropic Exponent

The isentropic exponent of a substance is defined as:

$$k = \left(\frac{\partial P}{\partial \ln V} \right)_S = -\frac{C_P}{C_V} \left(\frac{\partial P}{\partial V} \right)_T \frac{V}{P}$$

The ratio of specific heat capacity at temperature (T) and pressure (P) can be used as an approximation. For perfect gases, the specific heat capacities are constant; therefore, the isentropic exponent is constant. For ideal gases, heat capacity can be correlated as a simple function of temperature. The coefficients of such correlations are given in the book *"The Properties of Gases and Liquids"*. For real gases, an equation of state can be used to derive the isentropic exponent. The Redlich-Kwong equation can be used for general purposes. The Lee-Kesler BWR equation is expected to give better results for an isentropic exponent.

The isentropic exponent is also related to the speed of sound and can be calculated using equations in AGA-10-2003 (Speed of Sound in Natural Gas and Other Related Hydrocarbon Gases).

B.2 PVT Property-Generalized Methods

B.2.1 Redlich-Kwong Equation of State

B.2.1.1 Symbol Table

The symbol table for the Redlich-Kwong equation of state is shown in Table B-1.

Table B-1 Redlich-Kwong Symbol Table

Symbol	I/O	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain
y	I	-	$0 < y$	$0 < y$	$y \leq 1$	$y \leq 1$
P	I	kPa	$0 < P$			

Symbol	I/O	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain
P_c	I	kPa				
T	I	K	0 < T			
T_c	I	K				
a	-	-				
b	-	-				
A	-	-				
B	-	-				
R	-	$\frac{\text{kJ}}{\text{kmol - K}}$	8.31441			
Z	O	-	0 < Z			Z<5

Subscript “i” denotes a component property.

B.2.1.2 Calculations

The following information was taken from the book "Phase Equilibria in Chemical Engineering", by Walas, page 44.

The compressibility factor, Z, is found by solving the following equation:

$$Z^3 - Z^2 + \left(A - B - B^2\right)Z - AB = 0 \qquad \text{(Table 1.9, eq. 7)}$$

$$\frac{aP}{R^2T^{2.5}} = \frac{\left[\sum_{i=1}^{n}\sum_{j=1}^{n} y_i y_j a_{ij}\right]P}{R^2T^{2.5}} = \frac{\left[\sum_{i=1}^{n}\sum_{j=1}^{n} y_i y_j \sqrt{a_i a_j}\right]P}{R^2T^{2.5}} \qquad \text{(Table 1.9, eq. 15)}$$

$$a_i = \frac{\Omega_a R^2 T_{c_i}^{2.5}}{P_{c_i}} \qquad \text{(Table 1.9, eq. 2)}$$

Combining equation 2 and equation 15 yields:

$$A = \Omega_a \left[\sum_{i=1}^{n}\sum_{j=1}^{n} y_i y_j \sqrt{\frac{P_{r_i}}{T_{r_i}^{2.5}}\frac{P_{r_j}}{T_{r_j}^{2.5}}}\right]$$

$$P_{r_i} = \frac{P}{P_{c_i}}$$

$$T_{r_i} = \frac{T}{T_{c_i}}$$

$$\Omega_a = \frac{1}{9(2^{1/3} - 1)} = 0.42748 \qquad \text{(p. 43, eq. 1.111)}$$

$$B = \frac{bP}{RT} = \frac{\left[\sum_{i=1}^{n} y_i b_i\right] P}{RT}$$ (Table 1.9, eq. 5)

$$\mathrm{b_i} = \frac{\Omega_\mathrm{b} \mathrm{RT_{c_i}}}{P_{c_i}}$$ (Table 1.9, eq. 3)

$$B = \Omega_b \left[\sum_{i=1}^{n} y_i \frac{P_{r_i}}{T_{r_i}}\right]$$

$$\Omega_b = \frac{2^{1/3} - 1}{3} = 0.08664$$ (p. 43, eq. 1.112)

B.2.1.3 Restriction and Uncertainty

The Redlich-Kwong equation is not recommended for liquid phase (normally error will be more than 10%) or high pressure. As depicted in Figure 3-6 in the book “The Properties of Gases and Liquids” (R.C. Reid. J.M. Pranstitz, and B.Z. Poling, Fouth Edition, McGraw-Hill, 1987), for P_r<1, the percentage error in molar volume is less than 2%, for 1<P_r<10, the percentage error in molar volume is from 2% to 5%.

B.2.2 Modified Soave Equation of State

B.2.2.1 Symbol Table

The symbol table for the Modified Soave equation of state is shown in Table B-2.

Table B-2 Modified Soave Symbol Table

Symbol	I/O	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain
k_{ij}	I	-	0		1	
R	-	J/mol K	8.314			
P	I	Pa				
P_c	I	Pa				
T	I	K	40		1,000	
T_c	I	K	40		1,000	
V	O	cm^3/mol				
y	I	-	0.0		1.0	
ω	I	-	0.0		3	

B.2.2.2 Equations

The volume translated Soave equation of state proposed by Peneloux and Rauzy is:

$$P = \frac{RT}{V-b} - \frac{a}{(V+c)(V+b+2c)}$$

(①eq.(5))

Where:

$$a = \frac{0.42748 R^2 T_c^2}{P_c}\left[1 + f(\omega)(1-\sqrt{T_r})\right]^2$$

(PGL, Table 3-5, page 43)

$$b = \frac{0.08664 RT_c}{P_c} - c$$

(PGL, Table 3-5,page 43, under eq. (6))

$$c = 0.40768\frac{RT_c}{P_c}(0.29441 - Z_{RA})$$

(①eq.(8))

$$f(\omega) = 0.48508 + 1.55171\omega - 0.15613\omega^2$$

(ℑ,eq.(6-54), page 307)

For mixtures:

$$a_m = \sum_i \sum_j y_i y_j \sqrt{a_i a_j}(1-k_{ij})$$

(PGL, eq.(4-5.1))

$$b_m = \sum_i y_i b_i$$

(PGL, eq. (4-5.2))

$$c_m = \sum_i y_i c_i$$

(① under equation (6))

For Nitrogen systems:

$$k_{ij} = 0.107089 + 2.9776 k_{ij}^{\infty}$$

(②eq.(6-57))

For CO_2 systems:

$$k_{ij} = 0.08058 - 0.77215 k_{ij}^{\infty} - 1.8407(k_{ij}^{\infty})^2$$

(②eq.(6-58))

For H_2S systems:

$$k_{ij} = 0.07654 + 0.017921 k_{ij}^{\infty}$$

(②eq.(6-59))

For Methane systems:

$$k_{ij} = 0.17985 + 2.6958 k_{ij}^{\infty} + 10.853(k_{ij}^{\infty})^2$$

(②eq.(6-60))

Where:

$$k_{ij}^{\infty} = \left[-(\varepsilon_i - \varepsilon_j)^2 \right] / (2\varepsilon_i \varepsilon_j)$$ (②eq.(6-61))

And:

$$\varepsilon_i = [a_i \ln 2]^{0.5} / b_i$$ (②eq.(6-62))

① Peneloux, A. and Rauzy, E., "A Consistent Correction for Redlich-Kwong-Soave Volumes", Fluid Phase Equilibria, 8,7-23,(1982).

② Ahmed, T. "Hydrocarbon Phase Behavior", Gulf Publishing Company, Houston, 1989.

B.2.3 Modified Peng-Robinson Equation of State

B.2.3.1 Modified Peng-Robinson Symbol Table

The symbol table for the Modified Peng-Robinson equation of state is shown in Table B-3.

Table B-3 Modified Peng-Robinson Symbol Table

Symbol	I/O	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain
k_{ij}	I	-	0		1	
R	-	J/mol K	8.314			
P	I	Pa				
P_c	I	Pa				
T	I	K	40		1,000	
T_c	I	K	40		1,000	
V	O	cm^3/mol				
y	I	-	0.0		1.0	
ω	I	-	0.0		3	

B.2.3.2 Equations

The volume translated Peng-Robinson equation is:

$$P = \frac{RT}{V-b} - \frac{a}{V^2 + (2b-4c)V + (2c^2 - b^2)}$$ (①eq.(1))

Where:

$$a = \alpha a_c = \frac{0.45724 R^2 T_c^2}{P_c}\left[1 + f(\omega)(1-\sqrt{T_r})\right]^2$$ (PGL,Table3-5)

$$b = \frac{0.3112 RT_c}{(2+u)P_c}$$ (① in the paragraph under eq.(2),)

$$c = \frac{2-u}{4} b$$ (① in the paragraph under eq.(2),)

$$f(\omega) = 0.37464 + 1.54226\omega - 0.26992\omega^2$$ for $0 \le \omega \le 0.2$

$$f(\omega) = 0.37964 + 1.48503\omega - 0.16442\omega^2 + 0.01667\omega^3$$ for $0.2 \le \omega \le 2.0$

$$u = 1.5251 + 1.1146\omega + 1.1538\omega^2$$ (② eq.B3)

For mixture:

$$a_m = \sum_i \sum_j y_i y_j \sqrt{a_i a_j}(1-k_{ij})$$

$$b_m = \sum_i y_i b_i$$

$$c_m = \sum_i y_i c_i$$

Generalized form of binary interaction parameter:

$$k_{ij} = \delta_0 + \delta_1 T_{rj} + \delta_2 T_{rj}^2$$ (③p.313,eq.6-76)

For Nitrogen-Hydrocarbons:

$$\delta_0 = 0.1751787 - 0.7043\log\omega_j - 0.862066(\log\omega_j)^2$$ (③p.313,eq.6-76)

$$\delta_1 = -0.584474 - 1.328\log\omega_j + 2.035767(\log\omega_j)^2$$ (③p.313,eq.6-77)

$$\delta_2 = 2.257079 + 7.869765\log\omega_j + 13.50466(\log\omega_j)^2$$ (③p.313,eq.6-78)

$$+8.3864(\log\omega_j)^3$$

For Methane-Hydrocarbons:

$$\delta_0 = -0.01664 - 0.37283\log\omega_j + 1.31757(\log\omega_j)^2$$ (③p.313,eq.6-80)

$$\delta_1 = 0.48147 + 3.35342\log\omega_j - 1.0783(\log\omega_j)^2$$ (③p.313,eq.6-81)

$$\delta_2 = -0.4114 - 3.5072\log\omega_j - 0.78798(\log\omega_j)^2$$ (③p.313,eq.6-82)

For CO_2-Hydrocarbons:

$$\delta_0 = 0.4025636 + 0.1748927\log\omega_j$$ (③p.313,eq.6-83)

$\delta_1 = -0.94812 - 0.6009864 \log \omega_j$ (③p.313,eq.6-84)

$\delta_2 = 0.741843368 + 0.441775 \log \omega_j$ (③p.313,eq.6-85)

① Sheng, W. and Lu, B. C.-Y. "A Modified Volume Translated Peng-Robinson Equation with Temperature Dependent Parameters", Fluid Phase Equilibria, 56, 71-80,(1990).

② Yu, J.M. and Lu, B. C.-Y., "A Three-parameter Cubic Equation of State for Asymmetric Mixture Density Calculations", Fluid Phase Equilibria, 31, 1-19, (1987).

③ Ahmed, T. "Hydrocarbon Phase Behavior", Gulf Publishing Company, Houston, 1989.

B.2.4 Lee-Kesler BWR Equation

B.2.4.1 Lee-Kesler BWR Symbol Table

The symbol table for the Lee-Kesler BWR equation is shown in Table B-4.

Table B-4 Lee-Kesler BWR Symbol Table

Symbol	I/O	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain
R	-	J/mol K	8.314			
P	I	Pa	0	0		
P_c	I	Pa				
T	I	K	40		1,000	
T_c	I	K	40		1,000	
V	O	cm^3/mol				
y	I	-	0.0		1.0	
Z	O	-	0.0		5	
ω	I	-	0.0		3	
$\omega^{(r)}$	-	-	0.3978			

The meaning of the symbols above are shown in Table B-5.

Table B-5 Meaning of Symbols

Symbol	Description
R	Gas constant
P	Pressure
P_c	Critical pressure
T	Temperature
T_c	Critical temperature
V	Molar volume
y	Mole fraction

Symbol	Description
Z	Compressibility factor
ω	Acentric factor
$\omega^{(r)}$	Acentric factor of reference fluid
(0)	Superscript represents simple fluid property
(r)	Superscript represents reference fluid property
m	Subscript represents mixture property
i	Component index

B.2.4.2 Equations

Lee and Kesler developed a modified BWR equation within the context of Pitzer's three-parameter correlation. The compressibility factor equation is simply as follows:

$$Z = Z^{(0)} + \frac{\omega}{\omega^{(r)}}(Z^{(r)} - Z^{(0)})$$ (* eq.(2))

Where superscript (0) and (r) represent a simple fluid and a complex reference fluid respectively. The compressibility factors of both the simple and reference fluids have been represented by the following reduced form of a modified BWR equation of state:

$$Z = 1 + \frac{B}{V_r} + \frac{C}{V_r^2} + \frac{D}{V_r^5} + \frac{c_4}{T_r^3 V_r^2}\left(\beta + \frac{\gamma}{V_r^2}\right)e^{\left(-\frac{\gamma}{V_r^2}\right)}$$ (①eq.(3))

Where:

$$B = b_1 - b_2 / T_r - b_3 / T_r^2 - b_4 / T_r^3$$ (①eq.(4))

$$C = c_1 - c_2 / T_r + c_3 / T_r^3$$ (①eq.(5))

$$D = d_1 + d_2 / T_r$$ (①eq.(6))

$$T_r = \frac{T}{T_c}$$ (① paragraph 1 left up corner page 513)

$$V_r = \frac{VP_c}{RT_c}$$ (① paragraph 1 left up corner page 513)

The equation details are shown below.

Table B-6 Equation Details

Constant	Simple	Reference	Constant	Simple	Reference
	Fluids	Fluids		Fluids	Fluids
b_1	0.1181193	0.2026579	c_3	0.0	0.016901
b_2	0.265728	0.331511	c_4	0.042724	0.041577
b_3	0.154790	0.027655	d_1x10^4	0.155488	0.48736

Constant	Simple	Reference	Constant	Simple	Reference
b_4	0.030323	0.203488	d_2 x10^4	0.623689	0.0740336
c_1	0.0236744	0.0313385	β	0.65392	1.226
c_2	0.0186984	0.0503618	γ	0.060167	0.03754

B.2.4.3 Mixing Rules

Plocker, et al., suggested the following mixing rules for the Lee-Kesler BWR equation:

$$T_{cm} = \frac{1}{V_{cm}^{1/4}} \sum_i \sum_j y_i y_j V_{cij}^{1/4} T_{cij}$$ (②eq.(9))

(with *=1/4, PGL Table 4-3, page 84)

$$V_{cm} = \sum_i \sum_j y_i y_j V_{cij}$$ (②eq.(10))

$$\omega_m = \sum_i y_i \omega_i$$ (②eq.(11))

$$T_{cij} = (T_{ci} T_{cj})^{1/2} k_{ij}$$ (②eq.(12))

$$V_{cij} = \frac{1}{8}(V_{ci}^{1/3} + V_{cj}^{1/3})^3$$ (②eq.(13))

$$P_{cm} = (0.2905 - 0.085\omega_m) RT_{cm} / V_{cm}$$ (②eq.(14))

It is a reasonable assumption to let the binary interaction parameter *k*ij = 1.0 for a PVT calculation.

B.2.4.4 Restrictions and Uncertainties

The Lee-Kesler BWR equation has been tested over a wide range in temperature and pressure. It can be used for polar and non-polar compounds. The general expectation of errors are around 1%.

B.2.4.5 References

The references used for the above equations are:

① Lee, B.I. and Kesler, M.G. "A Generalized Thermodynamic Correlation Based on Three-Parameter Corresponding State", AIChE J. 21, 510-527. (1975).

② Plocker, U, Knapp, H and Prausnitz, J.M. "Calculation of High-pressure Vapor-Liquid Equilibria from a Corresponding-State Correlation with Emphasis on Asymmetric Mixtures", Ind.Eng. Chem. Process Des. Dev., 17,324-332,(1978).

B.2.5 Thomson-Brobst-Hankinson Equations

B.2.5.1 Thomson-Brobst-Hankinson Symbol Table

The Thomson-Brobst-Hankinson symbol table is shown in Table B-7.

Table B-7 Thomson-Brobst-Hankinson Symbol Table

Symbol	I/O	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain
R	-	J/mol K	8.314			
P	I	Pa	0	0		
P_c	I	Pa				
T	I	K	40		1,000	
T_c	I	K	40		1,000	
V	O	cm^3/mol				
V_s	O	cm^3/mol				
y	I	-	0.0		1.0	
Z	O	-	0.0		5	
V^*	I	L/mol	0.01		2.0	
ω_{SRK}	I	-	0.0		3	

B.2.5.2 Equations

Hankinson and Thomson present the following correlation for saturated densities of liquids:

$$\frac{V_s}{V^*} = V_R^{(0)}\left[1-\omega_{SRK}V_R^{(1)}\right] \qquad \text{(*eq.(16))}$$

$$V_R^{(0)} = 1+a(1-T_r)^{1/3}+b(1-T_r)^{2/3}+c(1-T_r)+d(1-T_r)^{4/3} \qquad \text{(*eq.(17))}$$

$$V_R^{(1)} = \left[e+fT_r+gT_r^2+hT_r^3\right]/(T_r-1.00001) \qquad \text{(*eq.(18))}$$

a	-1.52816	b	1.43907
c	-0.81446	d	0.190454
c	-0.81446	d	0.190454
e	-0.296123	f	0.386914
g	-0.0427258	h	-0.0480645

For compressed liquids:

$$V = V_s\left(1-c\ln\frac{\beta+P}{\beta+P_{vp}}\right) \qquad \text{(②eq.(5))}$$

$$\beta/P_c = -1+a(1-T_r)^{1/3}+b(1-T_r)^{2/3}+d(1-T_r)+e(1-T_r)^{4/3} \qquad \text{(②eq.(6))}$$

$$e = \exp(f+g\omega_{SRK}+h\omega_{SRK}^2) \qquad \text{(②eq.(7))}$$

$$c = j+k\omega_{SRK} \qquad \text{(②eq.(8))}$$

a	-9.070217	b	62.45326
d	-135.1102	f	4.79594
g	0.250047	h	1.14188
j	0.0861488	k	0.0344483

The mixing rules used for mixtures are:

$$T_{cm} = \frac{\sum_i \sum_j y_i y_j V_{ij}^* T_{cij}}{V_m^*}$$ (①eq.(19))

$$V_{ij}^* T_{cij} = (V_i^* T_{ci} V_j^* T_{cj})^{1/2}$$ (①eq.(20))

$$V_m^* = \tfrac{1}{4}\left[\sum_i y_i V_i^* + 3\left(\sum_i y_i V_i^{*2/3}\right)\left(\sum_i y_i V_i^{*1/3}\right)\right]$$ (①eq.(21))

And:

$$\omega_{SRKm} = \sum_i y_i \omega_{SRKi}$$ (①eq.(24))

$$P_{cm} = (Z_{cm} R T_{cm}) / V_m^*$$ (②eq.(17))

$$Z_{cm} = 0.291 - 0.080\,\omega_{SRKm}$$ (②eq.(18))

$$\log P_{Rm} = P_{Rm}^{(0)} + \omega_{SRKm} P_{Rm}^{(1)}$$ (②eq.(19))

$$P_{Rm}^{(0)} = 5.8031817 \log T_{Rm} + 0.07608141\alpha$$ (②eq.(20))

$$P_{Rm}^{(1)} = 4.86601\beta$$ (②eq.(21))

$$\alpha = 35.0 - 36.0 / T_{Rm} - 96.736 \log T_{Rm} + T_{Rm}^6$$ (②eq.(22))

$$\beta = \log T_{Rm} + 0.03721754\alpha$$ (②eq.(23))

Where:

$$T_{Rm} = T / T_{cm}$$

① Hankinson, R.W. and Thomson, G.H. "A New Correlation for Saturated Densities of Liquids and Their Mixtures", AIChE J.,25,653-663,(1979).

② Thomson, G.H., Brosbst, K.R. and Hankinson, R.W., "An Improved Correlation for Densities of Compressed Liquids and Liquid Mixtures", AIChE J., 28,671-676,(1982).

The substances dependent constant ω_{SRK} and V* are given in Table 3-10, page 57-66 of "The Properties of Gases and Liquids" for about 400 substances.

B.2.5.3 Restrictions and Uncertainties

The Thomson-Brobst-Hankinson equation is only applicable to the liquid phase. It can be used for saturated liquids as well as compressed liquids. It also can be used for liquid mixtures. The expectation of error is normally less than 1%.

It is not recommended for high asymmetric mixtures at high pressure.

B.2.6 Modified Rackett Equation

B.2.6.1 Modified Rackett Symbol Table

The Modified Rackett equation symbol table is shown in Table B-8.

Table B-8 Modified Rackett Symbol Table

Symbol	I/O	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain
R	-	J/mol K	8.314			
P_c	I	Pa				
T	I	K	40		1,000	
T_c	I	K	40		1,000	
V_s	O	cm^3/mol				
y	I	-	0.0		1.0	
V_c	I	cm^3/mol	0.01		2.0	
Z_{RA}	I	-	0.15		.3	
ω	I	-	0.0		3	

B.2.6.2 Equations

The Spencer and Danner modified Rackett equation is:

$$V_s = \frac{RT_c}{P_c} Z_{RA}^{[1+(1-T_r)^{2/7}]}$$ (①eq.(9))

Where Z_{RA} is a substance dependent constant and can be estimated by:

$$Z_{RA} = 0.29056 - 0.08775\omega$$ (②eq.(1))

The modified Rackett equation for mixtures at their bubble points is:

$$V_m = R\left(\sum_i \frac{y_i T_{ci}}{P_{ci}}\right) Z_{RAm}^{[1+(1-T_r)^{2/7}]}$$ (①eq.(10))

$$Z_{RAm} = \sum_i y_i Z_{RAi}$$ (①eq.(11))

Where $T_r = \frac{T}{T_{cm}}$ and mixing rules for critical properties:

$$T_{cm} = \sum_i \sum_j \phi_i \phi_j T_{cij}$$ (①eq.(14))

$$\phi_i = \frac{y_i V_{ci}}{\sum_i y_i V_{ci}}$$ (①eq.(13))

$$T_{cij} = (1 - k_{ij})(T_{ci} T_{cj})^{1/2}$$ (①eq.(15))

$$1 - k_{ij} = \frac{8(V_{ci} V_{cj})^{1/2}}{(V_{ci}^{1/3} + V_{cj}^{1/3})^3}$$ (①eq.(16))

① Spencer, C.F. and Danner, R. "Prediction of Bubble-point Density of Mixtures", J. Chem. Eng. Data, 18, 230-234, (1973).

② Yamada, T. and Gunn, R., "Saturated Liquid Molar Volumes. The Rackett Equation", J. Chem. Eng. Data, 18, 234-236,(1973).

B.2.6.3 Restrictions and Uncertainties

The modified (and the original) Rackett equation is only applicable to saturated liquid density. The expectation of error is normally less than 0.5% for pure fluids and around 2% for mixtures.

B.2.7 Density Calculations

B.2.7.1 Density Calculations Symbol Table

The density calculations symbol table is shown in Table B-9.

Table B-9 Density Calculations Symbol Table

Symbol	I/O	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain
MW	I	$\frac{\text{kg}}{\text{kmole}}$	0 < MW		500	
SG	I	-	0 < SG			
Z	I	-	0 < Z			
T	I	K	0 < T			
P	I	kPa	0 < P			
S_{Gr}	I	-	0 < S_{Gr}			
Z_{air}	I	-	0 < Z_{air}			
SGliq	I	-	0 < SGliq			

Symbol	I/O	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain
ρH_2O	I	kg/m^3	$0 < \rho H_2O$	Default base density 999.01211 kg/m^3		
ρ	O	kg/m^3	$0 < \rho$			

B.2.7.2 Calculations

Standard conditions are 15.6 °C and 101.325 kPa-abs (60 °F and 14.696 psia).

B.2.7.2.1 Gas/Vapor Density

B.2.7.2.1.1 Ideal Specific Gravity Method

$$\rho = \frac{3.483407\ SG\ P}{Z\ \ T}$$

B.2.7.2.1.2 Molecular Weight Method

$$\rho = \frac{MW\ P}{8.31441\ Z\ T}$$

B.2.7.2.1.3 Real Specific Gravity Method

$$\rho = \frac{3.483407\ SGr\ P}{Zair\ T}$$

B.2.7.2.2 Liquid Density

$$\rho = \mathrm{SGliq} \times \rho \mathrm{H_2O}$$

B.2.7.3 References

"Flow Measurement Engineering Handbook", Second Edition, R.W. Miller, McGraw-Hill, 1989.

Perry's Chemical Engineering Handbook, Sixth Edition, page 3-75.

B.2.8 Specific Gravity Calculations

B.2.8.1 Specific Gravity Calculations Symbol Table

The specific gravity calculations symbol table is shown in Table B-10.

Table B-10 Specific Gravity Calculations Symbol Table

Symbol	I/O	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain
MW	I	$\frac{kg}{kmole}$	0 < MW			
MW_{air}	I	$\frac{kg}{kmole}$	$0 < MW_{air}$	Default molecular weight is 28.96247 kg/kmol		
Z_{gas}	I	-	$0 < Z_{gas}$			
Z_{air}	I	-	$0 < Z_{air}$			
ρliq	I	kg/m^3	$0 < \rho liq$			
ρ_{base}	I	kg/m^3	$0 < \rho_{base}$			
ρH_2O	I	kg/m^3	$0 < \rho H_2O$	Default base density 999.01211 kg/m^3		
SG_{gasi}	O	-	SG_{gasi}			
SG_{gasr}	O	-	SG_{gasr}			
$SGliq_b$	O	-	$SGliq_b$			
SGliq	O	-	0 < SGliq			

B.2.8.2 Calculations

B.2.8.2.1 Gases/Vapors

B.2.8.2.1.1 Ideal Specific Gravity

$$SG_{gas_i} = \frac{MW}{MW_{air}}$$

B.2.8.2.1.2 Real Specific Gravity

$$SG_{gas_r} = \left(\frac{Z_{gas}}{Z_{air}}\right) SG_{gas_i}$$

B.2.8.3 Liquids

B.2.8.3.1 Base Specific Gravity

$$SG_{liq_b} = \left(\frac{\rho_{base}}{\rho_{H_2O}}\right)$$

B.2.8.3.2 *Liquid Specific Gravity at Flowing Conditions*

$$\mathrm{SG_{liq}} = \left(\frac{\rho}{\rho_{H_2O}}\right)$$

B.2.8.4 References

AGA Report No.3 Orifice Metering of natural gas and other hydrocarbon fluids Part 3. Natural Gas Applications. Third Edition, August 1992.

CRC Handbook of Chemistry and Physics, 64th Edition. CRC Press, 1982-84. Page F104.

B.3 PVT Property-Specialized Methods

B.3.1 Redlich-Kwong Equation with Wichert-Aziz Correction for Sour Natural Gases

B.3.1.1 Redlich-Kwong Equation with Wichert-Aziz Correction Symbol Table

The Redlich-Kwong equation, with Wichert-Aziz Correction, symbol table is shown in Table B-11.

Table B-11 Redlich-Kwong Equation with Wichert-Aziz Correction Symbol Table

Symbol	I/O	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain
A	I	-	$0 \le A$			$A \le 1$
B	I	-	$0 \le B$			$B \le 1$
ε	-	K	$0 < \varepsilon$			
T_{ci}	I	K	$0 < T_{ci}$			
T_{ci}'	O	K	$0 \le T_{ci}'$			$T_{ci}' \le T_{ci}$
P_{ci}	I	bar	$0 < P_{ci}$			
P_{ci}'	O	bar	$0 \le P_{ci}'$			$P_{ci}' \le P_{ci}$
P	I	bar	$0 \le P$			
T	I	K	$0 < T$			
T'	O	K	$0 < T'$			

B.3.1.2 Calculations

The critical temperature and critical pressure for each component are adjusted in the following manner.

$$\varepsilon = 15\left(A - A^2\right) + 4.1666667\left(B^{\frac{1}{2}} - B^2\right)$$ (p. 51, eq. 74)

$$T'_{ci} = T_{ci} - \varepsilon$$ (p. 51, eq. 75)

$$P'_{ci} = \frac{P_{ci}\,T'_{ci}}{T_{ci}}$$ (p. 51, eq. 76)

Where:

- A is the mole fraction of carbon dioxide and hydrogen sulfide
- B is the mole fraction of hydrogen sulfide

$$\text{For } 0 < P < 173\text{bar} \Rightarrow T' = T + 1.94444444\left(\frac{P}{27.579} - 0.0002103\,P^2\right)$$

(p. 51, eq. 77)

These values of T'_{ci}, P'_{ci}, and T' are used in the Redlich-Kwong equation of state to calculate the compressibility of a natural gas mixture.

Note: The coefficients of the above equations have been converted to the SI unit system.

B.3.1.3 Restriction and Uncertainty

As reported in Wichert's thesis, the expected percent error of this method is around 1% or less. It is only applicable for a sour natural gas system.

B.3.1.4 References

The acid gas corrections are taken from "Compressibility Factor of Sour Natural Gases", Edward Wichert, Thesis Submitted to the Faculty of Graduate Studies, Department of Chemical Engineering, University of Calgary, 1970.

B.3.2 AGA 8 – 1985 Compressibility

B.3.2.1 AGA 8 – 1985 Compressibility Symbol Table

The AGA 8 – 1985 compressibility symbol table is shown in Table B-12.

Table B-12 AGA 8 – 1985 Compressibility Symbol Table

Symbol	I/O	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain
P	I	Pa	0< P		P $\leq$ 138x10^6	
R	I	$\frac{kJ}{kmol \cdot K}$	8.31448			
T	I	K	0 < T	145	478	
d	-	kmol/m^3	0 < d			

Symbol	I/O	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain
Z	O	-				
M_r	I	kg/kmol	$0 < M_r$			
ρ	O	kg/m^3				
Z_b	O	-	$0 < Z_b$			
P_b	I	Pa	$0 < P_b$			
T_b	I	K	$0 < T_b$			
T_{ci}	I	^{o}R	$0 < T_{ci}$			
F_{pv}	O	-	$0 < F_{pv}$			
B	-	-				
C	-	-				
D	-	-				
E	-	-				
A1	-	-				
A2	-	-				
yi	I	-	$0 \le yi$			$yi \le 1$
ak	I	-				
n	I	-	$1 \le n$			
wij	I	-				
εi	I	°R	$0 < \varepsilon i$			
γi	I	-	$0 < \gamma i$			
σi	I	$\sqrt[3]{\frac{ft^3}{lbmol}}$	$0 < \sigma i$			
vij	I	-	$0 < vij$			
uij	I	-	$0 < uij$			
Gr	I	-	$0 < Gr$			
HV	I	Btu/ft^3	$0 < HV$			
yCO_2	I	-	$0 \le yCO_2$			$yCO_2 \le 1$
yN_2	I/O	-	$0 \le yN_2$			$yN_2 \le 1$
yCH_4	I/O	-	$0 \le yCH_4$			$yCH_4 \le 1$
yC_2H_6	O	-	$0 \le yC_2H_6$			$yC_2H_6 \le 1$
yC_3H_8	O	-	$0 \le yC_3H_8$			$yC_3H_8 \le 1$
$yn\text{-}C_4H_{10}$	O	-	$0 \le yn\text{-}C_4H_{10}$			$yn\text{-}C_4H_{10} \le 1$
$yi\text{-}C_4H_{10}$	O	-	$0 \le yi\text{-}C_4H_{10}$			$yi\text{-}C_4H_{10} \le 1$
ySC_5	O	-	$0 \le ySC_5$			$ySC_5 \le 1$
ySC_6P	O	-	$0 \le ySC_6P$			$ySC_6P \le 1$
ySDIL	O	-	$0 \le ySDIL$			$ySDIL \le 1$

The allowable composition range is shown below.

Table B-13 Allowable Composition Range

Component	Mole Percent Allowed
Methane	50 - 100%
Nitrogen	0 - 50%
Carbon Dioxide	0 - 50%
Ethane	0 - 20%
Propane	0 - 5%
Butanes	0 - 3%
Pentanes	0 - 2%
Hexanes and heavier	0 - 1%
$H_2O + H_2S + H_2 + O_2$ + He + Ar	0 - 1%

B.3.2.2 AGA 8 Equation of State Parameters

The AGA 8 generalized equation of state parameters are shown in Table B-14.

Table B-14 Generalized Equation of State Parameters

k	a_k	k	a_k
1	0.25837	15	21.35631
2	7.04794	16	14.15528
3	-19.53600	17	2.03047
4	14.43903	18	9.96509
5	-7.36355	19	4.55053
6	-0.18877	20	6.51706
7	0.03392	21	-12.33577
8	-0.28112	22	-4.82222
9	2.62998	23	12.22885
10	1.88315	24	-16.83781
11	-7.15823	25	0.55906
12	0.05833	26	18.25211
13	18.02809	27	11.79425
14	-40.20412		

The characterization parameters for use in correlation are shown in Table B-15.

Table B-15 Characterization Parameters for Use in Correlation

Compound	**Molar Mass Mr (lb/lb-mole)**	**Energy Parameter** ε (°R)	**Size Parameter** σ **(ft^3/lbmole)$^{1/3}$**	**Orientation Parameter** γ
Nitrogen	28.0134	180.386	0.772480	0.0404
Carbon Dioxide	44.0100	434.820	0.784121	0.1923
Hydrogen Sulfide	34.0800	533.439	0.795372	0.1000
Water	18.0153	925.228	0.658903	0.3440
Helium	4.0026	7.418	0.663962	0.0000
Methane	16.0430	272.373	0.798064	0.0115
Ethane	30.0700	436.514	0.910959	0.0915
Propane	44.0970	528.651	1.010207	0.1520
n-Butane	58.1230	607.766	1.092139	0.1957
i-Butane	58.1230	583.324	1.103425	0.1760
n-Pentane	72.1500	671.381	1.170828	0.2637
i-Pentane	72.1500	658.080	1.160552	0.2270
n-Hexane	86.1770	725.117	1.229673	0.2988
n-Heptane	100.2040	769.570	1.292305	0.3577
n-Octane	114.2310	811.165	1.352288	0.4026
n-Nonane	128.2580	849.815	1.404927	0.4342
n-Decane	142.2850	879.774	1.444874	0.4980
Oxygen	31.9988	220.980	0.721091	0.0210
Carbon Monoxide	28.0100	189.963	0.780565	0.0402
Hydrogen	2.0159	47.455	0.692463	0.0000

The binary interaction parameter values for use in correlation are shown in Table B-16.

Table B-16 Binary Interaction Parameter Values for Use in Correlation*

Component Pair	**uij**	**vij**	**wij**
Methane-Ethane	1.0414	0.9982	1.0015
Methane-Propane	1.0014	1.0041	0.9904
Methane-i-Butane	1.0000	1.0000	0.9779
Methane-n-Butane	1.0000	1.0000	0.9795
Methane-i-Pentane	1.0000	1.0000	0.9691
Methane-n-Pentane	1.0116	0.9738	0.9695
Methane-n-Hexane	1.1028	0.9681	0.9561
Methane-n-Heptane	0.9913	0.9793	0.9432
Methane-n-Octane	0.9673	0.9790	0.9321
Methane-n-Nonane	0.9433	0.9790	0.9205

Component Pair	uij	vij	wij
Methane-n-Decane	0.9193	0.9789	0.9084
Carbon dioxide-Methane	0.9642	1.0253	0.9559
Carbon dioxide-Ethane	0.8614	1.0159	0.9159
Carbon dioxide-Propane	0.7957	1.0126	0.8935
Carbon dioxide-i-Butane	1.0000	1.0000	0.8454
Carbon dioxide-n-Butane	1.0000	1.0000	0.8517
Carbon dioxide-i-Pentane	1.0000	1.0000	0.8115
Carbon dioxide-n-Pentane	1.0000	1.0000	0.8131
Carbon dioxide-n-Hexane	1.0000	1.0000	0.7620
Carbon dioxide-n-Heptane	1.0000	1.0000	0.7124
Carbon dioxide-n-Octane	1.0000	1.0000	0.6698
Carbon dioxide-n-Nonane	1.0000	1.0000	0.6252
Carbon dioxide-n-Decane	1.0000	1.0000	0.5786
Nitrogen-Methane	0.9555	1.0166	0.9757
Nitrogen-Ethane	1.0751	1.0118	0.9707
Nitrogen-Propane	1.0000	1.0000	0.9416
Nitrogen-i-Butane	1.0000	1.0000	0.9274
Nitrogen-n-Butane	1.0000	1.0000	0.9297
Nitrogen-i-Pentane	1.0000	1.0000	0.9155
Nitrogen-n-Pentane	1.0000	1.0000	0.9161
Nitrogen-n-Hexane	1.0000	1.0000	0.8981
Nitrogen-n-Heptane	1.0000	1.0000	0.8806
Nitrogen-n-Octane	1.0000	1.0000	0.8656
Nitrogen-n-Nonane	1.0000	1.0000	0.8499
Nitrogen-n-Decane	1.0000	1.0000	0.8335
Nitrogen-Carbon dioxide	1.0102	1.0494	1.0096
* For component pairs not shown in this table, use 1.0 for each binary interaction parameter value.			

B.3.2.3 AGA 8 Equation of State Calculations

B.3.2.3.1 Supercompressibility Factor (§5.1)

The supercompressibility factor, F_{pv}, is computed by:

$$F_{pv} = \left(\frac{Z_b}{Z}\right)^{0.5}$$

(p. 6, eq. 1)

B.3.2.3.2 Compressibility Factor, Z (§5.1)

The compressibility is determined from:

$$Z = \frac{PV}{nR\,T} = \frac{P}{dR\,T} = \frac{M_r\,P}{\rho\,R\,T}$$

(p. 7, eq. 2, eq.5, eq. 6)

B.3.2.3.3 Equation of State for Pressure (§5.3)

When the system pressure, temperature, and composition are known, the molar density of the gas is determined from the equation:

$$P=RTd+BRTd^2+CRTd^3+DRTd^4+ERTd^6+A_1RTd^3\left(1+A_2d^2\right)e^{\left[-A_2d^2\right]}$$

(p. 9, eq. 8)

B.3.2.3.4 The Coefficient B – The Second Virial Coefficient (§5.4)

$$B=\sum_{i=1}^{n}\sum_{j=1}^{n}y_iy_jB_{ij}$$

(p. 9, eq. 9)

$$B_{ij}=\left[a_1+a_2t_{ij}^{-1/2}+a_3t_{ij}^{-1}+a_4t_{ij}^{-3/2}+a_5t_{ij}^{-2}+a_6t_{ij}^{-5/2}+a_7t_{ij}^{-7/2}+a_8t_{ij}^{-4}+\gamma_{ij}\left(a_{20}t_{ij}^{-1/2}+a_{21}t_{ij}^{-2}\right)\right]\left[\sigma_i\sigma_j\right]^{3/2}$$

(p. 9, eq. 10)

The constant coefficients, a_k, are given in Table B-14.

The size parameters, σ, for twenty compounds are given in Table B-15. For other compounds the size parameter can be estimated using the following equation:

$$\sigma_i^3=\frac{0.3189}{d_{ci}}$$

(p. 9, eq. 11)

$$t_{ij}=\frac{T}{e_{ij}}$$

(p. 10, eq. 12)

$$e_{ij}=w_{ij}\left[\varepsilon_i\varepsilon_j\right]^{1/2}$$

(p. 10, eq. 13)

The binary temperature interaction parameters, w_{ij}, for 36 binaries are given in Table B-16. For component pairs not shown in the table, use 1.0 for the binary interaction parameter.

The characteristic energy parameters, ε_i, for twenty components are given in Table B-15. For other compounds, the characteristic energy parameter is estimated using the following relation:

$$\varepsilon_i = \frac{T_{ci}}{1.2593}$$

(p. 11, eq. 14)

The binary orientation parameter, γ_{ij}, is calculated using the following equation:

$$\gamma_{ij}=0.5\left(\gamma_i+\gamma_j\right)$$

(p. 11, eq. 15)

The component orientation parameters, γ_i, for twenty components are given in Table B-15. For other compounds, the component orientation parameter is estimated as equal to the acentric factor.

For equations 9 through 15, the following applies to all doubly subscripted variables:

$$\mathrm{B}_{\mathrm{ij}} = \mathrm{B}_{\mathrm{ji}}$$

B.3.2.3.5 Mixture Size Parameter, σ

$$\sigma = \left[\sum_{i=1}^{n} \sum_{j=1}^{n} y_i y_j \sigma_{ij}^{6} \right]^{1/6}$$

(p. 12, eq. 21)

$$\sigma_{ij} = v_{ij} \sqrt{\left(\sigma_i \sigma_j \right)}$$

(p. 12, eq. 22)

B.3.2.3.6 Mixture Dimensionless Temperature, T_r

$$\mathrm{T}_{\mathrm{r}} = \frac{\mathrm{T}}{\varepsilon}$$

(p. 12, eq. 23)

$$\varepsilon = \sigma^{-6} \left[\sum_{i=1}^{n} \sum_{j=1}^{n} y_i y_j \varepsilon_{ij} \sigma_{ij}^{6} \right]$$

(p. 12, eq. 24)

$$\varepsilon_{ij} = u_{ij} \sqrt{\left(\varepsilon_i \varepsilon_j \right)}$$

(p. 12, eq. 25)

B.3.2.3.7 Mixture Orientation Parameter, γ

$$\gamma = \varepsilon^{-3} \left[\sum_{i=1}^{n} \sum_{j=1}^{n} y_i y_j \varepsilon_{ij}^{3} \gamma_{ij} \right]$$

(p. 12, eq. 26)

B.3.2.3.8 Coefficient C

$$C = \left[a_9 T_r^{-1/2} + a_{10} T_r^{-2} + a_{11} T_r^{-5/2} + a_{12} T_r^{-5} + \gamma \left(a_{22} + a_{23} T_r^{-2} \right) \right] \sigma^{6}$$

(p. 12, eq. 16)

B.3.2.3.9 Coefficient D

$$D = \left[a_{13} T_r^{-1/2} + a_{14} T_r^{-1} + a_{15} T_r^{-3/2} + \gamma \left(a_{24} T_r^{-2} + a_{25} T_r^{-5/2} \right) \right] \sigma^{9}$$

(p. 12, eq. 17)

B.3.2.3.10 Coefficient E

$$E = \left[a_{16} T_r^{-1} + a_{17} T_r^{-3} + \gamma \left(a_{26} T_r^{-1} \right) \right] \sigma^{15}$$

(p. 12, eq. 18)

B.3.2.3.11 Coefficient A_1

$$A_1 = \left[a_{18} T_r^{-3} + \gamma \left(a_{27} T_r^{-3} \right) \right] \sigma^{6}$$

(p. 12, eq. 19)

B.3.2.3.12 Coefficient A_2

$$A_2 = \left[a_{19} \right] \sigma^{6}$$

(p. 12, eq. 20)

B.3.3 AGA 8 Gas Mixture Characterization

For computation purposes, when determining the equation coefficients, the following properties may be assumed:

Table B-17 Properties

Pseudo-Component	Composition (mole %)
ySDIL	100% helium
ySC5	50% normal pentane, 50% isopentane
ySC6P	85% normal hexane, 12% normal heptane, 3% normal octane

B.3.3.1.1 The Gravity, Carbon Dioxide, Nitrogen Method (§5.6.2)

$yCH4 = 1.63289 - 1.1458\ Gr + 0.13596\ yCO2 - 0.59633\ yN2$ (p. 14, eq. 27)

$yC2H6 = -0.31521 + 0.5816\ Gr - 0.60593\ yCO2 - 0.24416\ yN2$ (p. 14, eq. 28)

$yC3H8 = -0.18262 + 0.3236\ Gr - 0.30510\ yCO2 - 0.09545\ yN2$ (p. 14, eq. 29)

$ynC4H10 = -0.05417 + 0.0954\ Gr - 0.0892\ yCO2 - 0.02983\ yN2$ (p. 14, eq. 30)

$yiC4H10 = -0.03223 + 0.0579\ Gr - 0.05581\ yCO2 - 0.02846\ yN2$ (p. 14, eq. 31)

$ySC5 = -0.02925 + 0.0520\ Gr - 0.04805\ yCO2 - 0.02169\ yN2$ (p. 14, eq. 32)

$ySC6P = -0.01503 + 0.0284\ Gr - 0.02561\ yCO2 - 0.02192\ yN2$ (p. 14, eq. 33)

$ySDIL = -0.00291 + 0.0044\ Gr - 0.00408\ yCO2 + 0.04479\ yN2$ (p. 14, eq. 34)

B.3.3.1.2 The Gravity, Heating Value, Carbon Dioxide, Nitrogen Method (§5.6.2)

$yCH4 = 1.64569 - 1.0159\ Gr - 0.00008368\ HV - 0.07449\ yCO2 - 0.73631\ yN2$ (p. 14 eq. 35)

$yC2H6 = -0.32750 + 0.4569\ Gr + 0.0000803\ HV - 0.40397\ yCO2 - 0.10982\ yN2$ (p. 14 eq. 36)

$yC3H8 = -0.18843 + 0.2648\ Gr + 0.00003790\ HV - 0.20981\ yCO2 - 0.03213\ yN2$ (p. 14 eq. 37)

$ynC4H10 = -0.05619 + 0.075\ Gr + 0.00001313\ HV - 0.05618\ yCO2 - 0.00789\ yN2$ (p. 14 eq. 38)

$yiC4H10 = -0.03245 + 0.0557\ Gr + 0.00000142\ HV - 0.05224\ yCO2 - 0.02609\ yN2$ (p. 14 eq. 39)

$ysC5 = -0.02958 + 0.0486\ Gr + 0.0000022\ HV - 0.04252\ yCO2 - 0.01802\ yN2$ (p. 14 eq. 40)

$ySC6P = -0.0169 + 0.0094\ Gr + 0.00001220\ HV + 0.00506\ yCO2 - 0.00152\ yN2$ (p. 14 eq. 41)

$ySDIL = 0.0122 + 0.1602\ Gr - 0.00010008\ HV - 0.25612\ yCO2 - 0.12296\ yN2$ (p. 14 eq. 42)

B.3.3.1.3 The Gravity, Heating Value, Carbon Dioxide Method (§5.6.2)

$yN2 = 0.08728 + 0.9272\ Gr - 0.00059325\ HV - 1.4984\ yCO2$ (p. 14, eq. 43)

$yCH4 = 1.57921 - 1.7003 Gr + 0.000356 HV + 1.0272 yCO2$ (p. 14, eq. 44)
$yC2H6 = -0.3272 + 0.3526 Gr + 0.00013769 HV - 0.2379 yCO2$ (p. 14, eq. 45)
$yC3H8 = -0.19828 + 0.2379 Gr + 0.0000621 HV - 0.1579 yCO2$ (p. 14, eq. 46)
$ynC4H10 = -0.06061 + 0.0692 Gr + 0.00002052 HV - 0.043 yCO2$ (p. 14, eq. 47)
$yiC4H10 = -0.03237 + 0.0309 Gr + 0.00001499 HV - 0.0146 yCO2$ (p. 14, eq. 48)
$ysC5 = -0.03174 + 0.0322 Gr + 0.00001324 Hv - 0.0158 yCO2$ (p. 14, eq. 49)
$ySC6P = -0.01579 + 0.0073 Gr + 0.0000123 HV + 0.0058 yCO2$ (p. 15, eq. 50)
$ySDIL = 0.00235 + 0.0468 Gr - 0.0000283 HV - 0.0735 yCO2$ (p. 15, eq. 50)

B.3.3.1.4 The Heating Value, Carbon Dioxide, Nitrogen Method (§5.6.2)

$yCH4 = 1.73734 - 0.00073023 HV - 1.7181 yCO2 - 1.8295 yN2$ (p. 15, eq. 52)
$yC2H6 = -0.35947 + 0.00036249 HV + 0.3307 yCO2 + 0.3782 yN2$ (p. 15, eq. 53)
$yC3H8 = -0.2203 + 0.00021399 HV + 0.226 yCO2 + 0.2552 yN2$ (p. 15, eq. 54)
$ynC4H10 = -0.06702 + 0.00006469 HV + 0.0686 yCO2 + 0.0742 yN2$ (p. 15, eq. 55)
$yiC4H10 = -0.03521 + 0.00003471 HV + 0.0353 yCO2 + 0.0331 yN2$ (p. 15, eq. 56)
$ysC5 = -0.0347 + 0.00003377 HV + 0.0361 yCO2 + 0.0345 yN2$ (p. 15, eq. 57)
$ySC6P = -0.01644 + 0.00001694 HV + 0.0175 yCO2 + 0.0078 yN2$ (p. 15, eq. 58)
$ySDIL = -0.00175 + 0.00000135 HV + 0.0017 yCO2 + 0.0498 yN2$ (p. 15, eq. 59)

B.3.3.1.5 The Gravity, Methane, Carbon Dioxide, Nitrogen Method (§5.6.2)

$yC2H6 = 1.73468 - 0.85995 Gr - 1.2539 yCH4 - 0.42978 yCO2 - 0.9886 yN2$ (p. 15, eq. 60)
$yC3H8 = 0.11444 + 0.12969 Gr - 0.1907 yCH4 - 0.3027 yCO2 - 0.2283 yN2$ (p. 15, eq. 61)
$ynC4H10 = -0.21867 + 0.21578 Gr + 0.0977 yCH4 - 0.10984 yCO2 + 0.02132 yN2$ (p. 15, eq. 62)
$yiC4H10 = -0.13919 + 0.12532 Gr + 0.0703 yCH4 - 0.05272 yCO2 + 0.02361 yN2$ (p. 15, eq. 63)
$ysC5 = -0.22604 + 0.18802 Gr + 0.1219 yCH4 - 0.06107 yCO2 + 0.05276 yN2$ (p. 15, eq. 64)
$ySC6P = -0.11848 + 0.09655 Gr + 0.0658 yCH4 - 0.02962 yCO2 + 0.02376 yN2$ (p. 15, eq. 65)
$ySDIL = 0.06180 - 0.04167 Gr - 0.0394 yCH4 + 0.00265 yCO2 + 0.02480 yN2$ (p. 15, eq. 66)

B.3.3.2 Restriction and Uncertainty

This method is only applicable to the gas phase of natural gas systems. For the applicable composition range please refer to the table following the symbol table. The applicable pressure and temperature ranges are given in the symbol table.

The uncertainties in the computed compressibility factor for most natural gases at typical pipeline conditions are expected to be less than 0.1% on the average, provided the composition of the natural gas is known accurately. Uncertainty in the computed compressibility factor is expected to exceed 0.1% at a pressure higher than 500 psia (35 bar) or the natural gas composition is not accurately known. The uncertainty in the computed supercompressibility factor is about 0.7%, on average.

B.3.3.3 Reference

AGA Transmission Measurement Committee Report No.8, Compressibility and Supercompressibility for Natural Gas and other Hydrocarbon Gases., December 1985.

B.3.4 AGA 8-1992 Compressibility

B.3.4.1.1 AGA 8-1992 Compressibility Symbol Table

The AGA 8-1992 compressibility symbol table is shown in Table B-18.

Table B-18 AGA 8 – 1992 Compressibility Symbol Table

Symbol	I/O	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain
B	-					
B_{mix}	-					
B_{ij}	-					
C_{ijk}	-					
C_{mix}	-					
$C^{*}n$	-					
d	-					
D	-					
F	-					
F_{pv}	O	-	$0< F_{pv}$			
G	-					
G_r	I	-	$0< G_r$			
HCH	O	MJ/mol				
HN°	O	MJ/mol				
HV	I	Btu/ft^3	$0<HV$			
K	-	-				

Symbol	I/O	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain
M_r	I	kg/kmol	0<Mr			
$M_{r(air)}$	I	kg/kmol	0<Mr			
N	I	-	1			18
P	I	Pa	0<P		$P \le 280 \times 10^6$	
Q	-	-				
R	8.3145	kJ/kmol K				
U	-	-				
V°	-	-				
xi	I	-	0≤xi			xi≤1
Z	O	-				
Z_{air}	-	-	0			5
Z_h	-	-				
ρ	O	kg/m^3	0			
ρ_{air}	O	kg/m^3	0			

The symbols used above are described in Table B-19.

Table B-19 Symbol Descriptions

Symbol	Meaning
B	second virial coefficient
B_{mix}	second virial coefficient for the mixture
B_{ij}	the individual component interaction second virial coefficient
C_{ijk}	the individual component interaction third virial coefficient
C_{mix}	third virial coefficient for the mixture
C^*n	coefficients which are functions of composition
d	molar density of gas
D	reduced density of gas
F	mixture high temperature parameter
F_{pv}	supercompressibility factor
G	mixture orientation parameter
G_r	relative density of gas mixture
HCH	molar gross heating value of the equivalent hydrocarbon
HN°	molar ideal gross heating value
HV	volumetric gross heating value
K	mixture size parameter
M_r	molar mass for the gas mixture

Symbol	Meaning
$M_{r(air)}$	molar mass of air
N	number of components in gas mixture
P	absolute pressure
Q	mixture quadruple parameter
R	gas constant
T	absolute temperature
U	mixture energy parameter
V°	the ideal gas specific volume
xi	mole fraction of gas component i
Z	compressibility factor of gas mixture
Z_{air}	compressibility factor of air
Z_h	Compressibility factor at 60 °F, 14.73 psia
ρ	mass density of gas mixture
ρ_{air}	mass density of air
P_{gr}	reference pressure for relative density
T_{gr}	reference temperature for relative density
T_d, P_d, T_h, P_h	reference conditions

B.3.4.2 AGA 8 Equation of State Calculations

B.3.4.2.1 *The Supercompressibility Factor, F_{pv}*

$$F_{pv} = \left(\frac{Z_h}{Z} \right)^{0.5}$$ (p.11,eq.8)

B.3.4.2.2 *Relative Density Reference Condition*

The gas relative density (specific gravity) at the reference condition T_{gr}, P_{gr} is defined by the relation:

$$G_r(T_{gr}, P_{gr}) = \frac{\rho(T_{gr}, P_{gr})}{\rho(air, T_{gr}, P_{gr})}$$ (p.12,eq.9)

Using the mass density of both the gas mixture and air, the following relation exists:

$$G_r(T_{gr}, P_{gr}) = \frac{M_r Z(air, T_{gr}, P_{gr})}{M_r(air) Z(T_{gr}, P_{gr})}$$ (p.12,eq.10)

B.3.4.2.3 *Heating Value Reference Condition*

The volumetric gross heating value is the product of the molar ideal gross heating value and the molar density of the gas mixture:

$$HV(T_h, P_h, T_d, P_d) = HN^{\circ}(T_h, P_h) d(T_d, P_d)$$ (p.13,eq.11)

B.3.4.2.4 Detail Characterization Method

The equation of state:

$$Z = 1 + \frac{DB}{K^3} - D\sum_{n=13}^{18} C_n^* T^{-u_n} + \sum_{n=13}^{58} C_n^* T^{-u_n}(b_n - c_n k_n D^{k_n}) D^{b_n} \exp(-c_n D^{k_n})$$

(p.17,eq.12)

Where:

$$D = K^3 d$$

(p.18,eq.13)

And:

$$K^5 = \left[\sum_{i=1}^{N} x_i K_i^{\frac{5}{2}}\right]^2 + 2\sum_{i=1}^{N-1}\sum_{j=i+1}^{N} x_i x_j (K_{ij}^5 - 1)(K_i K_j)^{\frac{5}{2}}$$

(p.18,eq.14)

Second virial coefficient B:

$$B = \sum_{n=1}^{18} a_n T^{-u_n} \sum_{i=1}^{N}\sum_{j=1}^{N} x_i x_j E_{ij}^{u_n} (K_i K_j)^{\frac{3}{2}} B_{nij}^*$$

(p.18,eq.15)

$$B_{nij}^* = (G_{ij} + 1 - g_n)^{g_n} (Q_i Q_j + 1 - q_n)^{q_n} (F_i^{\frac{1}{2}} F_j^{\frac{1}{2}} + 1 - f_n)^{f_n} (S_i S_j + 1 - S_n)^{S_n} (W_i W_j + 1 - W_n)^{W_n}$$

(p.18,eq.16)

With:

$$E_{ij} = E_{ij}^* (E_i E_j)^{\frac{1}{2}}$$

(p.19,eq.17)

And:

$$G_{ij} = \frac{G_{ij}^* (G_i + G_j)}{2}$$

(p.19,eq.18)

The coefficients C^*_n (n=13 to 58) are given by the equation:

$$C_n^* = a_n (G + 1 - g_n)^{g_n} (Q^2 + 1 - q_n)^{q_n} (F + 1 - f_n)^{f_n} U^{u_n}$$

(p.20,eq.19)

The mixture parameters U, G, Q, and F are calculated using the following equations, where in the double sums, i ranges from 1 to N-1 and, for each value of i, j ranges from i+1 to N:

$$U^5 = \left[\sum_{i=1}^{N} x_i E_i^{\frac{5}{2}}\right]^2 + 2\sum_{i=1}^{N-1}\sum_{j=i+1}^{N} x_i x_j (U_{ij}^5 - 1)(E_i E_j)^{\frac{5}{2}} \qquad \text{(p.20,eq.20)}$$

$$G = \sum_{i=1}^{N} x_i G_i + \sum_{i=1}^{N-1}\sum_{j=i+1}^{N} x_i x_j (G_{ij}^* - 1)(G_i + G_j) \qquad \text{(p.20,eq.21)}$$

$$Q = \sum_{i=1}^{N} x_i Q_i \qquad \text{(p.20,eq.22)}$$

$$F = \sum_{i=1}^{N} x_i^2 F_i \qquad \text{(p.20,eq.23)}$$

B.3.4.2.4.1 Detail Characterization Method Equation of State Parameters

The following table shows the detail characterization method equation of state parameters.

Table B-20 (AGA 8, 1992, p.22-23, Table 4)

n	a_n	b_n	c_n	k_n	u_n	g_n	q_n	f_n	s_n	w_n
1	0.153832600	1	0	0	0.0	0	0	0	0	0
2	1.341953000	1	0	0	0.5	0	0	0	0	0
3	-2.998583000	1	0	0	1.0	0	0	0	0	0
4	-0.048312280	1	0	0	3.5	0	0	0	0	0
5	0.375796500	1	0	0	-0.5	1	0	0	0	0
6	-1.589575000	1	0	0	4.5	1	0	0	0	0
7	-0.053588470	1	0	0	0.5	0	1	0	0	0
8	0.886594300	1	0	0	7.5	0	0	0	1	0
9	-0.710237000	1	0	0	9.5	0	0	0	1	0
10	-1.471722000	1	0	0	6.0	0	0	0	0	1
11	1.321850000	1	0	0	12.0	0	0	0	0	1
12	-0.786659300	1	0	0	12.5	0	0	0	0	1
13	2.291290E-09	1	1	3	-6.0	0	0	1	0	0
14	0.157672400	1	1	2	2.0	0	0	0	0	0
15	-0.436386400	1	1	2	3.0	0	0	0	0	0
16	-0.044081590	1	1	2	2.0	0	1	0	0	0
17	-0.003433888	1	1	4	2.0	0	0	0	0	0
18	0.032059050	1	1	4	11.0	0	0	0	0	0
19	0.024873550	2	0	0	-0.5	0	0	0	0	0
20	0.073322790	2	0	0	0.5	0	0	0	0	0
21	-0.001600573	2	1	2	0.0	0	0	0	0	0

n	a_n	b_n	c_n	k_n	u_n	g_n	q_n	f_n	s_n	w_n
22	0.642470600	2	1	2	4.0	0	0	0	0	0
23	-0.416260100	2	1	2	6.0	0	0	0	0	0
24	-0.066899570	2	1	4	21.0	0	0	0	0	0
25	0.279179500	2	1	4	23.0	1	0	0	0	0
26	-0.696605100	2	1	4	22.0	0	1	0	0	0
27	-0.002860589	2	1	4	-1.0	0	0	1	0	0
28	-0.008098836	3	0	0	-0.5	0	1	0	0	0
29	3.150547000	3	1	1	7.0	1	0	0	0	0
30	0.007224479	3	1	1	-1.0	0	0	1	0	0
31	-0.705752900	3	1	2	6.0	0	0	0	0	0
32	0.534979200	3	1	2	4.0	1	0	0	0	0
33	-0.079314910	3	1	3	1.0	1	0	0	0	0
34	-1.418465000	3	1	3	9.0	1	0	0	0	0
35	-5.99905E-17	3	1	4	-13.0	0	0	1	0	0
36	0.105840200	3	1	4	21.0	0	0	0	0	0
37	0.034317290	3	1	4	8.0	0	1	0	0	0
38	-0.007022847	4	0	0	-0.5	0	0	0	0	0
39	0.024955870	4	0	0	0.0	0	0	0	0	0
40	0.042968180	4	1	2	2.0	0	0	0	0	0
41	0.746545300	4	1	2	7.0	0	0	0	0	0
42	-0.291961300	4	1	2	9.0	0	1	0	0	0
43	7.294616000	4	1	4	22.0	0	0	0	0	0
44	-9.936757000	4	1	4	23.0	0	0	0	0	0
45	-0.005399808	5	0	0	1.0	0	0	0	0	0
46	-0.243256700	5	1	2	9.0	0	0	0	0	0
47	0.049870160	5	1	2	3.0	0	1	0	0	0
48	0.003733797	5	1	4	8.0	0	0	0	0	0
49	1.874951000	5	1	4	23.0	0	1	0	0	0
50	0.002168144	6	0	0	1.5	0	0	0	0	0
51	-0.658716400	6	1	2	5.0	1	0	0	0	0
52	0.000205518	7	0	0	-0.5	0	1	0	0	0
53	0.009776195	7	1	2	4.0	0	0	0	0	0
54	-0.020487080	8	1	1	7.0	1	0	0	0	0
55	0.015573220	8	1	2	3.0	0	0	0	0	0
56	0.006862415	8	1	2	0.0	1	0	0	0	0
57	-0.001226752	9	1	2	1.0	0	0	0	0	0
58	0.002850908	9	1	2	0.0	0	1	0	0	0

B.3.4.2.4.2 Characterization Parameters for Use in the Detail Characterization Method

The following table shows the characterization parameters for use in the detail characterization method.

Table B-21 (AGA8, 1992, p.24,Table 5)

CID	Compound	Molar Mass Mr	Energy Parameter E (K)	Size Parameter K(m^3/kg-mole)$^{1/3}$	Orientation Param. G	Quadrupole Param. Q	High Temp. Param. F	Dipole Param. S	Ass. Param. W
1	Methane	16.0430	151.318300	0.4619255	0.0	0.0	0.0	0.0	0.0
2	Nitrogen	28.0135	99.737780	0.4479153	0.027815	0.0	0.0	0.0	0.0
3	Carbon Dioxide	44.0100	241.960600	0.4557489	0.189065	0.690000	0.0	0.0	0.0
4	Ethane	30.0700	244.166700	0.5279209	0.079300	0.0	0.0	0.0	0.0
5	Propane	44.0970	298.118300	0.5837490	0.141239	0.0	0.0	0.0	0.0
6	Water	18.0153	514.015600	0.3825868	0.332500	1.067750	0.0	1.582200	1.0
7	Hydrogen Sulfide	34.0820	296.355000	0.4618263	0.088500	0.633276	0.0	0.390000	0.0
8	Hydrogen	2.0159	26.957940	0.3514916	0.034369	0.0	1.0	0.0	0.0
9	Carbon Monoxide	28.0100	105.534800	0.4533894	0.038953	0.0	0.0	0.0	0.0
10	Oxygen	31.9988	122.766700	0.4186954	0.021000	0.0	0.0	0.0	0.0
11	i-Butane	58.1230	324.068900	0.6406937	0.256692	0.0	0.0	0.0	0.0
12	n-Butane	58.1230	337.638900	0.6341423	0.281835	0.0	0.0	0.0	0.0
13	i-Pentane	72.1500	365.599900	0.6738577	0.332267	0.0	0.0	0.0	0.0
14	n-Pentane	72.1500	370.682300	0.6798307	0.366911	0.0	0.0	0.0	0.0
15	n-Hexane	86.1770	402.636293	0.7175118	0.289731	0.0	0.0	0.0	0.0
16	n-Heptane	100.2040	427.722630	0.7525189	0.337542	0.0	0.0	0.0	0.0
17	n-Octane	114.2310	450.325022	0.7849550	0.383381	0.0	0.0	0.0	0.0
18	n-Nonane	128.2580	470.840891	0.8152731	0.427354	0.0	0.0	0.0	0.0
19	n-Decane	142.2850	489.558373	0.8437826	0.469659	0.0	0.0	0.0	0.0
20	Helium	4.0026	2.610111	0.3589888	0.0	0.0	0.0	0.0	0.0
21	Argon	39.9480	119.629900	0.4216551	0.0	0.0	0.0	0.0	0.0

B.3.4.2.4.3 Binary Interaction Parameter Values for Use in the Detail Characterization Method

The following table shows the binary interaction parameter values for use in the detail characterization method.

Table B-22 (AGA8 -1992, p25-26, Table 6)

CID (i)	CID (j)	Component	Pair	E^*ij	Uij	Kij	G^*ij
1	2	Methane	Nitrogen	0.971640	0.886106	1.003630	
	3		Carbon Dioxide	0.960644	0.963827	0.995933	0.807653
	4		Ethane				
	5		Propane	0.994635	0.990877	1.007619	
	6		Water	0.708218			
	7		Hydrogen Sulfide	0.931484	0.736833	1.000080	
	8		Hydrogen	1.170520	1.156390	1.023260	1.957310
	9		Carbon Monoxide	0.990126			
	10		Oxygen				
	11		i-Butane	1.019530			
	12		n-Butane	0.989844	0.992291	0.997596	
	13		i-Pentane	1.002350			
	14		n-Pentane	0.999268	1.003670	1.002529	
	15		n-Hexane	1.107274	1.302576	0.982962	
	16		n-Heptane	0.880880	1.191904	0.983565	
	17		n-Octane	0.880973	1.205769	0.982707	
	18		n-Nonane	0.881067	1.219634	0.981849	
	19		n-Decane	0.881161	1.233498	0.980991	
2	3	Nitrogen	Carbon Dioxide	1.022740	0.835058	0.982361	0.982746
	4		Ethane	0.970120	0.816431	1.007960	
	5		Propane	0.945939	0.915502		
	6		Water	0.746954			
	7		Hydrogen Sulfide	0.902271	0.993476	0.942596	
	8		Hydrogen	1.086320	0.408838	1.032270	
	9		Carbon Monoxide	1.005710			
	10		Oxygen	1.021000			
	11		i-Butane	0.946914			
	12		n-Butane	0.973384	0.993556		
	13		i-Pentane	0.959340			
	14		n-Pentane	0.945520			
3	4	Carbon Dioxide	Ethane	0.925053	0.969870	1.008510	0.370296

CID (i)	CID (j)	Component	Pair	E^*ij	Uij	Kij	G^*ij
	5		Propane	0.960237			
	6		Water	0.849408			1.673090
	7		Hydrogen Sulfide	0.955052	1.045290	1.007790	
	8		Hydrogen	1.281790			
	9		Carbon Monoxide	1.500000	0.900000		
	10		Oxygen				
	11		i-Butane	0.906849			
	12		n-Butane	0.897362			
	13		i-Pentane	0.726255			
	14		n-Pentane	0.859764			
	15		n-Hexane	0.855134	1.066638	0.910183	
	16		n-Heptane	0.831229	1.077634	0.895362	
	17		n-Octane	0.808310	1.088178	0.881152	
	18		n-Nonane	0.786323	1.098291	0.867520	
	19		n-Decane	0.765171	1.108021	0.854406	
4	5	Ethane	Propane	1.022560	1.065173	0.986893	
	6		Water	0.693168			
	7		Hydrogen Sulfide	0.946871	0.971926	0.999969	
	8		Hydrogen	1.164460	1.616660	1.020340	
	9		Carbon Monoxide				
	10		Oxygen				
	11		i-Butane		1.250000		
	12		n-Butane	1.013060	1.250000		
	13		i-Pentane		1.250000		
	14		n-Pentane	1.005320	1.250000		
5	8	Propane	Hydrogen	1.034787			
	12		n-Butane	1.004900			
7	15	Hydrogen Sulfide	n-Hexane	1.008692	1.028973	0.968130	
	16		n-Heptane	1.010126	1.033754	0.962870	
	17		n-Octane	1.011501	1.038338	0.957828	
	18		n-Nonane	1.012821	1.042735	0.952441	
	19		n-Decane	1.014089	1.046966	0.948338	
8	9	Hydrogen	Carbon Monoxide	1.100000			

CID (i)	CID (j)	Component	Pair	E*ij	Uij	Kij	G*ij
	10		Oxygen				
	11		i-Butane	1.300000			
	12		n-Butane	1.300000			

B.3.4.2.5 Gross Characterization Method

The SGERG model expresses the compressibility factor in terms of the molar density (d), the mixture's second virial coefficient (B_{mix}), and the mixture's third virial coefficient (C_{mix}):

$$Z = 1 + B_{mix} d + C_{mix} d^2 \qquad \text{(p.29,eq.25)}$$

$$B_{mix} = \sum_{i=1}^{N} \sum_{j=1}^{N} B_{ij} x_i x_j \qquad \text{(p.29,eq.26)}$$

And:

$$C_{mix} = \sum_{i=1}^{N} \sum_{j=1}^{N} \sum_{k=1}^{N} C_{ijk} x_i x_j x_k \qquad \text{(p.29,eq.27)}$$

$$\begin{aligned} B_{mix} &= B_{CO_2-CO_2} x_{CO_2}^2 + B_{N_2-N_2} x_{N_2}^2 + B_{CH-CH} x_{CH}^2 \\ &+2 B_{CO_2-N_2} x_{CO_2} x_{N_2} + 2 B_{CO_2-CH} x_{CO_2} x_{CH} + 2 B_{N_2-CH} x_{N_2} \end{aligned} \qquad \text{(p.30,eq.28)}$$

$$\begin{aligned} C_{mix} &= C_{CO_2-CO_2-CO_2} x_{CO_2}^3 + C_{N_2-N_2-N_2} x_{N_2}^3 + C_{CH-CH-CH} x_{CH}^3 \\ &+3 C_{CO_2-CO_2-N_2} x_{CO_2}^2 x_{N_2} + 3 C_{CO_2-CO_2-CH} x_{CO_2}^2 x_{CH} \\ &+3 C_{CO_2-N_2-N_2} x_{N_2}^2 x_{CO_2} + 3 C_{CO_2-CH-CH} x_{CH}^2 x_{CO_2} \\ &+3 C_{N_2-N_2-CH} x_{N_2}^2 x_{CH} + 3 C_{N_2-CH-CH} x_{CH}^2 x_{N_2} \\ &+6 C_{CO_2-N_2-CH} x_{CO_2} x_{N_2} x_{CH} \end{aligned} \qquad \text{(p.30,eq.29)}$$

B.3.4.2.5.1 Interaction Virial Coefficient Terms for Nitrogen and Carbon Dioxide

The B_{ij} values for the terms involving only nitrogen and carbon dioxide are expressed in (dm^3/mol) and are given by:

$$B_{ij} = b_0 + b_1 T + b_2 T^2 \qquad \text{(p.30,eq.30)}$$

Similarly, C_{ijk} values for the terms involving only nitrogen and carbon dioxide are expressed in (dm^6/mol^2) and are given by:

$$C_{ijk} = c_0 + c_1 T + c_2 T^2 \qquad \text{(p.30,eq.31)}$$

B.3.4.2.5.2 Interaction Virial Coefficient Terms for Nitrogen and Carbon Dioxide

The following table shows the interaction virial coefficient terms for nitrogen and carbon dioxide.

Table B-23 (AGA 8-1992, p.31,Table 7)

Fluid for B_{ij}	b0(dm^3/mol)	b1(dm^3/mol K)	b2(dm^3/mol K^2)
N_2-N_2	-0.144600	$0.740910*10^{-3}$	$-0.911950*10^{-6}$
CO_2-CO_2	-0.868340	$0.403760*10^{-2}$	$-0.516570*10^{-5}$
N_2-CO_2	-0.339693	$0.161176*10^{-2}$	$-0.204429*10^{-5}$
Fluid for C_{ijk}	**c0(dm^6/mol^2)**	**c1(dm^6/mol^2 K)**	**c2(dm^6/mol^2 K^2)**
N_2-N_2-N_2	$0.784980*10^{-2}$	$-0.398950*10^{-4}$	$0.611870*10^{-7}$
CO_2-CO_2-CO_2	$0.205130*10^{-2}$	$0.348880*10^{-4}$	$-0.837030*10^{-7}$
N_2-N_2-CO_2	$0.552066*10^{-2}$	$-0.168609*10^{-4}$	$0.157169*10^{-7}$
N_2-CO_2-CO_2	$0.358783*10^{-2}$	$0.806674*10^{-5}$	$-0.325798*10^{-7}$

B.3.4.2.5.3 Interaction Virial Coefficient Terms for the Equivalent Hydrocarbon, CH

The equation for the second and third interaction virial coefficients for the equivalent hydrocarbon are:

$$B_{CH-CH} = B_0 + B_1 H_{CH} + B_2 H_{CH}^2$$

(p.31,eq.32)

$$C_{CH-CH-CH} = C_0 + C_1 H_{CH} + C_2 H_{CH}^2$$

(p.31,eq.33)

B_0, B_1, B_2, C_0, C_1 and C_2, are temperature dependent functions defined as:

$$B_i = b_{i0} + b_{i1} T + b_{i2} T^2 \qquad i = 0,1,2$$

(p.31,eq.34)

And:

$$C_i = C_{i0} + C_{i1} T + C_{i2} T^2 \qquad i = 0,1,2$$

(p.32,eq.35)

B.3.4.2.5.4 Virial Coefficient Terms for the Equivalent Hydrocarbon

The following table shows the virial coefficient terms for the equivalent hydrocarbon.

Table B-24 (p.32,Table 8)

	i	b_{i0}	b_{i1}	b_{i2}
B_0 (dm^3/mol)	0	-0.425468	$0.286500*10^{-2}$	$-0.462073*10^{-5}$
B_1 (dm^3/kJ)	1	$0.877118*10^{-3}$	$-0.556281*10^{-5}$	$0.881510*10^{-8}$
B_2 (dm^3 mol/kJ^2)	2	$-0.824747*10^{-6}$	$0.431436*10^{-8}$	$-0.608319*10^{-11}$

	i	c_{i0}	c_{i1}	c_{i2}
C_0 (dm^6/mol^2)	0	-0.302488	$0.195861*10^{-2}$	$-0.316302*10^{-5}$
C_1 (dm^6/mol-kJ)	1	$0.646422*10^{-3}$	$-0.422876*10^{-5}$	$0.688157*10^{-8}$
C_2 (dm^6/kJ^2)	2	$-0.332805*10^{-6}$	$0.223160*10^{-8}$	$-0.367713*10^{-11}$

$$B_{N_2-CH} = (0.72 + 1.875\times 10^{-5}(320-T)^2)\frac{(B_{N_2-N_2} + B_{CH-CH})}{2} \tag{p.32,eq.36}$$

$$B_{CO_2-CH} = -0.865(B_{CO_2-CO_2}\, B_{CH-CH})^{\frac{1}{2}} \tag{p.32,eq.37}$$

$$C_{N_2-CH-CH} = (0.92 + 0.0013(T-270))(C^2_{CH-CH-CH}\, C_{N_2-N_2-N_2})^{\frac{1}{3}} \tag{p.32,eq.38}$$

$$C_{N_2-N_2-CH} = (0.92 + 0.0013(T-270))(C^2_{N_2-N_2-N_2}\, C_{CH-CH-CH})^{\frac{1}{3}} \tag{p.33,eq.39}$$

$$C_{CO_2-CH-CH} = 0.92(C^2_{CH-CH-CH}\, C_{CO_2-CO_2-CO_2})^{\frac{1}{3}} \tag{p.33,eq.40}$$

$$C_{CO_2-CO_2-CH} = 0.92(C^2_{CO_2-CO_2-CO_2}\, C_{CH-CH-CH})^{\frac{1}{3}} \tag{p.33,eq.41}$$

$$C_{CH-N_2-CO_2} = 1.10(C_{CH-CH-CH}\, C_{N_2-N_2-N_2}\, C_{CO_2-CO_2-CO_2})^{\frac{1}{3}} \tag{p.33,eq.42}$$

Pressure can be obtained through $P = ZRTd$ as:

$$P = dRT(1 + B_{mix}d + C_{mix}d^2) \tag{P.33,EQ.43}$$

There are two methods used to calculate the Molar Gross Heating Value of the Equivalent Hydrocarbon (Hch).

B.3.4.2.6 *Method 1. Input Parameters: Volumetric Gross Heating Value, Relative Density, Mole Fraction CO2*

Figure B.2-1 (p.85) outlines the procedures for calculating the molar gross heating value of the equivalent hydrocarbon, H_{CH}, and the nitrogen mole fraction, x_{N2}, based on the inputs of volumetric gross heating value, relative density, and mole fraction of carbon dioxide.

The compressibility Z^0 is initially set to 1. The mole ideal gross heating value is:

$$HN^0 = HVZ^0RT^0 / P^0 \tag{p.84,B.2-1}$$

The molar mass (molecular weight), M_r, of the mixture is:

$$M_r = G_r(273.15K, 0.101325MP_a)Z^{\circ}V^{\circ}d^{\circ}_{air} \tag{p.86,B.2-2}$$

The mole fraction of the equivalent hydrocarbon is:

$$x_{CH} = \frac{M_r - G_2 HN^{\circ} - M_{r(N_2)} + x_{CO_2} M_{r(N_2)} - x_{CO_2} M_{r(CO_2)}}{G_1 - M_{r(N_2)}} \qquad \text{(p.86,B.2-3)}$$

The mole fraction of nitrogen is:

$$x_{N2} = 1 - x_{CH} - x_{CO2} \qquad \text{(p.86,B.2-4)}$$

The molar gross heating value of the equivalent hydrocarbon is:

$$H_{CH} = \frac{HN^{\circ}}{x_{CH}} \qquad \text{(p.86,B.2-5)}$$

And the molar mass (molecular weight) of the equivalent hydrocarbon is:

$$M_{r(CH)} = G_1 + G_2 H_{CH} \qquad \text{(p.86,B.2-6)}$$

$B_{CH\text{-}CH}$ is calculated by:

$$B_{CH-CH} = B_0 + B_1 H_{CH} + B_2 H_{CH}^2 \qquad \text{(p.31,eq.32)}$$

And B_{mix} is calculated by:

$$B_{mix} = B_{CO_2-CO_2} x_{CO_2}^2 + B_{N_2-N_2} x_{N_2}^2 + B_{CH-CH} x_{CH}^2 \qquad \text{(p.30,eq.28)}$$

$$+2\, B_{CO_2-N_2} x_{CO_2} x_{N_2} + 2\, B_{CO_2-CH} x_{CO_2} x_{CH} + 2\, B_{N_2-CH} x_{N_2}$$

The compressibility factor is then updated:

$$Z_{new}^{\circ} = 1 + \frac{B_{mix} P^{\circ}}{RT^{\circ}} \qquad \text{(p.86,B.2-7)}$$

The calculation procedure is iterative.

B.3.4.2.7 Method 2. Input Parameters: Relative Density, Mole Fractions of N_2 and CO_2

Figure B.2-2 outlines the procedure for calculating the heating value of the equivalent hydrocarbon, H_{CH}, based on inputs of relative density at 0°C and 0.101325 MPa and the mole fractions of N_2 and CO_2. In this method the mole fraction of the equivalent hydrocarbon is determined by:

$$x_{CH} = 1 - x_{N2} - x_{CO2} \qquad \text{(p.87,B.2-8)}$$

The value of $B_{CH\text{-}CH}$ at 0°C and 0.101325 MPa is determined as follows:

Using an initial estimate of -0.065 dm^3/mol for $B_{CH\text{-}CH}$, B_{mix} at 0°C and 0.101325 MPa is calculated using following equations:

$$B_{mix} = B_{CO_2-CO_2} x_{CO_2}^2 + B_{N_2-N_2} x_{N_2}^2 + B_{CH-CH} x_{CH}^2 \qquad \text{(p.30,eq.28)}$$

$$+2\, B_{CO_2-N_2} x_{CO_2} x_{N_2} + 2\, B_{CO_2-CH} x_{CO_2} x_{CH} + 2\, B_{N_2-CH} x_{N_2} x_{CH}$$

$$B_{ij} = b_0 + b_1 T + b_2 T^2$$ (p.30,eq.30)

$$B_{N_2-CH} = (0.72 + 1.875\times 10^{-5}(320-T)^2)\frac{(B_{N_2-N_2} + B_{CH-CH})}{2}$$ (p.32,eq.36)

$$B_{CO_2-CH} = -0.865(B_{CO_2-CO_2}\, B_{CH-CH})^{\frac{1}{2}}$$ (p.32,eq.37)

Next, the reference volume at 0°C and 0.101325 MPa is estimated as:

$$V^\circ = 22.414097 + B_{mix}$$ (p.87,B.2-9)

The molar mass (molecular weight) of the equivalent hydrocarbon is:

$$M_{r(CH)} = \frac{V^\circ d^\circ_{air} G_r - x_{N2} M_{r(N2)} - x_{CO2} M_{r(CO2)}}{x_{CH}}$$ (p.87,eq.B.2-10)

From $M_{r(CH)}$, a new estimation of B_{CH-CH} is obtained by:

$$B_{CH-CH} = 0.0838137 - 0.00851644\, M_{r(CH)}$$ (p.87,B.2-11)

Once $M_{r(CH)}$ is known, the molar ideal gross heating value of the equivalent hydrocarbon is determined by:

$$H_{CH} = 134.2153 + 1067.943 d_{CH}$$ (p.87,B.2-12)

Where:

$$d_{CH} = M_{r(CH)} / (22.710811 + B_{CH-CH})$$ (p.89,B.2-13)

B.3.4.2.8 *Molar Heating Value From Composition*

The molar ideal gross heating value of the "ith" component at the reference condition T_h, P_h is given by the following relation:

$$HN_i^0(T_h, P_h) = -\sum_k SC_{i,k} HF_k^0(T_h, P_h)$$ (p.136,C.4-5)

Stoichiometric coefficients for complete oxidation and molar ideal gross heating value at 25°C, 0.101325MPa.

Table B-25 (AGA8-1992, p.137, Table C.4-1)

Compound	Specific Stoichiometric Coefficient, $SC_{i,k}$					Ideal Molar Gross Heating Value
	Compound	Oxygen	Water	Carbon Dioxide	Sulfur Dioxide	kJ/mol*
Methane	-1	-2	2	1	0	890.63
Ethane	-1	-3.5	3	2	0	1,560.69
Propane	-1	-5	4	3	0	2,219.17

Compound	**Specific Stoichiometric Coefficient, $SC_{i,k}$**					**Ideal Molar Gross Heating Value**
	Compound	**Oxygen**	**Water**	**Carbon Dioxide**	**Sulfur Dioxide**	**kJ/mol***
Isobutane	-1	-6.5	5	4	0	2,868.20
n-Butane	-1	-6.5	5	4	0	2,877.40
Isopentane	-1	-8	6	5	0	3,528.83
n-Pentane	-1	-8	6	5	0	3,535.77
n-Hexane	-1	-9.5	7	6	0	4,194.95
n-Heptane	-1	-11	8	7	0	4,853.43
n-Octane	-1	-12.5	9	8	0	5,511.80
n-Nonane	-1	-14	10	9	0	6,171.15
n-Decane	-1	-15.5	11	10	0	6,829.77
H_2S	-1	-1.5	1	0	1	562.01
Hydrogen	-1	-0.5	1	0	0	285.83
CO	-1	-0.5	0	1	0	282.98

Note: The unit given in AGA 8-1992 Table C.4-1 is not correct.

The molar ideal gross heating value of a dry gas mixture is:

$$HN_i^0(T_h, P_h) = -\sum_k SC_{i,k} HF_k^0(T_h, P_h)$$ (p.136,C.4-5)

$$HN^0(T_h, P_h) = \sum_{i=1}^{NC} x_i HN_i^0(T_h, P_h)$$ (p.137,C.4-6)

At temperature T_h^2:

$$HN^0(T_h, P_h) = \sum_{i=1}^{NC} x_i HN_i^0(T_h, P_h)$$ (p.137,C.4-6)

$$HN^0(T_{h2}, P_{h2}) = HN^0(T_{h1}, P_{h1}) - \sum_{i=1}^{NC} x_i \sum_k SC_{i,k} [\ HN_k^0(T_{h2}, P_{h2}) - HN_k^0(T_{h1}, P_{h1})\ ]$$

$$-\sum_{i=1}^{NC} x_i SC_{i,H_2O} \left[H_{H_2O}(Liq., T_{h2}, P_{h2}) - H_{H_2O}(Liq., T_{h1}, P_{h1})\right]$$

(p.138,C.4-7)

$$H_k^0(T_{h2}, P_{h2}) - H_k^0(T_{h1}, P_{h1}) = aR(T_{h2} - T_{h1}) +$$

$$+b_k R \frac{(T_{h2} - 273.15)^2 - (T_{h1} - 273.15)^2}{2} + c_k R \frac{(T_{h2} - 273.15)^3 - (T_{h1} - 273.15)^3}{3}$$

(p.140,C.4-9&C.4-10)

Ideal gas molar heat capacity coefficients (units, T, K; b_k, K^{-1};c_k, K^{-2}) range from 273.15°K < T < 298.15°K.

Table B-26 (AGA 8-1992, p.139,Table C.4-2)

Compound	a_k	$100b_k$	$c_k x10^5$
Methane	4.1947	0.3639	1.49
Ethane	5.9569	1.377	1.69
Propane	8.2671	2.286	1.90
Isobutane	10.824	3.153	0.82
n-Butane	11.109	2.875	1.82
Isopentane	13.412	3.540	1.40
n-Pentane	13.587	3.288	2.98
n-Hexane	16.134	3.986	3.60
n-Heptane	18.642	4.786	3.84
n-Octane	21.192	5.480	4.30
n-Nonane	23.730	6.172	4.76
n-Decane	26.280	6.869	5.25
H_2S	4.070	0.118	0.28
Hydrogen	3.433	0.155	-0.74
CO	3.503	0.009	0.09
Helium	2.500	0.000	0.000
Argon	2.500	0	0
Oxygen	3.520	0.044	0.28
Nitrogen	3.502	0.006	0
SO_2	4.707	0.439	0.09
CO_2	4.324	0.580	-0.65

$$H_{H_2O}(Liq., T_{h2}, P_{h2}) - H_{H_2O}(Liq., T_{h1}, P_{h1}) = C_p(H_2O, Liq.)(T_{h2} - T_{h1})$$
$$= 75.29(T_{h2} - T_{h1})$$

$$HN^0(T_{h2}, P_{h2}) = HN^0(T_{h2}, P_{h1}) - \sum_{i=1}^{NC} x_i SC_{i,H_2O}\left[H_{H_2O}(Liq., T_{h2}, P_{h2}) - H_{H_2O}(Liq., T_{h2}, P_{h1})\right]$$

B.3.4.2.8.1 Volumetric Heating Value

$$HV(T_h, P_h, T_d, P_d) = HN^0(T_h, P_h)d(T_d, P_d) \qquad \text{(p.142,C.5-1)}$$

or

$$HV(T_h, P_h, T_d, P_d) = HM^0(T_h, P_h)\rho(T_d, P_d) \qquad \text{(p.142,C.5-1)}$$

B.3.4.3 Restrictions and Uncertainties

This set of equations is only applicable to the gas phase. The temperature range is $-130^{o}C < T < 400^{o}C$ at pressure to 280 MPa.

Uncertainties for the detail characterization and gross characterization methods are almost the same.

For pressure between:

- 70 to 140 MPa, uncertainty <1.0%
- 17 to 70 MPa, uncertainty <0.5%

Temp. -200 to -80° F and 250 to 400°F with pressure up to 17 MPa	uncertainty <0.5%
Temp. -80 to 17° F and 143 to 250°F with pressure up to 12 MPa	uncertainty <0.3%
Temp. -80 to 250°F pressure 12 to 17 MPa	uncertainty <0.3%
Temp. 17 to 143 °F pressure up to 12 MPa	uncertainty <0.1%

B.3.4.4 Reference

AGA Transmission Measurement Committee Report No.8, Compressibility of Natural Gas and Other Related Hydrocarbon Gases, Second Edition, November 1992.

B.3.5 NX-19

B.3.5.1 NX-19 Symbol Table

The NX-19 symbol table is shown in Table B-27.

Table B-27 NX-19 Symbol Table

Symbol	I/O	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain
P	I	psig	$0 \leq P$			$P \leq 5000$
t	I	°F	$-40 \leq t$			$t \leq 240$
π	O	-	$0 < \pi$			
τ	O	-	$0 < \tau$			
P_{adj}	-	psig	$0 < P_{adj}$			
t_{adj}	-	°F	$-459.67 < t_{adj}$			
D	-	-				
E	I	-				
F_p	I	-	$0 < F_p$			
F_t	I	-	$0 < F_t$			
G	I	-	$0 < G$	Varies with method used.		
H	I	BTU/ft^3	$0 < H$			
F_{pv}	O	-	$0 < F_{pv}$			

Symbol	I/O	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain
Z	O	-	$0 \le Z$			$Z \le 1$
Z_b	O	-	$0 \le Z_b$			$Z_b \le 1$
n	I	-	$1 \le n$			
T_{ci}	I	$^{\circ}R$	$0 < T_{ci}$			
P_{ci}	I	psia	$0 < P_{ci}$			
yN_2	I	-	$0 \le yN_2$	$0 \le yN_2$	$yN_2 \le 0.15$	$yN_2 \le 1.0$
yCO_2	I	-	$0 \le yCO_2$	$0 \le yCO_2$	$yCO_2 \le 0.15$	$yCO_2 \le 1.0$
F_t	O	-	$0 < F_t$			
F_p	O	-	$0 < F_p$			

The component physical properties are shown in the following table.

Table B-28 Table 5, Component Physical Properties

Gas	Critical Pressure (psia)	Critical Temperature (^0R)	Ideal Specific Gravity	Ideal Gas Total Heating Value $^{(3)}$
Methane	673	344	0.554	994
Ethane	712	550	1.038	1,742
Propane	617	666	1.523	2,479
Iso-Butane	529	734	2.006	3,203
n-Butane	551	766	2.006	3,213
Iso-Pentane	483	830	2.490	3,939
n-Pentane	485	846	2.490	3,948
n-Hexane	440	911	2.973	4,684
n-Heptane	400	972	3.460	5,420
n-Octane	361	1025	3.943	6,153
Carbon Dioxide	1072	$510^{(1)}$	1.519	-
Nitrogen	492	$216^{(1)}$	0.967	-
Air	547	239	1.000	-
Oxygen	731	278	1.105	-
Helium	33	10	0.138	-
Hydrogen	188	60	0.070	319
Hydrogen Sulfide	1306	678	1.176	$630^{(2)}$
(1) Adjusted critical temperatures				
(2) For combustion to gaseous SO_2				
(3) Approximate BTU/SCF - 60°F., 30" Hg., sat.				

B.3.5.2 NX-19 Calculations

B.3.5.2.1 Supercompressibility Calculation, F_{pv}

The supercompressibility calculation is:

$$F_{pv} = \sqrt{\frac{Z_b}{Z}} = \frac{\sqrt{\frac{B}{D} - D + \frac{n}{3\pi}}}{1 + \left(\frac{0.00132}{\tau^{3.25}}\right)} \qquad \text{(p. 397, eq. 5)}$$

$$Z_b = \left[1 + \frac{0.00132}{\tau^{3.25}}\right]^{-2} \qquad \text{(Miller, p. 2-30, eq. 2.58)}$$

$$Z = \frac{Z_b}{F_{pv}^2} = \frac{1}{B/D - D + n/(3\pi)} \qquad \text{(Miller, p. 2-30, eq. 2.57)}$$

$$B = \frac{3 - m\,n^2}{9\,m\,\pi^2} \qquad \text{(p. 397, eq. 6)}$$

$$m = 0.0330378\,\tau^{-2} - 0.0221323\,\tau^{-3} + 0.0161353\,\tau^{-5} \qquad \text{(p. 397, eq. 7)}$$

$$n = \frac{0.265827\,\tau^{-2} + 0.0457697\,\tau^{-4} - 0.133185\,\tau^{-1}}{m} \qquad \text{(p. 397, eq. 8)}$$

$$\pi = \frac{P_{adj} + 14.7}{1000} \qquad \text{(p. 397, eq. 9)}$$

$$\tau = \frac{t_{adj} + 460}{500} \qquad \text{(p. 397, eq. 10)}$$

$$P_{adj} = P \times F_p \qquad \text{(p. 397, eq. 11)}$$

$$t_{adj} = \left[(t + 460)\;F_t\right] - 460 \qquad \text{(p. 397, eq. 12)}$$

$$D = \left[b + \sqrt{b^2 + B^3}\right]^{1/3} \qquad \text{(p. 397, eq. 13)}$$

$$b = \frac{9\,n - 2\,m\,n^3}{54\,m\,\pi^3} - \frac{E}{2\,m\,\pi^2}$$

B.3.5.2.2 The "E" Coefficient

The E coefficient calculation is:

$$Y = A\,(\pi - 2) + A_1\,(\pi - 2)^2 + A_2\,(\pi - 2)^3 + A_3\,(\pi - 2)^4 \qquad \text{(p. 403, eq. 31)}$$

$$A = 1.71720 - 2.33123\,\tau - 1.56796\,\tau^2 + 3.47644\,\tau^3 - 1.28603\,\tau^4 \qquad \text{(p. 403, eq. 32)}$$

$$A_1 = 0.016299 - 0.028094\,\tau + 0.48782\,\tau^2 - 0.728221\,\tau^3 + 0.27839\,\tau^4 \qquad \text{(p. 403, eq. 33)}$$

$$A_2 = -0.35978 + 0.51419\,\tau + 0.16453\,\tau^2 - 0.52216\,\tau^3 + 0.19687\,\tau^4 \qquad \text{(p. 403, eq. 34)}$$

$$A_3 = 0.075255 - 0.10573\,\tau - 0.058598\,\tau^2 + 0.14416\,\tau^3 - 0.054533\,\tau^4 \qquad \text{(p. 403, eq. 35)}$$

$$U = (\tau - 1.32)^2(\pi - 2)\left[3 - 1.483(\pi - 2) - 0.10(\pi - 2)^2 + 0.0833\,(\pi - 2)^3\right] \qquad \text{(p. 403, eq. 36)}$$

The “E” coefficient ranges are shown in the following table.

Table B-29 The “E” Coefficient

Region	Pressure Range (psia)	Range of π	Temperature Range (°F)	Range of τ	Equation For E
1	0 to 2,000	0.0 to 2.0	85 - 240	1.09 - 1.40	E_1
2	0 to 1,300	0.0 to 1.3	-40 - 85	0.84 - 1.09	E_2
3	1,300 to 2,000	1.3 to 2.0	-20 - 85	0.88 - 1.09	E_3
4	1,300 to 2,000	1.3 to 2.0	-40 - -20	0.84 - 0.88	E_4
5	2,000 to 5,000	2.0 to 5.0	-40 - -20	0.84 - 0.88	E_{5a}
6	2,000 to 5,000	2.0 to 5.0	-20 - 85	0.88 - 1.09	E_{5b}
7	2,000 to 5,000	2.0 to 5.0	85 - 200	1.09 - 1.32	E_{5c}
8	2,000 to 5,000	2.0 to 5.0	200 - 400	1.32 - 1.40	E_6

For ranges 5 through 8, if the value of π is greater than 2.0, use π = 2.0 in the calculation of the E parameter. However, the actual value of π is used in the calculation of the values of Y, A, A_1, A_2, A_3, and U.

$$E_1=1-0.00075\pi^{2.3}e^{\left[-20(\tau-1.09)\right]}-0.0011(\tau-1.09)^{0.5}\pi^2\left[2.17+1.4(\tau-1.09)^{0.5}-\pi\right]^2$$

(p. 403, eq. 23)

$$E_2=1-0.00075\pi^{2.3}\left[2-e^{\left[-20(1.09-\tau)\right]}\right]-1.317\pi[1.09-\tau]^4\left[1.69-\pi^2\right]$$

(p. 403, eq. 24)

$$\begin{aligned}E_3=1.0-0.00075\pi^{2.3}\left[2-e^{\left[-20(1.09-\tau)\right]}\right]+0.455[200(1.09-\tau)^6-0.03249(1.09-\tau)+\\2.0167(1.09-\tau)^2-18.028(1.09-\tau)^3+42.844(1.09-\tau)^4]\\[\pi-1.3]\left[1.69[2]^{1.25}-\pi^2\right]\end{aligned}$$

(p. 403, eq. 25)

$$\begin{aligned}E_4=1.0-0.00075\pi^{2.3}\left[2-e^{\left[-20(1.09-\tau)\right]}\right]+0.455[200(1.09-\tau)^6-0.03249(1.09-\tau)+\\2.0167(1.09-\tau)^2-18.028(1.09-\tau)^3+42.844(1.09-\tau)^4]\\[\pi-1.3]\left[1.69[2]^{\left[1.25+80[0.88-\tau]^2\right]}-\pi^2\right]\end{aligned}$$

(p. 403, eq. 26)

$$E_{5a} = E_4 - Y$$ (p. 403, eq. 27)

$$E_{5b} = E_3 - Y$$ (p. 403, eq. 28)

$$E_{5c} = E_1 - Y$$

(p. 403, eq. 29)

$$E_6 = E_{5c} - U$$

(p. 403, eq. 30)

B.3.5.3 NX-19 Pressure Adjustment Factor, F_P, and Temperature Adjustment Factor, F_T

B.3.5.3.1 The Standard Method

This method applies when the following conditions are satisfied:

1. The natural gas specific gravity does not exceed 0.750.
2. The carbon dioxide content of the natural gas does not exceed 15.0 mole percent.
3. The nitrogen content of the natural gas does not exceed 15.0 mole percent.

$$F_P = \frac{156.47}{160.8 - 7.22G + K_P}$$

(p. 2, eq. 1)

$$K_P = M_{CO_2} - 0.392 M_{N_2}$$

(p. 2, eq. 2)

$$K_P = \left[y_{CO_2} - 0.392 y_{N_2} \right] \times 100\%$$

$$F_T = \frac{226.29}{99.15 + 211.9G - K_T}$$

(p. 2, eq. 3)

$$K_T = M_{CO_2} + 1.681 M_{N_2}$$

(p. 2, eq. 4)

$$K_T = \left[y_{CO_2} + 1.681 y_{N_2} \right] \times 100\%$$

B.3.5.3.2 Analysis Method

This analysis method is most applicable when the natural gas has a specific gravity greater than 0.75. It is the recommended method when the natural gas contains appreciable amounts of components like hydrogen sulfide, oxygen, and helium.

$$P_c = \sum_{i=1}^{n} y_i P_{c,i}$$

(p. 401, eq. 15)

$$F_P = \frac{671.4}{P_c}$$

(p. 401, eq. 16)

$$T_c = \sum_{i=1}^{n} y_i T_{c,i}$$

(p. 401, eq. 17)

$$F_T = \frac{359.46}{T_c}$$

(p. 401, eq. 18)

B.3.5.4 Restrictions and Uncertainties

The range and applicability are:

- pressure, psia – 14.696 to 5000
- temperature, F – -40 to 240
- specific gravity – 0.554 to 1.00
- carbon dioxide mol % – 0 to 15
- nitrogen mol % – 0 to 15

B.3.5.5 Reference

AGA Manual for the Determination of Supercompressibility Factors for Natural Gas, Par Research Project NX-19, Extension Range of Supercompressibility Tables, December 1962.

B.3.6 Steam Properties

B.3.6.1 Steam Properties Symbol Table

The steam properties symbol table is shown in Table B-30.

Table B-30 Steam Properties Symbol Table

Symbol	I/O	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain
A	O	J/g				
A_{base}	O	J/g				
$A_{ideal\ gas}$	O	J/g				
$A_{residual}$	O	J/g				
b	-	-				
B	-	-				
P	I	MPa	0		1,500	
T	I	K	273.15		1,273.15	
C_v	O	J/mol				
C_p	O	J/mol				
ρi	I	g/cm^3	0			
δi	-	-				
τi	-	-				

The symbols used above are described in the following table.

Table B-31 Steam Properties Symbols

Symbol	Description
A	Helmohotz function
A_{base}	base function
$A_{ideal\ gas}$	ideal gas function
$A_{residual}$	residual function
b	molecular parameter
B	molecular parameter
P	pressure
T	temperature
C_v	heat capacity at constant volume
C_p	heat capacity at constant pressure
ρi	density
δi	reduced density
τi	reduced temperature

B.3.6.2 Notes

NBS/NRC Steam Tables are adopted here. These tables have been reviewed and approved by the Office of Standard Reference Data of the National Bureau of Standards and incorporated into the National Standard Reference Data System. The National Research Council of Canada contributed through the work of Dr. G.S. Kell. The International Association for the Properties of Steam (IAPS), through its Working Group I on Equilibrium Properties, contributed by testing and validating the formulation and providing on-going critical reviews of the work. The formulation has been accepted as the Provisional IAPS Formulation 1982 for the Thermodynamic Properties of Ordinary Water Substance for Scientific and General Use.

B.3.6.3 Equations

All of the properties can be derived from the following Helmhotz function:

$$A(\rho,T) = A_{base}(\rho,T) + A_{residual}(\rho,T) + A_{ideal-gas}(T) \qquad \text{(p.271,A.1)}$$

It consists of three parts: the contribution of base, residual, and ideal gas.

The following molecular data were used:

- Molar mass M=18.0152 g/mol; Universal gas constant Rc=8.31441 J/(mol·K)
- Specific gas constant R=Rc/M=0.46152 J/(g·K), or 4.6152 bar·cm^3/(g·K)

The base function is:

$$A_{base}(\rho,T)=RT[-\ln(1-y)-\frac{\beta-1}{1-y}+\frac{\alpha+\beta+1}{2(1-y)^2}+4y(\frac{B}{b}-\gamma) \quad \text{(p.272,A.2)}$$
$$-\frac{\alpha-\beta+3}{2}+\ln\frac{\rho RT}{P_0}]$$

Where y=bρ/4 is a dimensionless density; α=11; β=133/3; γ=7/2 are geometric constants.

P_0=1.01325 bar=1 atm.

$$b=b_1\ln\frac{T}{T_0}+\sum_{j=0,3,5}b_j(\frac{T_0}{T})^j \quad \text{(p.272,A.3)}$$

$$B=\sum_{j=0,1,2,4}B_j(\frac{T_0}{T})^j \quad \text{(p.272,A.4)}$$

Where T_0 = 647.073K

The residual function consists of 40 terms.

$$A_{residual}(\rho,T)=\sum_{i=1}^{36}\frac{g_i}{k(i)}(\frac{T_0}{T})^{l(i)}(1-e^{-\rho})^{k(i)}+\sum_{i=37}^{40}g_i\delta_i^{l(i)}\exp(-\alpha_i\delta_i^{k(i)}-\beta_i\tau_i^2)$$

(p.272,A.5)

The quantities δ_i and τ_i are reduced densities and temperatures, respectively, given by:

$$\delta_i=\frac{\rho-\rho_i}{\rho_i}$$

$$\tau_i=\frac{T-T_i}{T_i}$$

The ideal gas function is simple:

$$A_{ideal-gas}(T)=-RT[1+(\frac{C_1}{T_R}+C_2)\ln T_R+\sum_{i=3}^{18}C_iT_R^{i-6}] \quad \text{(p.273,A.6)}$$

Because A(ρ,T) is everywhere a single-valued analytical function, it is straightforward to evaluate appropriate derivatives and to obtain, in accord with the first and second laws of thermodynamics, closed-form relations for all thermodynamic properties. However, only pressure-specific heat capacities are interested here.

Pressure:

$$P=\rho^2\frac{\partial A}{\partial\rho} \quad \text{(p.273)}$$

$$P = RT\rho^2 [\frac{b}{4(1-y)}(1-\frac{\beta-1}{1-y}+\frac{\alpha+\beta+1}{(1-y)^2})+B-b\gamma+\frac{1}{\rho}]$$
$$+\sum_{i=1}^{36}\rho^2 g_i (\frac{T_0}{T})^{l(i)} e^{-\rho}(1-e^{-\rho})^{(k(i)-1)}+\sum_{i=37}^{40}\rho^2\frac{g_i}{\rho_i}\exp(\alpha_i\delta_i^{k(i)}-\beta_i\tau_i^2)[l(i)\delta_i^{(l(i)-1)}$$
$$+\alpha_i k(i)\delta_i^{(k(i)+l(i)-1)}]$$

Saturated vapor pressure equation is simply as (up to within a degree of the critical temperature):

$$P_s = 0.1\exp(6.3573118 - 8858.843/T + 607.56335/T^{0.6})$$

The coefficients for the base function are shown in the following table.

Table B-32 Coefficients for Base Function

bj (cm^3 g^{-1})	j	Bj (cm^3 g^{-1})
0.7478629	0	1.1278334
-0.3540782	1	-0.5944001
0	2	-5.010996
0.007159876	3	0
0	4	0.63684256
-0.003528426	5	0

The coefficients for the residual function are shown in the following table.

Table B-33 Coefficients for Residual Function

i	k(i)	l(i)	g(i) (J g^{-1})
1	1	1	-530.62968529023
2	1	2	2,274.4901424408
3	1	4	787.79333020687
4	1	6	-69.830527374994
5	2	1	17,863.832875422
6	2	2	-39,514.731563338
7	2	4	33,803.884280753
8	2	6	-13,855.050202703
9	3	1	-256,374.36613260
10	3	2	482,125.75981415
11	3	4	-341,830.16969660
12	3	6	122,231.56417448
13	4	1	1,179,743.3655832
14	4	2	-2,173,481.0110373

i	k(i)	l(i)	g(i) (J g^{-1})
15	4	4	1,082,995.2168620
16	4	6	-254,419.98064049
17	5	1	-3,137,777.4947767
18	5	2	5,291,191.0757704
19	5	4	-1,380,257.7177877
20	5	6	-251,099.14369001
21	6	1	4,656,182.6115608
22	6	2	-7,275,277.3275387
23	6	4	417,742.46148294
24	6	6	1,401,635.8244614
25	7	1	-3,155,523.1392127
26	7	2	4,792,966.6384584
27	7	4	409,126.64781209
28	7	6	-1,362,636.9388386
29	9	1	696,252.20862664
30	9	2	-1,083,490.0096447
31	9	4	-227,228.27401688
32	9	6	383,654.86000660
33	3	0	6,883.3257944332
34	3	3	21,757.245522644
35	1	3	-2,662.7944829770
36	5	3	-70,730.418082074

Table B-34 Coefficients for Residual Function, Continued

i	k (i)	l (i)	ρi (g cm^{-3})	Ti (K)	αi	βi	gi (J g^{-1})
37	2	0	0.319	640.	34	20,000	-0.225
38	2	2	0.319	640.	40	20,000	-1.68
39	2	0	0.319	641.6	30	40,000	0.055
40	4	0	1.55	270.	1,050	25	-93.0

The coefficients for the ideal gas function are shown in the following table.

Table B-35 Coefficients for Ideal Gas Function

i	Ci	i	Ci
1	$1.97302710180\times10^{1}$	10	$4.1238460633\times10^{-3}$
2	$2.09662681977\times10^{1}$	11	$-2.7929052852\times10^{-4}$
3	-0.483429455355	12	$1.4481695261\times10^{-5}$
4	6.05743189245	13	$-5.6473658748\times10^{-7}$
5	2.256023885×10^{1}	14	1.620044600×10^{-8}

i	Ci	i	Ci
6	-9.875324420	15	$-3.3038227960\times10^{-10}$
7	-4.3135538513	16	$4.51916067368\times10^{-12}$
8	4.581557810×10^{-1}	17	$-3.70734122708\times10^{-14}$
9	$-4.7754901883\times10^{-2}$	18	$1.37546068238\times10^{-16}$

B.3.6.4 Restrictions and Uncertainties

$$273.15 \le T \le 1273.15K$$

Where for T>423.15K the maximum pressure is:

$$P_{\max} = 1500\,MPa$$

And for $273.15 \le T < 423.15K$ the maximum pressure is:

$$P_{\max} = 100\left[5 + \frac{(T-273.15)K}{15K}\right]MPa$$

The applicable range of viscosity equation is:

$0 \le T \le 1073K$, $0 \le P \le 100\,MPa$

The expectation of uncertainties are less than 0.1% except the critical region.

B.3.6.5 References

Lester Haar, John S. Gallagher and George S. Kell "NBS/NRC Steam Tables-Thermodynamic and transport properties and computer programs for vapor and liquid states of water in SI units". 1984, Hemisphere, Washington.

B.3.7 *Methane, Ethane, Ethylene, Propane, i-Butane, n-Butane, Hydrogen, Argon, Nitrogen, and Oxygen*

The Methane, Ethane, Ethylene, Propane, i-Butane, n-Butane, Hydrogen, Argon, Nitrogen and Oxygen symbol table is shown in Table B-36.

Table B-36 Methane, Ethane, Ethylene, Propane, i-Butane, n-Butane, Hydrogen, Argon, Nitrogen and Oxygen Symbol Table

Symbol	I/O	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain
P	I	bar	0		1,000	
T	I	K	35		100	
ρ	O	g/cm^3	0			

B.3.7.1 Equations

The modified BWR equation was used to accurately represent PVT properties of Methane, i-Butane, and n-Butane:

$$\begin{aligned}
P = {} & \rho RT + \rho^2[G_1T + G_2T^{1/2} + G_3 + G_4/T + G_5/T^2] \\
& + \rho^3[G_6T + G_7 + G_8/T + G_9/T^2] + \rho^4[G_{10}T + G_{11} + G_{12}/T] \\
& + \rho^5[G_{14}/T + G_{15}/T^2] + \rho^7G_{16}/T + \rho^8[G_{17}/T + G_{18}/T^2] \\
& + \rho^9G_{19}/T^2 + \rho^3[G_{20}/T^2 + G_{21}/T^3]\exp(\gamma\rho^2) \\
& + \rho^5[G_{22}/T^2 + G_{23}/T^4]\exp(\gamma\rho^2) + \rho^7[G_{24}/T^2 + G_{25}/T^3]\exp(\gamma\rho^2) \\
& + \rho^9[G_{26}/T^2 + G_{27}/T^4]\exp(\gamma\rho^2) + \rho^{11}[G_{28}/T^2 + G_{29}/T^3]\exp(\gamma\rho^2) \\
& + \rho^{13}[G_{30}/T^2 + G_{31}/T^3 + G_{32}/T^4]\exp(\gamma\rho^2)
\end{aligned}$$

The empirical coefficients of the MBWR equation were obtained by least-square fit the all the available experimental data.

Table B-37 Methane, i-Butane, and n-Butane

	Methane	i-Butane	n-Butane
i	Gi		
1	0.9898937956e-5	0.1307325972e-2	0.153740104603e-2
2	0.2199608275e-1	0.3927802742e-1	-0.160980034611e-1
3	-0.5322788000	-0.3185427394e1	-0.979782459010
4	0.2021657962e2	0.7608825192e3	0.499660674504e2
5	-0.2234398926e4	-0.1753919859e6	-0.102115607687e6
6	0.1067940280e-4	-0.2090019755e-3	0.236032147756e-3
7	0.1457922469e-3	0.8959557971	-0.137475757093
8	-0.9265816666	-0.6816710130e3	-0.907038733865e2
9	0.2915364732e3	-0.1111271045e6	0.385421748213e5
10	0.2313546209e-6	0.3248737572e-4	-0.349453710700e-5
11	0.1387214274e-3	-0.1046526456	0.157361122714e-1
12	0.4780467451e-2	0.6536598969e2	0.102301474068e2
13	0.1176103833e-4	0.3726503734e-2	0.182335737331e-2
14	-0.1982096730e-3	0.8553649395	-0.404114307787
15	-0.2512887756e-1	0.2109987236e3	0.187979855783
16	0.9748899826e-5	-0.1401267363	0.362088795040e-1
17	-0.1202192137e-6	0.5213089327e-2	-0.738762248266e-3
18	0.4128353939e-4	-.1925026382e1	-0.218618590563
19	-0.7215842918e-6	0.7640067895e-1	0.118802729027e-1
20	0.5081738255e3	0.3425854273e6	0.706854198713e5
21	-0.9198903192e5	-0.3373475924e8	-0.219469885796e8

	Methane	i-Butane	n-Butane
22	-0.2732264677e1	0.1180683444e5	-0.182454361268e4
23	0.7499024351e5	0.1529683738e9	0.206790377277e9
24	0.1114060908e-2	0.3323837416e3	0.111757550145e2
25	0.1083955159e1	0.6423169487e4	0.558779925986e4
26	-0.4490960312e-4	0.3891706042e1	-0.159579054026e1
27	-0.1380337847e1	-0.1494755736e6	-0.148034214622e6
28	-0.2371902232e-7	-0.1720240173e-2	-0.245206328201e-1
29	0.3761652197e-4	0.2894195375e2	0.218305259309e2
30	-0.2375166954e-9	0.2002086329e-3	-0.923990627338e-5
31	-0.1237640790e-7	-0.4448393005e-1	-0.205267776639
32	0.6766926453e-6	0.8028488415e1	0.387639044820e1
γ	$-1/\rho_C$		

The following table shows values for ethane and propane.

Table B-38 Ethane and Propane

	Ethane	Propane
i	Gi	
1	-0.3204748852e-3	-0.2804337729e-3
2	0.6529792241e-1	0.1180666107
3	-0.1669704591e1	-0.3756325860e1
4	0.1147983381e3	0.5624374521e3
5	-0.1854721998e5	-0.9354759605e5
6	0.4994149431e-4	-0.4557405505e-4
7	-0.4858871291e-1	0.1530044332
8	0.1225345776e2	-0.1078107476e3
9	0.8622615988e4	0.2218072099e5
10	-0.1081290283e-5	0.6629473971e-5
11	0.6279096996e-2	-0.6199354447e-2
12	-0.1716912675e1	0.6754207966e1
13	-0.1640779401e-4	0.6472837570e-3
14	-0.4356516111e-2	-0.6804325262e-1
15	-0.1966649699e1	-0.9726162355e1
16	0.4026724698e-3	0.5097956459e-2
17	-0.6498241861e-5	-0.1004655900e-3
18	0.5111594139e-2	0.4363693352e-1
19	-0.1113010349e-3	-0.1249351947e-2
20	-0.7157747547e3	0.2644755879e5
21	-0.1848571024e7	-0.7944237270e7

	Ethane	**Propane**
22	-0.2137365569e3	-0.7299920845e3
23	0.6275079986e7	0.5381095003e8
24	-0.9974911056	0.3450217377e1
25	0.1129115014e3	0.9936666689e3
26	-0.1026469558e-1	-0.2166699036
27	-0.5660525915e3	-0.1612103424e5
28	-0.4209846430e-4	-0.3633126990e-3
29	0.2374523553e-1	0.1108612343e1
30	-0.1289637823e-6	-0.1330932838e-4
31	-0.5423801068e-4	-0.3157701101e-2
32	0.223971723e-2	0.1423083811
γ	$-1/\rho_C$	

The following table shows values for ethylene and hydrogen.

Table B-39 Ethylene and Hydrogen

	Ethylene	**Hydrogen**
i	Gi	
1	-0.2146684366683e-2	0.4675528393416e-4
2	0.1791433722534	0.4289274251454e-2
3	-0.3675315603930e1	-0.5164085596504e-1
4	0.3707178934669e3	0.2961790279801
5	-0.3198282566709e5	-0.3027194968412e1
6	0.5809379774732e-4	0.1908100320379e-5
7	-0.7895570824899e-1	-0.1339776859288e-3
8	0.1148620375835e2	0.3056473115421e-1
9	0.2713774629193e5	0.5161197159532e1
10	-0.8647124319107e-5	0.1999981550224e-7
11	0.1617727266385e-1	0.2896367059356e-4
12	-0.2731527496271e1	-0.2257803939041e-2
13	-0.2672283641459e-3	-0.2287392761826e-6
14	-0.4752381331990e-2	0.2446261478645e-5
15	-0.6255637346217e1	-0.1718181601119e-3
16	0.4576234964434e-3	-0.5465142603459e-7
17	-0.7534839269320e-5	0.4051941401315e-9
18	0.1638171982209e-1	0.1157595123961e-6
19	-0.3563090740740e-3	-0.1269162728389e-8
20	-0.1833000783170e5	-0.4983023605519e1
21	-0.1805074209985e7	-0.1606676092098e2

	Ethylene	Hydrogen
22	-0.4794587918874e3	-0.1926799185310e-1
23	0.3531948274957e7	0.9319894638928
24	-0.2562571039155e1	-0.3222596554434e-4
25	0.1044308253292e3	0.1206839307669e-3
26	-0.1695303363659e-1	-0.3841588197470e-7
27	-0.1710334224958e3	-0.4036157453608e-5
28	-0.2054114462372e-4	-0.1250868123513e-10
29	0.6727558766661e-2	0.1976107321888e-9
30	-0.1557168403328e-6	-0.2411883474011e-13
31	-0.1229814736077e-4	-0.4127551498251e-13
32	0.4234325938573e-4	0.8917972883610e-12
γ	-0.0172	-0.0041

The maximum RMS deviation in density is 0.552% for Nitrogen and 0.302% for Oxygen.

Table B-40 Argon

	Argon
1	-0.65697312940e-4
2	0.18229578010e-1
3	-0.3649470140
4	0.12320121070e2
5	-0.86135782740e3
6	0.79785796910e-5
7	-0.29114891100e-2
8	0.75818217580
9	0.87804881690e3
10	0.14231459890e-7
11	0.16741461310e-3
12	-0.32004479090e-1
13	0.25617663720e-5
14	-0.54759349410e-4
15	-0.45050320580e-1
16	0.20132546530e-5
17	-0.16789412730e-7
18	0.42073292710e-4
19	-0.54442129960e-6
20	-0.80048550110e3
21	-0.13193042010e5

	Argon
22	-0.49549239300e1
23	0.80921321770e4
24	-0.98701040610e-2
25	0.20204415620
26	-0.16374172050e-4
27	-0.70389441360e-1
28	-0.11543245390e-7
29	0.15559901170e-5
30	-0.14921785360e-10
31	-0.10013560710e-8
32	0.29339632160e-7

The following table shows values for Oxygen and Nitrogen.

Table B-41 Oxygen and Nitrogen

	Oxygen	Nitrogen
i	Gi	
1	-0.4365859650e-4	0.138029747465691e-3
2	0.2005820677e-1	0.108450650134880e-1
3	-0.4197909916	-0.247132406436209
4	0.1878215317e2	0.345525798080709e1
5	-0.1287473398e4	-0.427970769066595e3
6	0.1556745888e-5	0.106491156699760e-4
7	0.1343639359e-3	-0.114086707973499e-2
8	-0.2228415518	0.144490249728747e-4
9	0.4767792275e3	0.187145756755327e4
10	0.4790846641e-7	0.821887688683079e-8
11	0.2462611107e-3	0.236099049334759e-3
12	-0.1921891680e-1	-0.514480308120135e-1
13	-0.6978320847e-6	0.491454501366803e-5
14	-0.6214145909e-4	-0.115162716239893e-3
15	-0.1860852567e-1	-0.716803724664983e-1
16	0.2609791417e-5	0.761666761949981e-5
17	-0.2447611408e-7	-0.113093006621295e-6
18	0.1457743352e-4	0.373683116683089e-4
19	-0.1726492873e-6	-0.203985150758086e-6
20	-0.2384892520e3	-0.171966200898966e4
21	-0.2301807796e5	-0.121305519974777e5
22	-0.2790303526e1	-0.988139914142789e1

	Oxygen	Nitrogen
23	0.9400577575e4	0.561988689351085e4
24	-0.4169449637e-2	-0.182304396411845e-1
25	0.2008497853	-0.259982649847705
26	-0.1256076520e-4	-0.419189342315742e-4
27	-0.6406362964e-1	-0.259640667053023e-1
28	-0.2475580168e-8	-0.125868320192119e-7
29	0.1346309703e-5	0.104928659940046e-5
30	-0.1161502470e-10	-0.545836930515201e-10
31	-0.1034699798e-8	-0.767451167059717e-9
32	0.2365936964e-7	0.593123287099439e-8
γ	-0.0056	

B.3.7.2 Uncertainties

The expectations of uncertainties in the computed densities are listed in Table B-42.

Table B-42 Uncertainties

	Liquid below Tc	Gas below Tc	Fluid above Tc	Critical region
Methane	0.2	0.3	0.1	5.0
i-Butane	0.007	0.007	0.1	2
n-Butane	0.05	0.4	0.06	3

B.3.7.3 Reference

Jacobsen, R.T., Stewart, R.B. and Myers, A.F., "An Equation of Sate for Oxygen and Nitrogen", Advances in Cryogenic Engineering, 18(1978):248.

Younglove, B.A. and Ely, J.F., "Thermophysical Properties of Fluids. II. Methane, Ethane, Propane, i-Butane, n-Butane", Journal of Physical and Chemical Reference Data, Vol 16, No.4, 1987.

B.3.8 Ammonia

The ammonia symbol table is shown in Table B-43.

Table B-43 Ammonia Symbol Table

Symbol	I/O	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain
P	I	bar	0		5,000	
T	I	K	196		750	
ρ	O	g/cm^3	0			

B.3.8.1 Ammonia Equations

$$P = \rho RT[1 + \rho Q + \rho^2 \frac{\partial Q}{\partial \rho}]$$

Where:

$$Q = \sum_{i=1}^{9}\sum_{j=1}^{6} a_{ij}\rho^{i-1}(\tau - \tau_c)^{j-1}$$

With τ=500/T, T is the value of temperature in Kelvin's, τ_c=1.2333498, ρ is the density in g/cm^3.

Table B-44 Ammonia Equation Values

i	j	a_{ij}
1	1	-6.453022304053
	2	-13.719926770503
	3	-8.100620315713
	4	-4.880096421085
	5	-12.028775626818
	6	6.806345929616
2	1	8.080094367688
	2	14.356920005615
	3	-45.052976699428
	4	-166.188998570498
	5	37.908950229818
	6	-40.7302083372
3	1	1.032994880724
	2	55.843955809332
	3	492.016650817652
	4	1737.835999472605
	5	-30.874915263766
	6	71.483530416272
4	1	-8.948264632008
	2	-169.777744139056
	3	-1,236.532371671939
	4	-7,812.161168316763
	5	1.779548269140
	6	-38.974610958503
5	1	-66.922858820152
	2	-1.753943775320

i	j	a_{ij}
	3	208.553371335492
	4	21,348.946614397509
6	1	247.341745995422
	2	299.983915547501
	3	4,509.080578789798
	4	-37,980.849881791548
7	1	-306.557885430971
	2	24.116551098552
	3	-9,323.356799989199
	4	42,724.098530588371
8	1	161.791003337459
	2	-507.478070464266
	3	8,139.470397409345
	4	-27,458.710626558130
9	1	-27.821688793683
	2	298.812917313344
	3	-2,772.597352058112
	4	7,668.928677924520

B.3.8.2 Reference

Haar, L. and Gallagher, J.S., "Thermodynamic Properties of Ammonia", Journal of Physical and Chemical Reference Data, 7(30)1978:635.

B.3.9 Carbon Dioxide

The carbon dioxide symbol table is shown in Table B-45.

Table B-45 Carbon Dioxide Symbol Table

Symbol	I/O	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain
P	I	bar	0		1,000	
T	I	K	220		700	
ρ	O	g/cm^3	0			

B.3.9.1 Equation of State

$$Z = 1 + \omega \sum_{i=0}^{9} \sum_{j=0}^{j_i} b_{ij} (\tau - 1)^j (\omega - 1)^i$$

Where: $\omega=\rho/\rho_I$ and $\tau=T_I/T$and $\rho_I=0.01063\ mol/cm^3$ and $T_I=304.2K$

Table B-46 Carbon Dioxide Equation Values

i	j	B_{ij}
0	0	-0.725854437x10^{0}
1		0.447869183x10^{0}
2		-0.172011999x10^{0}
3		0.446304911x10^{-2}
4		0.255491571x10^{0}
5		0.594667298x10^{-1}
6		-0.147960010x10^{0}
7		0.136710441x10^{-1}
8		0.392284575x10^{-1}
9		-0.119872097x10^{-1}
0	1	-0.168332974x10^{1}
1		0.126050691x10^{1}
2		-0.183458178x10^{1}
3		-0.176300541x10^{1}
4		0.257414246x10^{1}
5		0.116974683x10^{1}
6		-0.169233071x10^{1}
7		-0.100492330x10^{0}
8		0.441503812x10^{0}
9		-0.846051949x10^{-1}
0	2	0.259587221x10^{0}
1		0.596957049x10^{1}
2		-0.461487677x10^{1}
3		-0.111436705x10^{2}
4		0.750925141x10^{1}
5		0.743706410x10^{1}
6		-0.468219937x10^{1}
7		-0.163653806x10^{1}
8		0.886741970x10^{0}
9		0.464564370x10^{-1}
0	3	0.376945574x10^{0}
1		0.154645885x10^{2}
2		-0.38121926x10^{1}
3		-0.278215446x10^{2}
4		0.661133318x10^{1}
5		0.150646731x10^{2}
6		-0.313517448x10^{1}

i	j	B_{ij}
7		-0.187082988x10^{1}
0	4	-0.670755370x10^{0}
1		0.194449475x10^{2}
2		0.360171349x10^{1}
3		-0.271685720x10^{2}
4		-0.242663210x10^{1}
5		0.957496845x10^{1}
0	5	-0.871456126x10^{0}
1		0.864880497x10^{1}
2		0.492265552x10^{1}
3		-0.642177872x10^{1}
4		-0.257944032x10^{1}
0	6	-0.149156928x10^{0}

B.3.9.2 Reference

Angus, S., Armstrong, B. and de Reuck, K.M., IUPAC international thermodynamic tables of the fluid state-Carbon Dioxide. London, Butterworths,1977

B.3.10 Density of Air

Air is a special and important fluid. The new AGA 8 can be used for extended composition of nitrogen up to 100% and oxygen up to 21%. Therefore, AGA 8 -1992 detailed method is used to calculate the density of air. Jones listed the composition of air as follows.

Table B-47 Density of Air

Constituent	Abundance (mole fraction)
Nitrogen(N_2)	0.78102
Oxygen(O_2)	0.20946
Carbon Dioxide(CO_2)	0.00033
Argon(Ar)	0.00916
Neon(Ne)	0.00001818
Helium(He)	0.00000524
Krypton(Kr)	0.00000114
Xenon(Xe)	0.000000087
Hydrogen(H_2)	0.0000005
Methane(CH_4)	0.0000015
Nitrous Oxide(N_2O)	0.0000003

Since the AGA 8 equation does not support Neon, Krypton, Xenon, and Nitrous Oxide, the mole fraction of these components are treated to equivalent Argon.

The calculated density of air using the above method is compared with tabulated data given in the Chemical Engineers' Handbook. The agreement is normally within 0.1%.

B.3.10.1 Reference

Frank E. Jones, "The Air Density Equation and Transfer of Mass Unit", Journal Research of the National Bureau of Standards. Vol. 83, No.5, pp419-428,1978.

Robert H. Perry and Cecil H. Chilton, Chemical Engineers' Handbook. Fifth Edition, page 3-105, McGraw-Hill Book Company, New York,1973.

B.4 Viscosity

The viscosity symbol table is shown in Table B-48.

Table B-48 Viscosity Symbol Table

Symbol	I/O	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain
D	-	-				
E	-	-				
F	-	-				
F_P	-	-				
F_{Pm}	-	-				
F°_{P}	-	-				
F_P	-	-				
F_{Qm}	-	-				
F°_{Q}	-	-				
M_i	I	g/mol				
M_m	I	g/mol				
M_H	I	g/mol				
M_L	I	g/mol				
P	I	bar	0			
P_r	O	-	0			
ΔPr	-	bar				
P_{cm}	I	bar				
P_{vp}	I	bar				
T	I	K	200	150		
T_r	O	-	.4	.4		

Symbol	I/O	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain
Tc m	I	K	80		1500	1500
V_{ci}	I					
y_i	I	-	0.0	0.0	1	1
Z_{ci}	I	-	.2	.2	.5	.5
Ψ	O	-				
η	O	μcp	0.	0.0	1000	1000
ηL	O	μcp	0.0	0.0	1500	1500
ξ	O	-				

Note: There are many viscosity correlation's available in the literature. As compiled and evaluated by R.C. Reid, J.M. Prausnitz and Poling, Lucas method may be used with the expectation of errors of 0.5 to 1.5% percent for low-pressure viscosity of non-polar substances and only requires T_c, P_c and M for non-polar compounds. The accuracy of the Lucas method for high-pressure gas mixtures is about 8 to 9 percent. Lucas also proposed methods to calculate liquid viscosity. For consistency and simplicity, only the Lucas method will be included in this section.

B.4.1 Gas Viscosity

Lucas proposed the following correlation based on critical properties:

$$\eta\xi = [0.807T_r^{0.618} - 0.357\exp(-0.449T_r\ ) + 0.340\exp(-4.058T_r) + 0.018]F_P^0 F_Q^0 \qquad \text{(PGL,p.400,eq.9-4.15)}$$

Where:

$$\xi = 0.176\left(\frac{T_c}{M^3 P_c^4}\right)^{1/6} \qquad \text{(PGL,p.397,eq.9-4.14)}$$

F_P^0 and F_Q^0 are two corrections for polar and quantum gas respectively:

$$F_P^0 = 1 \qquad 0 \le \mu_r < 0.022 \qquad \text{(PGL,p.400,eq.9-4.17)}$$

$$F_P^0 = 1 + 30.55(0.292 - Z_c)^{1.72} \qquad 0.022 \le \mu_r < 0.075 \qquad \text{(PGL,p.400,eq.9-4.17)}$$

$$F_P^0 = 1 + 30.55(0.292 - Z_c)^{1.72}\left|0.96 + 0.1(T_r - 0.7)\right| \qquad 0.075 \le \mu_r$$

The reduced dipole momentum is calculated as:

$$\mu_r = 52.46\frac{\mu^2 P_c}{T_c^2} \qquad \text{(PGL,p.400,eq.9-4.16)}$$

The quantum correction term:

$$F_Q^0 = 1.22Q^{0.15}\left\{1 + 0.00385\left[(T_r - 12)^2\right]^{1/M} sign(T_r - 12)\right\} \qquad \text{(PGL,p.400,eq.9-4.18)}$$

Where Q=1.38(He), Q=0.76(H_2) and Q=0.52(D_2).

If $T_r \le 1.0$ and $P_r < (P_{vp}/P_c)$:

$$\psi = 0.600 + 0.760 P_r^{\alpha} + (6.990 P_r^{\beta} - 0.6)(1 - T_r)$$

PGL,p422,eq.9-6.5)

With:

$$\alpha = 3.262 + 14.98 P_r^{5.508}$$

$$\beta = 1.390 + 5.746 P_r$$

If $(1<T_r <40.0)$ and $(0<P_r \le 100)$:

$$\psi = \eta\xi\left[1 + \frac{aP_r^e}{bP_r^f + (1 + cP_r^d)^{-1}}\right]$$

(PGL,p422,eq.9-6.6)

With:

$$a = \tfrac{a_1}{T}\exp(a_2 T_r^{\gamma})$$

(PGL,mid. of p.422)

$$b = a(b_1 T_r - b_2)$$

$$c = \tfrac{c_1}{T_r}\exp(c_2 T_r^{\delta})$$

$$d = \frac{d_1}{T_r}\exp(d_2 T_r^{\varepsilon})$$

$$e = 1.3088$$

$$f = \frac{f_1}{T_r}\exp(f_2 T_r^{\zeta})$$

Table B-49 (PGL, above eq.9-6.7 on p.422)

a_1	0.001245	a_2	5.1726	γ	-0.3286
b_1	1.6553	b_2	1.2723	δ	-37.7332
c_1	0.4489	c_2	3.0578	ε	-7.6351
d_1	1.7368	d_2	2.2310	ζ	0.4489
f_1	0.9425	f_2	-0.1853		

$$Y = \frac{\psi}{\eta\xi}$$

(PGL,p.422,eq.9-6.7)

$$F_P = \frac{1 + (F_P^0 - 1)Y^{-3}}{F_P^0}$$

(PGL,p.422,eq.9-6.8)

$$F_Q = \frac{1 + (F_Q^0 - 1)\left[Y^{-1} - 0.007(\ln Y)^4\right]}{F_Q^0}$$ (PGL,p.422,eq.9-6.9)

Viscosity η at pressure P and temperature T is calculated as follows:

$$\eta = \frac{\psi F_P F_Q}{\xi}$$ (PGL,p.422,eq.9-6.10)

Where:

$$\xi = 0.176\left(\frac{T_c}{M^3 P_c^4}\right)^{1/6}$$ (PGL,p.397,eq.9-4.14)

For mixture, the following mixing rule should be used:

$$T_{cm} = \sum_i y_i T_{ci}$$ (PGL,p.411,eq.9-5.18)

$$P_{cm} = RT_{cm} \frac{\sum_i y_i Z_{ci}}{\sum y_i V_{ci}}$$ (PGL,p.411,eq.9-5.19)

$$M_m = \sum_i y_i M_i$$ (PGL,p.411,eq.9-5.20)

$$F_{Pm}^0 = \sum_i y_i F_{Pi}^0$$ (PGL,p.411,eq.9-5.21)

$$F_{Qm}^0 = \left(\sum_i y_i F_{Qi}^0 \right) A$$ (PGL,p.411,eq.9-5.22)

$$A = 1 - 0.01\left(\frac{M_H}{M_L}\right)^{0.87} \quad \text{for} \quad \frac{M_H}{M_L} > 9 and 0.05 < y_H < 0.7$$ (PGL,p.411,eq.9-5.23)

Otherwise, A=1.

B.4.1.1 Reference

R. C. Reid, J.M. Prausnitz and B. E. Poling, "The Properties of Gases and Liquids", Fourth Edition, 1987, McGraw-Hill Book Company, New York.

This was also checked with the following original papers:

- K. Lucas, Chem. Ing. Tech., 46:157(1974).
- K. Lucas, Chem. Ing. Tech. 53:959(1981).
- K. Lucas, Int.J. Heat Mass Trans., 16:371(1973).
- K. Lucas, AIChEJ. , 32:139(1986).

B.4.2 Viscosity of Water and/or Steam

In a 1975 release, IAPS announced approval for the following equation for the dynamic viscosity of water and steam:

$$\eta(\rho,T) = \eta_0(T)\exp[\frac{\rho}{\rho^*}\sum_{i=0}^{5}\sum_{j=0}^{4} b_{ij}(\frac{T^*}{T}-1)^i(\frac{\rho}{\rho^*}-1)^j]$$

Where: $\eta_0(T) = (\frac{T}{T^*})^{1/2}[\sum_{k=0}^{3} a_k(\frac{T^*}{T})^k]^{-1}\times 10^{-6} kg/(sm)$

$\rho^*=317.763$ kg/m^3 ; $T^*=647.27$K.

Coefficients a_k for the above equation are as shown in the following table.

Table B-50 Coefficients a_k

Coefficient	Value
a_0	0.0181583
a_1	0.0177624
a_2	0.0105287
a_3	-0.0036744

Coefficients b_{ij} for the above equation are as shown in the following table.

Table B-51 Coefficients b_{ij}

j\\i	0	1	2	3	4	5
0	0.501938	0.162888	-0.130356	0.907919	-0.551119	0.146543
1	0.235622	0.789393	0.673665	1.207552	0.0670665	-0.0843370
2	-0.274637	-0.743539	-0.959456	-0.687343	-0.497089	0.195286
3	0.145831	0.263129	0.347247	0.213486	0.100754	-0.032932
4	-0.0270448	-0.0253093	-0.0267758	-0.0822904	0.0602253	-0.0202595

B.4.3 Restrictions and Uncertainties

Lucas equations can be used over a wide range of temperatures and pressures, for gases and liquids and mixtures, for non-polar and polar substances.

For pure gas at a low pressure, expect errors of 0.5 to 1.5 percent for non-polar compounds and 2 to 4 percent for polar compounds. For gas mixtures, the expected errors are within 5%. For dense gases, the expected errors are normally less than 5%. The expectation of errors for dense gas mixtures are around 8% for both polar and non-polar systems.

IAPS viscosity equations for water yields values that agree with data to within their accuracy over the range 0 ≤ *t* ≤ 800°C; 0 ≤ P ≤ 1,000 bar. It yields useful estimates for values of pressure up to 10,000 bar for *t* < 100°C and up to 3,500 bar for *t* ≤ 560°C.

B.5 Bubblepoint Pressure

The bubblepoint pressure symbols are shown in Table B-52.

Table B-52 Bubblepoint Pressure Symbol Table

Symbol	I/O	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain
R	-	J/mol K	8.314			
P	I	Pa				
P_c	I	Pa				
T	I	K	40		1,000	
T_c	I	K	40		1,000	
V	O	cm^3/mol				
x_i	I	-	0.0		1.0	
y_i	I	-	0.0		1.0	
ϕ_i	-	-	0.0<			

B.5.1 Equations

In addition to equal temperature and pressure in both phases, thermodynamic conditions for vapor-liquid equilibrium can be simplified as: $\phi_i y_i = \phi_i x_i$

Where the fugacity coefficient ϕi can be calculated by either SRK or PR equations of state.

For the SRK equation:

$$\ln\phi_i = \frac{b_i}{b}(z-1) - \ln\left[z(1-\frac{b}{V})\right] + \frac{a\alpha}{bRT}\left[\frac{b_i}{b} - \frac{2}{a\alpha}\sum_j y_j (a\alpha)_{ij}\right]\ln(1+\frac{b}{V})$$

For the PR equation:

$$\ln\phi_i = \frac{b_i}{b}(z-1) - \ln\left[z(1-\frac{b}{V})\right] + \frac{a\alpha}{2.828bRT}\left[\frac{b_i}{b} - \frac{2}{a\alpha}\sum_j y_j (a\alpha)_{ij}\right]\ln\frac{V+2.414b}{V-0.414b}$$

B.5.2 Vapor Pressure

B.5.2.1 Antoine

Equation 1: $\ln(P_{vp} / P_c) = (1-x)^{-1}\left[(VPA)x + (VPB)x^{1.5} + (VPC)x^3 + (VPD)x^6\right]$
$x = 1 - T / T_c$

Equation 2: $\ln P_{vp} = (VPA) - (VPB)/T + (VPC)\ln T + (VPD)P_{vp} / T^2$

Equation 3: $\ln P_{vp} = (VPA) - (VPB)/[T + (VPC)]$

Where coefficients VPA, VPB, VPC and VPD were taken from, “The Properties of Gases and Liquids”.

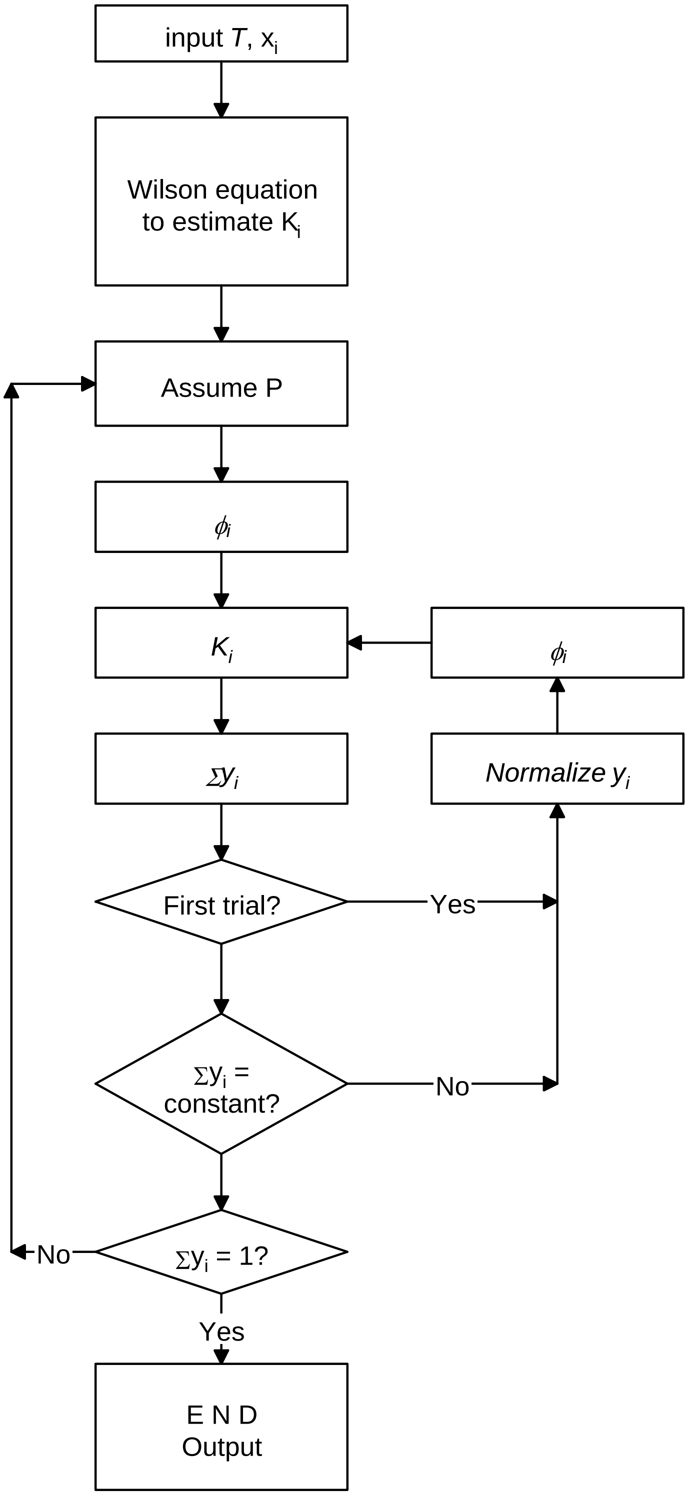
B.5.2.2 Reference

Reid, J.M. Prausnitz and B.Z. Poling, “The Properties of Gases and Liquids”. Fourth Edition. McGraw-Hill Book Company.

B.5.3 Bubblepoint Pressure Calculation Algorithm

The liquid composition is known but that of the vapor is not. For pressure determination, the key starting assumptions are in box 2. The Wilson equation is used to estimate initial equilibrium constants. The method iterates at a particular pressure until $S = \Sigma y_i$ becomes constant. If Σy_i is greater than unity, the pressure should be incremented for the next series of iterations. If Σy_i is less than one, the pressure should be reduced for the next series of iterations. The criteria of convergency is $| \Sigma y_i -1| < 10^{-6}$.

Figure B-1 Bubblepoint Pressure



B.5.4 Additional Notes

For details of both the SRK and PR equation of state, please refer to Section B.2.2 of this document. These two equations of state are the most widely used equations of state for phase equilibrium calculations.

For pure fluids like steam, the vapor pressure equation will be used to check if two phases will coexist at the given temperature and pressure.

B.6 Isentropic Exponent

B.6.1 Basic Equations

For idealized one-dimensional expansion: $\frac{P_1}{P_2} = \left(\frac{V_2}{V_1}\right)^k$

Where *k* is the isentropic exponent.

For ideal gas: $k = \frac{C_p^i}{C_v^i}$

For real gas: $k = \left(\frac{\partial P}{\partial \ln V}\right)_s = -\frac{C_p}{C_v}\left(\frac{\partial P}{\partial V}\right)_T \frac{V}{P}$

Where:

$$C_v - C_v^i = -T\int_\infty^V \left(\frac{\partial^2 P}{\partial T^2}\right)_V dV$$

$$C_P - C_v = -T\left(\frac{\partial P}{\partial T}\right)_V^2 \Big/ \left(\frac{\partial P}{\partial V}\right)_T$$

For natural gas where the composition is known, the isentropic exponent can be calculated from the speed of sound using AGA-10.

$$\kappa = W^2 \frac{M_w}{ZRT}$$

B.6.2 Ideal Gas Specific Heat Capacity

$$C_P^i = A + BT + CT^2 + DT^3$$

Where the coefficients A, B, C and D were taken from, “The Properties of Gases and Liquids”.[2]

$$C_V^i = C_P^i - R$$

R is the gas constant.

B.6.3 Lee-Kesler BWR Equation

$$\frac{C_v - C_v^i}{R} = \frac{2(b_3 + 3b_4 / T_r)}{T_r^2 V_r} - 6E - \frac{3C_3}{T_r^3 V_r^3}$$

$$\frac{C_p - C_p^i}{R} = \frac{C_v - C_v^i}{R} - 1 - T_r \left(\frac{\partial P_r}{\partial T_r} \right)_{V_r}^2 \Big/ \left(\frac{\partial P_r}{\partial V_r} \right)_{T_r}$$

Where:

$$E = \frac{c_4}{2T_r^3 \gamma} \left\{ \beta + 1 - (\beta + 1 + \frac{\gamma}{V_r^2}) \exp(-\frac{\gamma}{V_r^2}) \right\}$$

$$\left(\frac{\partial P_r}{\partial T_r} \right)_{V_r} = \frac{1}{V_r} \Bigg\{ 1 + \frac{b_1 + b_3 / T_r^2 + 2b_4 / T_r^3}{V_r} + \frac{c_1 - 2c_3 / T_r^3}{2V_r^2}$$
$$+ \frac{d_1}{5V_r^5} - \frac{2c_4}{T_r^3 V_r^2} \left[(\beta + \tfrac{\gamma}{V_r^2}) \exp(-\tfrac{\gamma}{V_r^2}) \;\; \right] \Big\}$$

$$\left(\frac{\partial P_r}{\partial V_r} \right)_{T_r} = -\frac{T_r}{V_r^2} \{ 1 + \frac{2B}{V_r} + \frac{3C}{V_r^2} + \frac{6D}{V_r^5} + \frac{c_4}{T_r^3 V_r^2} [3\beta +$$
$$+ \{ 5 - 2(\beta + \frac{\gamma}{V_r^2}) \} \frac{\gamma}{V_r^2}] \exp(-\tfrac{\gamma}{V_r^2}) \}$$

For the meaning of the symbols and values of parameters, please refer to the Section B.2.4, Lee-Kesler BWR Equation.

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[2] Reid, J.M. Prausnitz and B.Z. Poling, “The Properties of Gases and Liquids”. Fourth Edition. McGraw-Hill Book Company.

B.6.4 RK Equation

$$C_V - C_v^i = -T\int_{\infty}^{V}\left(\frac{\partial^2 P}{\partial T^2}\right)_v dV = -\frac{0.75}{T^{2.5}}\frac{a}{b}\ln\frac{V}{V+b}$$

$$C_p - C_v = \frac{-T\left(\frac{\partial P}{\partial T}\right)^2 V}{\left(\frac{\partial P}{\partial V}\right)_T}$$

$$\left(\frac{\partial P}{\partial V}\right)_{\mathrm{T}} = \frac{-RT}{\left(V-b\right)^2} + \frac{a\left(2V+b\right)}{\sqrt{T}V^2(V+b)^2}$$

$$\left(\frac{\partial P}{\partial T}\right)_V = \frac{R}{V-b} + \frac{a}{2T^{3/2}}\frac{1}{V(V+b)}$$

For the meaning of the symbols and values of parameters, please refer to Section B.2.1, Redlich-Kwong Equation of State.

B.6.5 Reference

Reid, J.M. Prausnitz and B.Z. Poling, “The Properties of Gases and Liquids.” Fourth Edition. McGraw-Hill Book Company.

Walas, “Phase Equilibrium in Chemical Engineering”. Butterworth Publisher, Boston, 1985.

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C Flow Calculation Methods

C1 Introduction

C1.1 Scope

Appendices C1 to C12 describe the calculation methods used in Flowel to determine flow through a differential pressure flow element.

C1.2 ASME MFC-3M-1989

ASME MFC-3M-1989 was made as "consistent and technically equivalent as practical with ISO 5167-1980". In addition to ISO 5167-1980, this standard covers a considerably broader span of fluids and flowing conditions, and reduces the uncertainty in the prediction of the discharge coefficient. This standard specifies the geometry and method of use for orifice plates, nozzles, and Venturi tubes to determine the rate of the fluid flowing. It also gives necessary information for calculating flow rate and its associated uncertainty.

The following primary devices are covered in ASME MFC-3M-1989:

- orifice plates, which can be used with the following arrangements of pressure taps:
  - flange pressure taps
  - D and D/2 pressure taps
  - corner pressure taps
- nozzles:
  - ASME long radius nozzles
- venturi tubes

C1.2.1 Comparison of ASME MFC-3M-1989 and ISO 5167-1980

C1.2.1.1 Orifice Plates

For orifice plates with the above three pressure tappings arrangements, ASME MFC-3M-1989 provides the same discharge coefficient equation, expansibility equation, pressure loss equation and uncertainties in discharge coefficient and expandability as ISO 5167-1980.

C1.2.1.2 Nozzles

For nozzles, ASME MFC-3M-1989 provides additional equations for ASME flow nozzle.

The discharge coefficient is:

$$C = 0.9975 - 0.00653\left(10^6 \frac{\beta}{\mathrm{Re}_D}\right)^{0.5}$$

While ISO 5167-1980 provides (long radius nozzles):

$$C = 0.9965 - 0.00653\left[10^6 \frac{\beta}{\mathrm{Re}_D}\right]^{0.5}$$

Both ISO 5167-1980 and ASME MFC-3M-1989 provide the same equation for expansion factor.

Limit of use for ASME MFC-3M-1989 is:

- 100 mm ≤ D ≤ 750 mm
- $10^4 \leq R_{eD} \leq 10^7$

While ISO 5167-1980 gives:

- 50 mm ≤ D ≤ 630 mm
- $10^4 \leq R_{eD} \leq 10^7$

C1.2.1.3 Venturi Tubes

For Venturi tubes, ISO 5167-1980 and ASME MFC-3M-1989 give the same discharge coefficient value for "as cast" convergent venturi tube but provide different limits of use.

ISO 5167-1980:

- 100 mm ≤ D ≤ 800 mm
- $2\mathrm{x}10^5 \leq R_{eD} \leq 2\ \mathrm{x}10^6$

This standard:

- 100 mm ≤ D ≤ 1200 mm
- $2\mathrm{x}10^5 \leq R_{eD} \leq 6\ \mathrm{x}10^6$

ISO 5167-1980 and ASME MFC-3M-1989 give the same discharge coefficient value for machined convergent venturi tube but provide different limits of use.

ISO 5167-1980:

- $0.4 \leq \beta \leq 0.75$
- $2x10^5 \leq Re_D \leq 1\ x10^6$

ASME MFC-3M-1989:

- $0.3 \leq \beta \leq 0.75$
- $2x10^5 \leq R_{eD} \leq 2\ x10^6$

C1.3 ASME/ANSI Standard MFC-7M-1987

This standard was approved by the American National Standards Institute (ANSI) on February 27, 1987. It applies only to the steady flow of single-phase gases and deals with devices for which direct calibration experiments have been made, sufficient in number and quantity to enable inherent systems of applications to be based on their results and coefficients to be given with certain predictable limits of uncertainty.

This standard applies only to venturi nozzles in which the flow is critical. It provides methods to calculate discharge coefficient and real gas critical flow coefficient. It illustrates the calculation of the critical flow coefficient in Appendix E of MFC-7M-1987.

C1.4 ASME MFC-14M-2003

ASME MFC-14M-2003, entitled Measurement of Fluid Flow Using Small Bore Precision Orifice Meters, applies to orifice meters of 6 mm to 40 mm (¼ to 1½ inches) line size.

ASME MFC-14M-2003 was approved as an American National Standard on February 26, 2003.

C1.5 International Standard ISO 5167-1980(E)

This standard covers:

- orifice plates, which can be used with the various following arrangements of pressure tappings:
  - corner pressure tappings
  - D and D/2 pressure tappings
  - flange pressure tappings
- nozzles:
  - ISA 1932 nozzle
  - long radius nozzle

- venturi tubes:
  - classical venturi tube
  - venturi-nozzle

This standard can not be used for pipe sizes less than 50 mm, or more than 1200 mm, or for pipe Reynolds number below 3150.

C1.6 International Standard ISO 5167-1-1991(E)

This standard is a technical revision of ISO 5167-1980(E). It covers the same types of primary devices and conditions.

- orifice plates, which can be used with the various following arrangements of pressure tappings:
  - corner pressure tappings
  - D and D/2 pressure tappings
  - flange pressure tappings
- nozzles:
  - ISA 1932 nozzle
  - long radius nozzle
- venturi tubes:
  - classical venturi tube
  - venturi-nozzle

This standard can not be used for pipe sizes less than 50 mm, or more and 1200 mm, or for pipe Reynolds number below 3150.

C1.6.1 Difference Between ISO 5167-1980(E) and ISO 5167-1-1991(E)

ISO 5167-1-1991(E) provides an informative guideline for iterative computations as Annex D.

For orifice plates with corner tappings, the limit of use for β changed from 0.23≤β ≤ 0.80 to 0.20≤β ≤0.75. For orifice pates with flange or D and D/2 tappings, the D range increased from 50≤D≤760 to 50≤D≤1000.

The discharge coefficient for ISA 1932 nozzle is changed from:

$$C = 0.9900 - 0.2262\beta^{4.1} + \left[0.000215 - 0.001125\beta + 0.002490\beta^{4.7}\right]\left[\frac{10^6}{\mathrm{Re}_D}\right]^{1.15}$$

To: $C = 0.9900 - 0.2262\beta^{4.1} - \left[0.00175\beta^{2} - 0.0033\beta^{4.15}\right]\left[\frac{10^6}{\mathrm{Re}_D}\right]^{1.15}$

C1.7 International Standard ISO 5167-2003

This revision to ISO-5167 is only a revision of the orifice metering section. The equations for the coefficient of discharge and the expansion factor are changed.

C1.8 ISO Technical Report ISO/TR 15377:1998

This technical report, entitled ‘Guidelines for the Specification of Nozzles and Orifice Plates Beyond the Scope of ISO 5167-1, covers flow elements such as quadrant edged orifice plates, conical edged orifice plates, and vent and drain holes.

C1.9 British Standard 1042, Part 1, Section 1.2

This standard describes the measurement of fluid flow in closed conduits and will be applied to liquid, vapor or gas flows in the following types of orifice plates: conical entrance, quadrant, and eccentric.

C1.10 American Gas Association Report No.3, Part 1, 3rd Ed., 1990

AGA-3 Part 1 (1990) provides a single reference for engineering equations, uncertainty estimations, construction and installation requirements, and standardized implementation recommendations for the calculation of flow rate through concentric, square-edged, flange-tapped orifice meters.

AGA-3 Part 1 (1990) applies to fluids that, for all practical purposes, are considered to be clean, single phase, homogeneous, and Newtonian, measured using concentric, square-edged, flange-tapped orifice meters and have pipe Reynolds numbers of 4000 or greater.

This new third edition divided the document into four relatively independent parts. The part 1 was issued in 1990, part 2 in 1991, and parts 3 and 4 in 1992. Each part can be used independently.

The major change over the second edition is on the discharge coefficient equation. The empirical coefficient of discharge equation has been changed with new broad data base (with a total of 10192 experimental data points for flange, corner, radius tappings).

2nd Edition (1985)

$$K_e = 0.5993 + \frac{0.007}{\mathrm{D}_{\mathrm{meas}}} + \left[0.364 + \frac{0.076}{\mathrm{D}_{\mathrm{meas}}^{0.5}}\right]\beta^4$$

$$+0.4\left[1.6 - \frac{1}{D_{meas}}\right]^5 \left[\left(0.07 + \frac{0.5}{D_{meas}}\right) - \beta\right]^{5/2}$$

$$-\left[0.009 + \frac{0.034}{\mathrm{D}_{\mathrm{meas}}}\right]\left[0.5 - \beta^{3/2}\right] + \left[\frac{65}{D_{meas}^2} + 3\right]\left[\beta - 0.7\right]^{5/2}$$

3rd Edition (1990)

$$\mathrm{C_d}\left(\mathrm{FT}\right) = \mathrm{C_i}\left(\mathrm{FT}\right) + 0.000511\left(\frac{10^6\ \beta}{\mathrm{Re_D}}\right)^{0.7} + \left(0.0210 + 0.0049\mathrm{A}\right)\beta^4\ \mathrm{C}$$

$$\mathrm{C_i}\left(FT\right) = \mathrm{C_i}\left(CT\right) + UPSTRM + DNSTRM$$

$$\mathrm{C_i}\left(CT\right) = 0.5961 + 0.0291\,\beta^2 - 0.2290\,\beta^8 + 0.003\,\left(1 - \beta\right)\mathrm{M_1}$$

$$UPSTRM = \left(0.0433 + 0.0712\,\mathrm{e}^{-8.5\mathrm{L_1}} - 0.1145\,\mathrm{e}^{-6.0\mathrm{L_1}}\right)\left(1 - 0.23\mathrm{A}\right)\mathrm{B}$$

$$DNSTRM = -0.0116\left(\mathrm{M_2} - 0.52\,\mathrm{M_2}^{1.3}\right)\beta^{1.1}\left(1 - 0.14\,\mathrm{A}\right)$$

$$\mathrm{B} = \frac{\beta^4}{1 - \beta^4}$$

$$\mathrm{M_1} = \max\left(2.8 - \frac{\mathrm{D}}{0.0254},\ 0.0\right)$$

$$\mathrm{M_2} = \frac{2\,\mathrm{L_2}}{1 - \beta}$$

$$\mathrm{A} = \left(\frac{19000\beta}{\mathrm{Re_D}}\right)^{0.8}$$

$$\mathrm{C} = \left(\frac{10^6}{\mathrm{Re_D}}\right)^{0.35}$$

$$L_1 = L_2 = \frac{0.0254}{D}$$

C1.11 American Gas Association Report No.3, 2nd Ed., 1985

The second edition of AGA 3 has been changed significantly in the format. Buxton made a comprehensive comparison analysis of this edition vs. the 1978 edition.

It provides equations for computing mass flow rate when the density of the fluid flowing is known, the volume flow rate when the density of the fluid flowing are known, the mass flow rate when the ideal gas relative density of fluid flowing is known, the volume flow rate when the ideal gas relative density of fluid flowing is known, mass flow rate when the real gas relative density of the fluid flowing is known, and the volume flow rate when the real gas relative density of the fluid flowing is known.

C1.12 General Application

This chapter (C12) contains information on calculating fluid flow in the general case. It also contains calculation methods not covered in any of the standards mentioned before. Those devices include:

- concentric orifice plate with flange taps, vena contracta taps, corner taps and radius taps
- eccentric orifice plate with flange taps, vena contracta taps
- segmental orifice plate with flange taps, vena contracta taps
- quadrant orifice plate with corner or flange taps
- conic orifice with corner taps
- small bore orifice meter runs with flange or corner taps
- critical flow calculation

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C2 ASME Standard MFC-3M-1989

C2.1 Flow Element Applicability

The ASME standard is defined for the following flow measurement elements:

- orifice plates with:
    - flange taps
    - D and D/2 (radius) taps
    - corner taps
- ASME long radius nozzles:
    - high β ratio nozzles
    - low β ratio nozzles
    - throat tap flow nozzles
- classical venturi tubes:
    - as-cast convergent section
    - machined convergent section
    - fabricated (welded) convergent section

ASME MFC-3M-1989 applies to liquid, vapor, or gas flows which are homogenous (single phase), turbulent, subsonic and steady with time (a slow pulsation can be acceptable).

C2.2 Calculation of Reynolds Numbers

C2.2.1 Symbol Table

The symbol table for calculation of Reynolds Numbers is shown below.

Table C-1 Calculation of Reynolds Numbers Symbol Table

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain
d	m	0 < d	0 < d	None	d < =D
D	m	0 < D	0 < D	None	None
q_m	kg/s	$0 \leq q_m$	$0 \leq q_m$	None	None
μ	Pa-s	$0 < \mu$	$0 < \mu$	None	None
R_d	-	$0 < R_d$	$0 < R_d$	None	None

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain
R_D	-	$0 < R_D$	$0 < R_D$	None	None
β	-	$0 < \beta$	$0 < \beta$	$\beta \leq 1$	$\beta \leq 1$

C2.2.2 Reynolds Number Based on the Upstream Condition of the Fluid and the Inside Diameter of the Pipe

The equation for the Reynolds Number based on the upstream condition of the fluid and the inside diameter of the pipe is:

$$R_D = \frac{4\,q_m}{\pi\,\mu\,D}$$ (eq. 1, p. 7)

C2.2.3 Reynolds Number Based on the Orifice or Throat Diameter of the Primary Device

The equations for the Reynolds Number based on the orifice or throat diameter of the primary device are:

$$\beta = \frac{d}{D}$$ (Table 1, p. 4)

$$R_d = \frac{R_D}{\beta}$$ (eq. 2, p. 7)

C2.3 Orifice Plate Discharge Coefficients

C2.3.1 Symbol Table

The symbol table for the orifice plant discharge coefficients is shown below.

Table C-2 Symbols

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain	Ref.
β	-	$0 < \beta$	$0.2 < \beta$	$\beta < 0.70$	$\beta < 1$	§7.1.6.1
d	m	None	None	$K < D$	$K < D$	§3.2
R_D	-	$0 < R_D$	$2000 < R_D$	$R_D < 10^8$	None	§7.3.2.1
D	m	$0 < D$	$0.0429 < D$	$D < 0.900$	None	§7.3.2.1
C	-	$C > 0$	None	$C < 1$	None	

C2.3.2 Calculations

C2.3.2.1 Base Discharge Coefficients (§7.3.1.1)

The base discharge coefficients equation is:

$$C = 0.5959 + 0.0312\beta^{2.1} - 0.1840\beta^{8} + 0.0900 L_1 \beta^{4} (1 - \beta^{4})^{-1} - 0.0337 L_2' \beta^{3} + 91.71 \beta^{2.5} R_D^{-0.75} \quad \text{(eq. 25, p. 30)}$$

Where:

$$L_1 = \frac{l_1}{D}$$

$$L_2 = \frac{l_2}{D}$$

$$L_2' = \frac{l_2'}{D} = \frac{(l_2 - E)}{D}$$

If $L_1 \geq 0.4333$ then $0.0900\ L_1 \equiv 0.0390$

- l_1 – distance of upstream pressure tap from upstream face of orifice plate
- l_2 – distance of downstream pressure tap from downstream face of orifice plate
- E – thickness of orifice plate

The valid tap arrangements are defined in paragraphs 7.2.3.4, 7.2.3.5, or 7.2.4. It is not permitted to use l_1 and l_2 which do not match one of the three standardized tap arrangements.

C2.3.2.2 Corner Taps (§7.3.1.1)

The relative roughness ratio limits for corner taps are given below (§7.2.4.11):

Table C-3 Relative Roughness Ratio Limits for Corner Taps

β	≤0.30	0.32	0.34	0.36	0.38	0.40	0.45	0.5	0.6	0.7
10^4k/D	25	18.1	12.9	10.0	8.3	7.1	5.6	4.9	4.2	4.0

$$L_1 = L_2' = 0 \quad \text{(eq. 26, p.30)}$$

C2.3.2.3 Flange Taps, $D \geq 58.6\ \text{mm}$ (§7.3.1.1)

The relative roughness limit for flange taps is:

$k/D \leq 3.8 \times 10^{-4}$ (§7.2.4.11)

$L_1 = L_2' = 0.0254\,D^{-1}$ (eq. 27a, p. 30)

C2.3.2.4 Flange Taps $50.8\ \text{mm} \leq D \leq 58.6\ \text{mm}$ (§7.3.1.1)

The relative roughness limit for flange taps is:

$k/D \leq 3.8 \times 10^{-4}$ (§7.2.4.11)

$L_1 = 0.4333,\ L_2' = 0.0254\,D^{-1}$ (eq. 27b, p. 30)

C2.3.2.5 Radius Taps (D and D/2) (§7.3.1.1)

The relative roughness limit for radius taps is:

$k/D \leq 3.8 \times 10^{-4}$ (§7.2.4.11)

$L_2' = 0.47$ (eq. 28, p. 30)

Since $L_1 \geq 0.4333$, $0.0090\ L_1 \equiv 0.0390$

C2.4 Long Radius Nozzles Discharge Coefficients

C2.4.1 Symbol Table

The symbol table for long radius nozzles discharge coefficients is shown below.

Table C-4 Long Radius Nozzles Discharge Coefficients Symbol Table

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain	Ref.
β	-	$0 < \beta$	varies with	design	$\beta < 1$	§8
R_D	-	$0 < R_D$	$10^4 \leq R_D$	$R_D \leq 6 \times 10^6$	None	§8.4.4
D	m	$0 < D$	$0.1 \leq D$	$D \leq 0.75$	None	§8.4.4
p_{f1}	Pa	$0 < p_{f1}$	$0 < p_{f1}$	None	None	§5.3.3
p_{f2}	Pa	$0 < p_{f2}$	$0.75\ p_{f1} < p_2$	$p_{f2} < p_{f1}$	None	§5.3.3
C	-	$C > 0$	None	$C < 1$	None	

The standard applies to 3 types of long radius style flow nozzles (§8):

1. High beta ratio nozzle, $(0.50 \leq \beta \leq 0.80)$
2. Low beta ratio nozzle, $(0.20 \leq \beta \leq 0.50)$
3. Throat tap flow nozzle, $(0.25 \leq \beta \leq 0.50)$

C2.4.2 Calculations

C2.4.2.1 Wall Tap Nozzle Discharge Coefficient (§8.4.1)

The well tap nozzle discharge coefficient calculation is:

$$C = 0.9975 - 0.00653\left(10^{6}\,\frac{\beta}{R_D}\right)^{0.5}$$ (eq. 32, p.35)

C2.4.2.2 Throat Tap Nozzle Discharge Coefficient (§8.4.2)

The un-calibrated discharge coefficient of ASME flow nozzles with throat taps is given in ANSI/ASME PTC 6 and Steam Turbines Performance Test Codes 1976 (reaffirmed in 1982 and 1991).

Discharge Coefficient @ $\beta = 0.43$ (§4.22d)

The Standard provides the following discharge coefficients for β=0.43, at various Reynolds numbers.

Table C-5 Discharge Coefficients

Throat Reynolds Number x 10^{-6}	Discharge Coefficient $C_{\beta=0.43}$
0.10	0.9834
0.2	0.9909
0.3	0.9939
0.4	0.9953
0.5	0.9961
0.6	0.9966
0.8	0.9970
1.0	0.9972
2.0	0.9970
3.0	0.9970
4.0	0.9972
5.0	0.9974
6.0	0.9978
8.0	0.9980
10.0	0.9983
20.0	0.9991
30.0	0.9994
40.0	0.9998

The following equation was fitted to the above points. The maximum deviation is 0.03%.

$$C_{\beta=0.43} = -2.9385202378 + 2.353680507\left[\log(R_d)\right] - 0.5261432417\left[\log(R_d)\right]^2 + 0.0520709677\left[\log(R_d)\right]^3 - 0.0019238022\left[\log(R_d)\right]^4$$

For beta ratios other than 0.43:

$$C = C_{\beta=0.43} + (0.011339\beta - 0.0049)$$

C2.5 Classical Venturi Tubes Discharge Coefficients

C2.5.1 Symbol Table

The symbol table for classic Venturi tubes discharge coefficients is shown below.

Table C-6 Classical Venturi Tubes Discharge Coefficients Symbol Table

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain	Ref.
β	-	$0 < \beta$	$0.30 \le \beta$	$\beta \le 0.75$	$\beta < 1$	§9.5.2 §9.5.3
R_D	-	$0 < R_D$	varies with	design	None	§9.5.2 §9.5.3
D	m	0 < D	varies with	design	None	§8.4.4
C	-	C > 0	None	None	$C \le 1$	

The standard applies to 3 types of venturi tubes (§9):

1. Venturi with an as-cast convergent
2. Venturi with a machined convergent
3. Venturi with a fabricated convergent

C2.5.2 Calculations

C2.5.2.1 ASME Venturi Tubes With an As-Cast or Fabricated Convergent (§9.5.2)

The calculation for ASME Venturi tubes with an as-cast or fabricated convergent is:

$$0.100 \le D \le 1.200$$

$$2 \times 10^5 \le R_D \le 6 \times 10^6$$

$$0.3 \le \beta \le 0.75$$

C = 0.984

Note: The current data indicates that venturis may be used with diameters up to 2.1 meters.

C2.5.2.2 ASME Venturi Tubes With a Machined Convergent (§9.5.3)

The calculation for ASME Venturi tubes with a machined convergent is:

$$0.050 \leq D \leq 0.250$$

$$2 \times 10^5 \leq R_D \leq 2 \times 10^6$$

$$0.3 \leq \beta \leq 0.75$$

C = 0.995

C2.6 Orifice Plate Expansion Factors

C2.6.1 Symbol Table

The symbol table for orifice plate expansion factors is shown below.

Table C-7 Orifice Plate Expansion Factors Symbol Table

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain	Ref.
R_D	-	$0 < R_D$	$2000 \leq R_D$	$R_D < 10^8$	None	§7.3.2.1
D	m	0 < D	0.0429 < D	D < 0.900	None	§7.3.2.1
β	-	$0 < \beta$	$0.20 \leq \beta$	$\beta \leq 0.70$	$\beta < 1$	§7.1.6.1
κ	-	$0 < \kappa$	None	None	None	
P_1	Pa	$0 < P_1$	$0 < P_1$	None	None	
P_2	Pa	$0 < P_2$	varies w/fluid states	$P_2 < P_1$	None	
ΔP	Pa	$0 \leq \Delta P$	$0 \leq \Delta P$	None	None	
Y_1	-	$0 < Y_1$	None	None	None	
Y_2	-	$0 < Y_2$	None	None	None	

C2.6.2 Calculations

C2.6.2.1 Gas Expansion Factor Based on Upstream Conditions (§7.3.1.2)

The calculation for the gas expansion factor based on upstream conditions is:

$$P_2 / P_1 \geq 0.75$$

$$\Delta P = P_1 - P_2$$

$$Y_1 = 1 - (0.41 + 0.35\beta^4)\frac{\Delta P}{\kappa P_1}$$ (eq. 29, p. 31)

C2.6.2.2 Gas Expansion Factor Based on Downstream Conditions (§7.3.1.2)

The calculation for the gas expansion factor based on downstream conditions is:

$$P_2/P_1 \geq 0.75$$

$$\Delta P = P_1 - P_2$$

$$Y_2 = \sqrt{1 + \frac{\Delta P}{P_2}\left[1 - (0.41 + 0.35\beta^4)\frac{\Delta P}{\kappa P_1}\right]}$$ (eq. 30, p. 31)

C2.6.2.3 Liquid Expansion Factor (§3.2.3)

The liquid expansion factor calculation is:

$$Y_1 = Y_2 = 1$$

C2.7 ASME Long Radius Nozzles Expansion Factors

C2.7.1 Symbol Table

The symbol table for ASME long radius nozzles expansion factors is shown below.

Table C-8 ASME Long Radius Nozzles Expansion Factors Symbol Table

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain	Ref.
R_D	-	$0 < R_D$	$10^4 \leq R_D$	$R_D < 10^8$	None	§8.4.4
D	m	0 < D	0.100 < D	D < 0.750	None	§8.4.4
β	-	$0 < \beta$	varies with design	$\beta < 1$	§8	
κ	-	$0 < \kappa$	None	None	None	
P_1	Pa	$0 < P_1$	$0 < P_1$	None	None	§5.3.3
P_2	Pa	$0 < P_2$	varies w/fluid state	$P_2 < P_1$	None	§5.3.3
ΔP	Pa	$0 \leq \Delta P$	$0 \leq \Delta P$	None	None	
τ		$0 < \tau$	0.75	None	$\tau < 1$	
Y_1	-	$0 < Y_1$	None	None	None	
Y_2	-	$0 < Y_2$	None	None	None	

C2.7.2 Calculations

C2.7.2.1 Gas Expansion Factor Based on Upstream Conditions (§8.4.3)

The gas expansion factor based on upstream conditions calculation is:

$$\tau = {P_2}/{P_1}, \quad \tau \geq 0.75$$

$$Y_1 = \left[\left[\frac{\kappa\tau^{\frac{2}{\kappa}}}{\kappa - 1}\right]\left[\frac{1-\beta^4}{1-\beta^4\tau^{\frac{2}{k}}}\right]\left[\frac{1-\tau^{\frac{\kappa-1}{\kappa}}}{1-\tau}\right]\right]^{0.5}$$

(eq. 33, p. 35)

C2.7.2.2 Gas Expansion Factor Based on Downstream Conditions (§8.4.3)

The gas expansion factor based on downstream conditions calculation is:

$$\tau = {P_2}/{P_1}, \quad \tau \geq 0.75$$

$$\Delta P = P_1 - P_2$$

$$Y_2 = (1 + \frac{\Delta P}{P_2})^{0.5} Y$$

(eq. 34, p. 35)

C2.7.2.3 Liquid Expansion Factor (§3.2.3)

The liquid expansion factor calculation is:

$$Y_1 = Y_2 = 1$$

C2.8 Classical Venturi Tube Expansion Factor

C2.8.1 Symbol Table

The symbol table for classical Venturi tubes expansion factor is shown below.

Table C-9 Classical Venturi Tube Expansion Factor Symbol Table

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain	Ref.
R_D	-	$0 < R_D$	varies with design	None	§9.5.2 §9.5.3	
D	m	0 < D	varies with design	None	§9.5.2	
β	-	$0 < \beta$	$0.30 \leq \beta$	$\beta \leq 0.75$	$\beta < 1$	§9.5.2 §9.5.3
κ	-	$0 < \kappa$	None	None	None	

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain	Ref.
P_1	Pa	$0 < P_1$	$0 < P_1$	None	None	§5.3.3
P_2	Pa	$0 < P_2$	varies w/fluid state	$P_2 < P_1$	None	
ΔP	Pa	$0 \leq \Delta P$	$0 \leq \Delta P$	None	None	
τ		$0 < \tau$	None	None	$\tau < 1$	
Y_1	-	$0 < Y_1$	None	None	None	
Y_2	-	$0 < Y_2$	None	None	None	

C2.8.2 Calculations

C2.8.2.1 Gas Expansion Factor Based on Upstream Conditions (§9.5.4)

The calculation for gas expansion factor based on upstream conditions is:

$$\tau = {P_2}/{P_1}, \quad \tau \geq 0.75$$

$$Y_1 = \left[\left[\frac{\kappa \tau^{\frac{2}{\kappa}}}{\kappa - 1} \right] \left[\frac{1 - \beta^4}{1 - \beta^4 \tau^{\frac{2}{k}}} \right] \left[\frac{1 - \tau^{\frac{\kappa - 1}{\kappa}}}{1 - \tau} \right] \right]^{0.5}$$

(eq. 33, p. 35)

C2.8.2.2 Gas Expansion Factor Based on Downstream Conditions (§9.5.4)

The calculation for gas expansion factor based on downstream conditions is:

$$\tau = {P_2}/{P_1}, \quad \tau \geq 0.75$$

$$\Delta P = P_1 - P_2$$

$$Y_2 = (1 + \frac{\Delta P}{P_2})^{0.5} Y_1$$

(eq. 34, p. 35)

C2.8.2.3 Liquid Expansion Factor (§3.2.3)

The liquid expansion factor calculation is:

$$Y_1 = Y_2 = 1$$

C2.9 Thermal Expansion Correction

C2.9.1 Symbol Table

The symbol table for thermal expansion correction is shown below.

Table C-10 Thermal Expansion Correction Symbol Table

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain
d_{meas}	m	$0< d_{meas}$	None	None	$d_{meas} \leq D_{meas}$
D_{meas}	m	$0< D_{meas}$	None	None	None
α_{PE}	m/m/°C	$0 < \alpha_{PE}$	None	None	None
α_P	m/m/°C	$0 < \alpha_P$	None	None	None
t	°C	$-273.15 < t$	None	None	None
t_{meas}	°C	$-273.15 < t_{meas}$	t_{meas} is usually assumed to be 20°C		
d	m	$0<d$	None	None	None
D	m	$0<D$	None	None	None

C2.9.2 Calculations

C2.9.2.1 Bore Diameter, d, Temperature Correction

The calculation for bore diameter temperature correction is:

$$d = \left[1 + \alpha_{PE}\left[t - t_{meas}\right]\right] d_{meas}$$ (ASME MFC-3M-1989 eq. 19a, p. 12)

C2.9.2.2 Pipe Diameter, D, Temperature Correction

The calculation for pipe diameter temperature correction is:

$$D = \left[1 + \alpha_{P}\left[t - t_{meas}\right]\right] D_{meas}$$ (ASME MFC-3M-1989 eq. 19b, p. 12)

C2.10 Flow Rate Calculation

C2.10.1 Symbol Table

The symbol table for flow rate calculation is shown below.

Table C-11 Flow Rate Calculation Symbol Table

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain	Ref.
d_{meas}	m	$0 < d_{meas}$	None	None	$d_{meas} \leq D_{meas}$	
D_{meas}	m	$0 < D_{meas}$	varies with design	None		
P_1	Pa	$0 < P_1$	$0 < P_1$	None	None	
P_2	Pa	$0 < P_2$	varies w/fluid state	$P_2 < P_1$	None	

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain	Ref.
t	°C	$-273.15 < t$	None	None	None	§4.2
t_{meas}	°C	$-273.15 < t_{meas}$	None	None	None	§4.2
α_P	m/m/°C	$0 < \alpha_P$	None	None	None	§4.2
α_{PE}	m/m/°C	$0 < \alpha_{PE}$	None	None	None	§4.2
ΔP	Pa	$0 < \Delta P$	None	None	None	
ρ_B	kg/m^3	$0 < \rho_B$	None	None	None	
ρ_{f1}	kg/m^3	$0 < \rho_{f1}$	None	None	None	
ρ_{f2}	kg/m^3	$0 < \rho_{f2}$	None	None	None	
C	-	$0 < C$	$0 < C$	$C < 1$	None	
Y_1	-	$0 < Y_1$	None	None	None	
Y_2	-	$0 < Y_2$	None	None	None	
d	m	$0 < d$	None	None	None	
D	m	$0 < D$	varies with design	None		
β	-	$0 < \beta$	varies with design	$\beta < 1$		
q_m	kg/s	$0 < q_m$	None	None	None	§4.2

C2.10.2 Calculations (§4.3)

The actual flow is found by iteration, since C and R_D are dependent on the flow rate q_m.

$$d = d_{meas}\left(1 + \alpha_{PE}\left(t - t_{meas}\right)\right) \qquad \text{(eq. 19a, p. 12)}$$

$$D = D_{meas}\left(1 + \alpha_{P}\left(t - t_{meas}\right)\right) \qquad \text{(eq. 19b, p. 12)}$$

$$\beta = \frac{d}{D}$$

The above values of d, D, and β should be used to calculate C and Y.

$$q_m = \text{fuser}\,\frac{\pi}{4}\,C\,Y_1\,d^2\sqrt{\frac{2\,\Delta p\,\rho_{f1}}{1-\beta^4}} \qquad \text{(eq. 13, p. 11)}$$

or:

$$q_m = \text{fuser}\,\frac{\pi}{4}\,C\,Y_2\,d^2\sqrt{\frac{2\,\Delta p\,\rho_{f2}}{1-\beta^4}} \qquad \text{(eq. 14, p. 10)}$$

Where fuser can be used for various calibration factors.

C2.11 Permanent Pressure Loss

C2.11.1 Symbol Table

The symbol table for permanent pressure loss is shown below.

Table C-12 Permanent Pressure Loss Symbol Table

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain
C	-	0 < C	None	C < 1	None
ΔP	Pa	$0 < \Delta P$	None	None	None
β	-	$0 < \beta$	varies with primary element		$\beta < 1$
ϕ	°	$0 < \phi$	$7° \le \phi$	$\phi \le 15°$	None
$\Delta\varpi$	Pa	$0 < \Delta\varpi$	None	None	None

C2.11.2 Calculations

C2.11.2.1 Orifice Plate (§7.4)

The orifice plate calculation is:

$$\Delta\varpi = \Delta p \left(\frac{\sqrt{1 - \beta^4} - C\beta^2}{\sqrt{1 - \beta^4} + C\beta^2} \right)$$ (eq. 31, p. 32)

Note: This equation may generate negative permanent pressure loss if β is out of range.

C2.11.2.2 ASME Flow Nozzles (§8.6)

The ASME flow nozzle calculation is:

$$\Delta\varpi = \left(1 + 0.014\,\beta - 2.06\,\beta^2 + 1.18\,\beta^3\right) \Delta p$$ (eq. 36, p.36)

C2.11.2.3 ASME Venturi Tube (§9.7)

For the divergent angle, $\phi = 15^{o}$:

$$\zeta = 0.436 - 0.86\,\beta + 0.59\,\beta^2$$

For the divergent angle, $\phi = 7^{o}$:

$$\zeta = 0.218 - 0.42\,\beta + 0.38\,\beta^2$$

For a divergent angle, 7° ≤ ϕ ≤ 15 °, assume that linear interpolation will provide an accurate pressure loss value.

$$\zeta_{\phi} = \zeta_7 + \left(\zeta_{15} - \zeta_7\right)\left(\frac{\phi - 7°}{15° - 7°}\right)$$

$$\Delta\varpi \quad = \quad \zeta\,\Delta P \qquad (\S 9.7)$$

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C3 ASME/ANSI Standard MFC-7M-1987

C3.1 Flow Element Applicability

This standard applies to the critical flow measurement of single phase gases, using venturi nozzles. The nozzles may have toroidal throats or cylindrical throats.

C3.2 Calculation of Reynolds Numbers

C3.2.1 Symbol Table

The symbol table for the calculation of Reynolds Numbers is shown below.

Table C-1 Calculation of Reynolds Numbers Symbol Table

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain
d	m	$0 < d$	$0 < d$	None	$d < D$
q_m	kg/s	$0 < q_m$	$0 < q_m$	None	None
μ_o	Pa-s	$0 < \mu_o$	$0 < \mu_o$	None	None
R_d	-	$0 < R_d$	$0 < R_d$	None	None

C3.2.2 Reynolds Numbers Based on Stagnation Properties and the Throat Diameter (§2.2.4)

The equation for Reynolds Numbers based on stagnation properties and the throat diameter is:

$$R_d = \frac{4q_m}{\pi \mu_o d}$$

C3.3 Discharge Coefficients Calculation

C3.3.1 Symbol Table

The symbol table for discharge coefficients calculation is shown below.

Table C-2 Discharge Coefficients Calculation Symbol Table

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain	Ref.
R_d	-	$0 < R_d$	varies with device	None	§7.2.2	
C	-	0 < C	None	C < 1	None	

C3.3.2 Calculations

C3.3.2.1 Toroidal Throat Discharge Coefficient (§7.2.2)

The Toroidal throat discharge coefficient calculation is:

$$10^5 < R_d < 10^7 \qquad C = 0.9935 - \frac{1.525}{R_d^{0.5}}$$

C3.3.2.2 Cylindrical Throat Discharge Coefficient (§7.2.2)

The cyndrical throat discharge coefficient calculation is:

$$3.5\times10^5 < R_d < 2.5\times10^6 \qquad C = 0.9887$$

$$2.5\times10^6 < R_d < 2.0\times10^7 \qquad C = 1.0000 - \frac{0.2165}{R_d^{0.2}}$$

C3.4 Critical Flow Coefficient

C3.4.1 Symbol Table

The symbol table for critical flow coefficient is shown below.

Table C-3 Critical Flow Coefficient Symbol Table

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain
k	-	0 < *k*	None	None	None
C_{Ri}	-	$0 < C_{Ri}$	None	None	None
z	-	0 < z	None	None	None

C3.4.2 Calculations (§2.2.4)

C3.4.2.1 Real Gas Critical Flow Function

The real gas critical flow function calculation is:

$$C_{Ri} = \frac{1}{\sqrt{z}} \sqrt{k\left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}}$$

C3.5 Flow Rate Calculation

C3.5.1 Symbol Table

The symbol table for flow rate calculation is shown below.

Table C-4 Flow Rate Calculation Symbol Table

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain
β	-	$0 < \beta$	None	$\beta < 0.25$	$\beta < 1$
C	-				
C_{Ri}	-				
P	Pa	$0 < P$	$0 < P$	None	None
Z	-	$0 < Z$			
ρ	kg/m^3	$0 < \rho$			
q_m	kg/s	$0 < q_m$			

C3.5.2 Calculations (§3.3)

The flow rate calculation is:

$$q_m = \frac{\pi}{4} d^2 C C_{Ri} \sqrt{ZP\rho}$$

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C4 ASME Standard MFC-14M-2003

C4.1 Flow Element Applicability

This ASME standard is applicable to small bore precision orifice meters:

- orifice plates with corner taps
- orifice plates with flange taps
- specially designed orifice meters with integral fittings (inline sizes ¼ to 1½ inches (6 mm to 40 mm))

C4.2 Calculation of Reynolds Number

The calculation for Reynolds Number for R_D and R_d is found in C2.2. The limit of applicability of this standard is for R_D greater than 1,000.

C4.3 Discharge Coefficients

C4.3.1 Symbol Table

The symbol table for the orifice plant discharge coefficients is shown below.

Table C-1 Symbols

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain
β	-	$0 < \beta$	$0.1 < \beta$	$\beta < 0.80$	$\beta < 1$
d	m	None	None	d<D	d<D
R_D	-	$0 < R_D$	$1000 < R_D$	none	None
D (corner taps)	m	0 < D	$0.0064 \le D$	$D \le 0.0450$	None
D (flange taps)	m	0 < D	$0.0152 \le D$	$D \le 0.0450$	None
C	-	C > 0	None	C < 1	None

While the standard is valid down to line size ¼ inch (6 mm), the discharge coefficient for flange taps is valid down to ½ inch (13 mm) and for flange taps down to 1 inch (25 mm). These are taken to be nominal sizes, although this is not stated explicitly in the standard.

C4.3.2 Corner Taps

$$C = \left[0.5991 + \frac{0.0044}{D} + \left(0.3155 + \frac{0.0175}{D}\right)\left(\beta^4 + 2\beta^{16}\right)\right]\sqrt{1-\beta^4}$$

$$+\left[\frac{0.52}{D} - 1.92 + \left(16.48 - \frac{1.16}{D}\right)\right]\left(\beta^4 + 4\beta^{16}\right)\sqrt{\frac{1-\beta^4}{R_D}}$$

C4.3.3 Flange Taps

$$C = \left[0.5980 + 0.468\left(\beta^4 + 10\beta^{12}\right)\right]\sqrt{1-\beta^4} + \left(0.87 + 8.1\beta^4\right)\sqrt{\frac{1-\beta^4}{R_D}}$$

C4.4 Expansion Factor

$$Y_1 = 1 - \frac{\left(0.41 + 0.35\beta^4\right)\Delta P}{\kappa P_1}$$

$$Y_2 = \sqrt{1 + \frac{\Delta P}{P_2}} - \frac{\left(0.41 + 0.35\beta^4\right)\Delta P}{\kappa P_2\sqrt{1 + \frac{\Delta P}{P_2}}}$$

C4.5 Thermal Expansion Correction

C4.5.1 Symbol Table

The symbol table for thermal expansion correction is shown below.

Table C-2 Thermal Expansion Correction Symbol Table

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain
d_{meas}	m	$0 < d_{meas}$	None	None	$d_{meas} \le D_{meas}$
D_{meas}	m	$0 < D_{meas}$	None	None	None
α_2	m/m/°C	$0 < \alpha_2$	None	None	None
α_1	m/m/°C	$0 < \alpha_1$	None	None	None
t	°C	-273.15 < t	None	None	None
t_{meas}	°C	$-273.15 < t_{meas}$	t_{meas} is usually assumed to be 20°C		
d	m	0<d	None	None	None
D	m	0<D	None	None	None

C4.5.2 Calculations

C4.5.2.1 Bore Diameter, d, Temperature Correction

The bore diameter temperature correction calculation is:

$$d = \left[1+\alpha_2\left[t-t_{meas}\right]\right]d_{meas}$$

C4.5.2.2 Pipe Diameter, D, Temperature Correction

The pipe diameter temperature correction is:

$$D = \left[1+\alpha_1\left[t-t_{meas}\right]\right]D_{meas}$$

C4.6 Flow Rate Calculation

C4.6.1 Symbol Table

The symbol table for the flow rate calculation is shown below.

Table C-3 Flow Rate Calculation Symbol Table

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain
d_{meas}	m	$0 < d_{meas}$			$d_{meas} < D_{meas}$
D_{meas}	m	$0 < D_{meas}$			None
P_1	Pa	$0 < P_1$	$0 < P_1$	None	None
P_2	Pa	$0 < P_2$	$0.75 P_1 < P_2$	$P_2 < P_1$	None
t	°C	$-273.15 < t$	None	None	None
t_{meas}	°C	$-273.15 < t_{meas}$	None	None	None
α_1	m/m/°C	$0 < \alpha_1$	None	None	None
α_2	m/m/°C	$0 < \alpha_2$	None	None	None
ρ_1	kg/m³	$0 < \rho_1$	None	None	None
C	-	$0 < C$	None	$C \leq 1$	None
d	m	$0 < d$	varies tap type		$d \leq D$
D	m	$0 < D$			None
ΔP	Pa	$0 < \Delta P$	None	None	None
β	-	$0 < \beta$			$\beta < 1$
Y	-	$0 < Y$	None	$Y \leq 1$	None
q_m	kg/s	$0 < q_m$	None	None	None

C4.6.2 Calculations (§3.3)

The actual flow may be found by iteration, since R_D and for some primary elements C depend on the flow, rate q_m.

$$d = \left[1 + \alpha_{PE}\left[t - t_{meas}\right]\right] d_{meas}$$

$$D = \left[1 + \alpha_{P}\left[t - t_{meas}\right]\right] D_{meas}$$

$$\beta = \frac{\mathrm{d}}{\mathrm{D}}$$

$$\Delta P = P_1 - P_2$$

$$q_m = \frac{\pi}{4} C Y d^2 \sqrt{\frac{2 \Delta P \rho}{1 - \beta^4}}$$

C4.7 Permanent Pressure Loss

C4.7.1 Symbol Table

The symbol table for permanent pressure loss is shown below.

Table C-4 Permanent Pressure Loss Symbol Table

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain
C	-	$0 < C$	None	$C \le 1$	None
ΔP	Pa	$0 < \Delta p$	None	None	None
β	-	$0 < \beta$	varies with primary element type		$\beta < 1$
ϕ	°	$0 < \phi$	varies with primary element type		None
$\Delta\varpi$	Pa	$0 < \Delta\varpi$	None	None	None

§

C5 International Standard ISO 5167-1980 (E)

C5.1 Flow Element Applicability

The ISO standard is defined for the following flow measurement elements:

- orifice plates with:
  - flange taps
  - D and D/2 (radius) taps
  - corner taps
- nozzles:
  - ISA 1932 nozzle
  - long radius nozzles, including:
    - high β ratio
    - low β ratio
- venturi tubes:
  - venturi-nozzle
  - classical venturi tubes, including:
    - as-cast convergent section
    - machined convergent section
    - fabricated (welded) convergent section

The standard applies to liquid, vapor, or gas flows which are homogenous (single phase), turbulent, subsonic and steady with time (a slow pulsation can be acceptable).

C5.2 Calculation of Reynolds Numbers

C5.2.1 Symbol Table

The symbol table for the calculation of Reynolds Numbers is shown below.

Table C-1 Calculation of Reynolds Numbers Symbol Table

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain
d	m	$0 < d$	$0 < d$	None	$d < D$
D	m	$0 < D$	$0 < D$	None	None
U_1	m/s	$0 \leq U_1$	$0 \leq U_1$	None	None
ν_1	m^2/s	$0 < \nu_1$	$0 < \nu_1$	None	None
R_d	-	$0 < R_d$	$0 < R_d$	None	None
R_D	-	$0 < R_D$	$0 < R_D$	None	None
β	-	$0 < \beta$	$0 < \beta$	$\beta \leq 1$	$\beta \leq 1$

C5.2.2 Reynolds Number Based on the Upstream Condition of the Fluid and the Upstream Diameter of the Pipe (§2.4.2)

The equation for the Reynolds Number based on the upstream condition of the fluid and the upstream diameter of the pipe is:

$$R_D = \frac{U_1 D}{\nu_1}$$

C5.2.3 Reynolds Number Based on the Orifice or Throat Diameter of the Primary Device (§2.4.2)

The equation for the Reynolds Number based on the orifice or throat diameter of the primary device is:

$$\beta = \frac{d}{D}$$

$$R_d = \frac{R_D}{\beta}$$

C5.3 Orifice Plate Discharge Coefficients

C5.3.1 Symbol Table

The symbol table for the orifice plate discharge coefficients is shown below.

Table C-2 Orifice Plate Discharge Coefficients Symbol Table

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain	Ref
β	-	$0 < \beta$	varies with pressure tappings		$\beta < 1$	7.3.1

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain	Ref
R_D	-	$0 < R_D$	varies with pressure tappings		None	7.3.1
k	m	0 < k	None	None	None	
D	m	0 < D	varies with pressure tappings		None	7.3.1
C	-	0 < C	0 < C	C < 1	none	

C5.3.2 Calculations

C5.3.2.1 Base Discharge Coefficients (§7.3.2.1)

The base discharge coefficients calculation is:

$$C = 0.5959 + 0.0312\beta^{2.1} - 0.1840\beta^{8} + 0.0029\beta^{2.5}\left[\frac{10^6}{R_D}\right]^{0.75}$$

$$+ 0.0900L_1\beta^{4}(1-\beta^{4})^{-1} - 0.0337L_2'\beta^{3}$$

Where:

$$L_1 = \frac{l_1}{\mathrm{D}}$$

$$L_2 = \frac{l_2}{\mathrm{D}}$$

$$L_2^{'} = \frac{l_2'}{\mathrm{D}} = \frac{(l_2 - E)}{D}$$

$$If: \quad L_1 \geq 0.4333 \quad then \quad 0.0900L_1 \equiv 0.0390$$

- l_1 - distance of upstream pressure tap from upstream face of orifice plate
- l_2 - distance of downstream pressure tap from downstream face of orifice plate
- E - thickness of orifice plate

The valid tap arrangements are defined in paragraphs 7.2.3.4, 7.2.3.5, or 7.2.4. It is not permitted to use l_1 and l_2 which do not match one of the three standardized tap arrangements.

C5.3.2.2 Corner Taps

C5.3.2.2.1 Limits (§7.3.1)

The corner taps limits are:

- $d \geq 0.0125$
- $0.050 \leq D \leq 1.000$
- $0.23 \leq \beta \leq 0.45$ $0.45 < \beta \leq 0.77$ $0.77 < \beta \leq 0.80$
- $5{,}000 \leq R_D \leq 10^8$ $10{,}000 \leq R_D \leq 10^8$ $20{,}000 \leq R_D \leq 10^8$

The roughness upper limits for the corner taps are shown in the table below.

Table C-3 Corner Taps Roughness Upper Limits

β	$\leq$0.3	0.32	0.34	0.36	0.38	0.4	0.45	0.5	0.6	0.7	0.8
$10^4k/D$	25	18.1	12.9	10.0	8.3	7.1	5.6	4.9	4.2	4.0	3.9

C5.3.2.2.2 Tap Spacing (§7.3.2.1)

The tap spacing calculation is:

$$L_1 = L_2' = 0$$

C5.3.2.3 Flange Taps

C5.3.2.3.1 Limits (§7.3.1)

The flange taps limits are:

- $d \geq 0.0125$
- $0.050 \leq D \leq 0.760$
- $0.2 \leq \beta \leq 0.75$
- $1{,}260\ \beta^2\ D\ 10^3 \leq R_D \leq 10^8$

The roughness upper limits for flange taps are shown in the table below.

Table C-4 Flange Taps Roughness Upper Limits

β	$\leq$0.3	0.32	0.34	0.36	0.38	0.4	0.45	0.5	0.6	0.7	0.8
$10^4k/D$	25	18.1	12.9	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0

C5.3.2.3.2 Tap Spacing, D > 58.62mm (§7.3.2.1)

The tap spacing calculation is:

$$L_1 = L_2' = 0.0254\,D^{-1}$$

C5.3.2.3.3 Tap Spacing, 50.8.. $\leq D \leq 58.62$, (§7.3.2.1)

The tap spacing calculation is:

$$L_1 = 0.4333,\ L_2' = 0.0254\,D^{-1}$$

C5.3.2.4 Radius Taps (D and D/2)

C5.3.2.4.1 Limits (§7.3.1)

The radius taps limits are:

- $d \geq 0.0125$
- $0.050 \leq D \leq 0.760$
- $0.2 \leq \beta \leq 0.75$
- $1{,}260\ \beta^2\ D\ 10^3 \leq R_D \leq 10^8$

The radius taps roughness upper limits are shown below.

Table C-5 Radius Taps Roughness Upper Limits

β	≤ 0.3	0.32	0.34	0.36	0.38	0.4	0.45	0.5	0.6	0.7	0.8
$10^4 k/D$	25	18.1	12.9	10	10	10	10	10	10	10	10

C5.3.2.4.2 Tap Spacing, (§7.3.2.1)

Since $L_1 \geq 0.4333$, $0.0090L_1 \equiv 0.0390$

$L_2 = 0.47$

C5.4 Nozzles

C5.4.1 Symbol Table

The symbol table for nozzles is shown below.

Table C-6 Nozzles Symbol Table

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain
β	-	$0 < \beta$	varies with design	$\beta < 1$	
R_D	-	$0 < R_D$	varies with design	None	
k	m	$0 < k$	None	None	None
D	m	0 < D	varies with design	None	
C	-	0 < C	None	C < 1	None

C5.4.2 Calculations

C5.4.2.1 ISA 1932 Nozzle

C5.4.2.1.1 Limits (§8.1.6.1)

The ISA 1932 nozzle limits are:

- $0.050 \le D \le 0.500$
- $0.3 \le \beta < 0.44$ $0.44 \le \beta \le 0.80$
- $70{,}000 \le Re_D \le 10^7$ $20{,}000 \le Re_D \le 10^7$

The roughness upper limits are listed in the table below.

Table C-7 ISA 1932 Nozzle Roughness Upper Limits

β	≤0.35	0.36	0.38	0.40	0.42	0.44	0.46	0.48	0.50	0.60	0.70	0.77	0.80
$10^4k/D$	25	18.6	13.5	10.6	8.7	7.5	6.7	6.1	5.6	4.5	4.0	3.9	3.9

C5.4.2.1.2 Discharge Coefficients (§8.1.6.2)

The discharge coefficients calculation is:

$$C = 0.9900 - 0.2262\beta^{4.1} + \left[0.000215 - 0.001125\beta + 0.002490\beta^{4.7}\right]\left[\frac{10^6}{R_D}\right]^{1.15}$$

C5.4.2.2 Long-Radius Nozzles (§8.2)

C5.4.2.2.1 Limits (§8.2.5.1)

The long radius nozzle limits are:

- $0.050 \le D \le 0.630$
- $0.2 \le \beta \le 0.8$
- $10^4 \le R_D \le 10^7$
- $k/D \le 10 \times 10^{-4}$
  - high ratio nozzles, $0.25 \le \beta \le 0.8$ and, (§8.2)
  - low ratio nozzles, $0.20 \le \beta \le 0.5$ (§8.2)

C5.4.2.2.2 Discharge Coefficients (§8.2.5.2)

The discharge coefficients calculation is:

$$C = 0.9965 - 0.00653\beta^{0.5}\left[\frac{10^6}{R_D}\right]^{0.5}$$

C5.5 Classical Venturi Tubes and Venturi Nozzles

C5.5.1 Symbol Table

The symbol table for classical Venturi tubes and Venturi nozzles is shown below.

Table C-8 Classical Venturi Tubes and Venturi Nozzles Symbol Table

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain
β	-	$0 < \beta$	varies with design		$\beta < 1$
R_D	-	$0 < R_D$	varies with design		None
D	m	0 < D	varies with design		None
C	-	0 < C		$C \leq 1$	

The standard applies to 3 types of venturi tubes (§9.1) and Venturi nozzle (§9.2):

1. Classical Venturi with an as-cast convergent
2. Classical Venturi with a machined convergent
3. Classical Venturi with a fabricated (welded) convergent

C5.5.2 Calculations

C5.5.2.1 Classical Venturi Tube With an As-Cast or Fabricated Convergent (§9.1.5.2)

C5.5.2.1.1 Limits

The limits for the classical venturi tube with an as-cast or fabricated convergent are:

- $0.100 \leq D \leq 0.800$
- $0.3 \leq \beta \leq 0.75$
- $2 \times 10^5 \leq R_D \leq 2 \times 10^6$

C5.5.2.1.2 Discharge Coefficient

The discharge coefficient is:

C = 0.984

C5.5.2.2 Classical Venturi Tubes With a Machined Convergent (§9.1.5.3)

C5.5.2.2.1 Limits

The limits for the classical venturi tubes with a machined convergent are:

- $0.050 \leq D \leq 0.250$
- $0.4 \leq \beta \leq 0.75$
- $2 \times 10^5 \leq R_D \leq 1 \times 10^6$

C5.5.2.2.2 Discharge Coefficient

The discharge coefficient is:

$C = 0.995$

C5.5.2.3 Classical Venturi Tubes with a Fabricated (welded) Convergent (§9.1.5.4)

C5.5.2.3.1 Limits

The limits for the classical venturi tubes with a fabricated (welded) convergent are:

- $0.200 \leq D \leq 1.200$
- $0.4 \leq \beta \leq 0.7$
- $2 \times 10^5 \leq R_D \leq 2 \times 10^6$

C5.5.2.3.2 Discharge Coefficient

The discharge coefficient is:

$C = 0.985$

C5.5.2.4 Classical Venturi Nozzles

C5.5.2.4.1 Limits (§9.2.4.1)

The limits for the classical venturi nozzle are:

- $0.065 \leq D \leq 0.500$
- $d \geq 0.050$
- $0.316 \leq \beta \leq 0.775$
- $1.5 \times 10^5 \leq R_D \leq 2 \times 10^6$

C5.5.2.4.2 Discharge Coefficient (§9.2.4.2)

The discharge coefficient is:

$$C = 0.9858 - 0.196\beta^{4.5}$$

C5.6 Orifice Plates Expansion Factors

C5.6.1 Symbol Table

The symbol table for orifice plates expansion factors is shown below.

Table C-9 Orifice Plates Expansion Factors Symbol Table

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain	Ref.
β	-	$0 < \beta$	varies with pressure tapping		$\beta < 1$	§7.3.1
κ	-	$0 < \kappa$	None	None	None	
P_1	Pa	$0 < P_1$	$0 < P_1$	None	None	
P_2	Pa	$0 < P_2$	$0.75 P_1 < P_2$	$P_2 < P_1$	None	§5.3.3
ΔP	Pa	$0 \leq \Delta P$	$0 \leq \Delta P$	None	None	
Y	-	$0 < Y$	None	$Y \leq 1$	None	

C5.6.2 Calculations

C5.6.2.1 Gas Expansion Factor (§7.3.2.2)

The gas expansion factor calculations are:

$$\frac{P_2}{P_1} \geq 0.75$$

$$\Delta P = P_1 - P_2$$

$$Y_1 = 1 - (0.41 + 0.35\beta^4)\frac{\Delta P}{\kappa P_1}$$

C5.6.3 Gas Expansion Factor based on Downstream Conditions (ISO 5167 (1991) p.23)

The calculation for the gas expansion factor based on downstream conditions is:

$$Y_2 = Y_1\sqrt{1 + \frac{\Delta p}{p_2}}$$

Gas expansion factors based on downstream conditions are not specified in ISO 5167 (1980). However, ISO 5167 (1991) does support downstream conditions and will be implemented in ISO 5167 (1980).

C5.6.3.1 Liquid Expansion Factor (§2.4.7)

The liquid expansion factor is:

$$Y = 1$$

C5.7 Nozzles Expansion Factors

C5.7.1 Symbol Table

The symbol table for the nozzle expansion factors is shown below.

Table C-10 Nozzles Expansion Factors Symbol Table

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain	Ref
β	-	$0 < \beta$	varies with design		$\beta < 1$	
κ	-	$0 < \kappa$	None	None	None	
P_1	Pa	$0 < P_1$	$0 < P_1$	None	None	
P_2	Pa	$0 < P_2$	$0.75\ P_1 < P_2$	$P_2 < P_1$	None	§5.3.3
ΔP	Pa	$0 \le \Delta P$	$0 \le \Delta P$	None	None	
τ		$0 < \tau$	$0.75 \le \tau$	None	$\tau < 1$	
Y	-	$0 < Y$	None	$Y \le 1$	None	§2.4.7

C5.7.2 Calculations

C5.7.2.1 ISA 1932 Nozzle

C5.7.2.1.1 Gas Expansion Factor (§8.1.6.3)

The calculations for the gas expansion factors are:

$$\tau = \frac{p_2}{p_1}, \qquad \tau \ge 0.75$$

$$Y = \left[\left[\frac{\kappa \tau^{\frac{2}{\kappa}}}{\kappa - 1} \right] \left[\frac{1 - \beta^4}{1 - \beta^4 \tau^{\frac{2}{k}}} \right] \left[\frac{1 - \tau^{\frac{\kappa - 1}{\kappa}}}{1 - \tau} \right] \right]^{\frac{1}{2}}$$

C5.7.2.1.2 Liquid Expansion Factor (§2.4.7)

The liquid expansion factor is:

Y = 1

C5.7.2.2 Long Radius Nozzles

C5.7.2.2.1 Gas Expansion Factor (§8.2.5.3)

The long radium nozzles gas expansion factor calculations are:

$$\tau = \frac{p_2}{p_1}, \qquad \tau \geq 0.75$$

$$Y = \left[\left[\frac{\kappa \tau^{\frac{2}{\kappa}}}{\kappa - 1} \right] \left[\frac{1 - \beta^4}{1 - \beta^4 \tau^{\frac{2}{k}}} \right] \left[\frac{1 - \tau^{\frac{\kappa - 1}{\kappa}}}{1 - \tau} \right] \right]^{\frac{1}{2}}$$

C5.8 Classical Venturi Tubes and Venturi Nozzles Expansion Factor

C5.8.1 Symbol Table

The symbol table for the classical venturi tubes and venturi nozzles expansion factor is shown below.

Table C-11 Classical Venturi Tubes/Nozzles Expansion Factor Symbol Table

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain	Ref.
β	-	$0 < \beta$	varies with design		$\beta < 1$	
κ	-	$0 < \kappa$	None	None	None	
p_1	Pa	$0 < p_1$	$0 < p_1$	None	None	
p_2	Pa	$0 < p_2$	$0.75\ p_1 < p_2$	$p_2 < p_1$	None	§5.3.3
Δp	Pa	$0 \leq \Delta p$	$0 \leq \Delta p$	None	None	
τ		$0 < \tau$	None	None	$\tau < 1$	
Y	-	$0 < Y$	None	$Y \leq 1$	None	

C5.8.2 Calculations

C5.8.2.1 Classical Venturi Tube

C5.8.2.1.1 Gas Expansion Factor (§9.1.6)

The gas expansion factor calculations are:

$$\tau = \frac{p_2}{p_1}, \qquad \tau \geq 0.75$$

$$Y = \left[\left[\frac{\kappa \tau^{\frac{2}{\kappa}}}{\kappa - 1} \right] \left[\frac{1 - \beta^4}{1 - \beta^4 \tau^{\frac{2}{k}}} \right] \left[\frac{1 - \tau^{\frac{\kappa - 1}{\kappa}}}{1 - \tau} \right] \right]^{\frac{1}{2}}$$

C5.8.2.2 Venturi Nozzle

C5.8.2.2.1 Gas Expansion Factor (§9.1.6)

The gas expansion factor calculation is:

$$\tau = \frac{p_2}{p_1}, \qquad \tau \geq 0.75$$

$$Y = \left[\left[\frac{\kappa \tau^{\frac{2}{\kappa}}}{\kappa - 1} \right] \left[\frac{1 - \beta^4}{1 - \beta^4 \tau^{\frac{2}{k}}} \right] \left[\frac{1 - \tau^{\frac{\kappa - 1}{\kappa}}}{1 - \tau} \right] \right]^{\frac{1}{2}}$$

C5.9 Thermal Expansion Correction

ISO 5167 requires temperature compensation to be applied to d and D, but does not provide a method to do so, therefore, the correction stated in ASME MFC-3M-1989 will be applied.

C5.9.1 Symbol Table

The symbol table for thermal expansion correction is shown below.

Table C-12 Thermal Expansion Correction Symbol Table

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain
d_{meas}	m	$0< d_{meas}$	None	None	$d_{meas} \leq D_{meas}$
D_{meas}	m	$0< D_{meas}$	None	None	None
α_{PE}	m/m/°C	$0 < \alpha_{PE}$	None	None	None
α_{P}	m/m/°C	$0 < \alpha_{P}$	None	None	None
t	°C	$-273.15 < t$	None	None	None
t_{meas}	°C	$-273.15 < t_{meas}$	t_{meas} is usually assumed to be 20°C		
d	m	0<d	None	None	None
D	m	0<D	None	None	None

C5.9.2 Calculations

C5.9.2.1 Bore Diameter, d, Temperature Correction

The bore diameter temperature correction calculation is:

$$d = \left[1 + \alpha_{PE}\left[t - t_{meas}\right]\right] d_{meas}$$ (ASME MFC-3M-1989 eq. 19a, p. 12)

C5.9.2.2 Pipe Diameter, D, Temperature Correction

The pipe diameter temperature correction is:

$$D = \left[1 + \alpha_{P}\left[t - t_{meas}\right]\right] D_{meas}$$ (ASME MFC-3M-1989 eq. 19b, p. 12)

C5.10 Flow Rate Calculation

C5.10.1 Symbol Table

The symbol table for the flow rate calculation is shown below.

Table C-13 Flow Rate Calculation Symbol Table

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain
d_{meas}	m	$0 < d_{meas}$	varies with primary element type		$d_{meas} < D_{meas}$
D_{meas}	m	$0 < D_{meas}$	varies with primary element type		None
P_1	Pa	$0 < P_1$	$0 < P_1$	None	None
P_2	Pa	$0 < P_2$	$0.75\ P_1 < P_2$	$P_2 < P_1$	None
t	°C	$-273.15 < t$	None	None	None
t_{meas}	°C	$-273.15 < t_{meas}$	None	None	None
α_P	m/m/°C	$0 < \alpha_P$	None	None	None
α_{PE}	m/m/°C	$0 < \alpha_{PE}$	None	None	None
ρ_1	kg/m^3	$0 < \rho_1$	None	None	None
C	-	$0 < C$	None	$C \leq 1$	None
d	m	$0 < d$	varies with primary element type		$d \leq D$
D	m	$0 < D$	varies with primary element type		None
ΔP	Pa	$0 < \Delta P$	None	None	None
β	-	$0 < \beta$	varies with primary element type		$\beta < 1$
Y	-	$0 < Y$	None	$Y \leq 1$	None
q_m	kg/s	$0 < q_m$	None	None	None

C5.10.2 Calculations (§3.3)

The actual flow may be found by iteration, since R_D and for some primary elements C depend on the flow, rate qm.

$$d = \left[1 + \alpha_{PE}\left[t - t_{meas}\right]\right] d_{meas}$$ (ASME MFC-3M-1989 eq. 19a, p. 12)

$$D = \left[1 + \alpha_{P}\left[t - t_{meas}\right]\right] D_{meas}$$ (ASME MFC-3M-1989 eq. 19b, p. 12)

$$\beta = \frac{\mathrm{d}}{\mathrm{D}}$$

$$\Delta P = P_1 - P_2$$

The above values of d, D, and β should be used to calculate C and Ỹ.

$$q_m = \frac{\pi}{4} C\, Y_1\, D^2 \beta^2 \sqrt{\frac{2\, \Delta P\, \rho_1}{1 - \beta^4}} \quad \text{or} \quad q_m = \frac{\pi}{4} C\, Y_2\, D^2 \beta^2 \sqrt{\frac{2\, \Delta P\, \rho_1}{1 - \beta^4}}$$

C5.11 Permanent Pressure Loss

C5.11.1 Symbol Table

The symbol table for permanent pressure loss is shown below.

Table C-14 Permanent Pressure Loss Symbol Table

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain
C	-	$0 < C$	None	$C \leq 1$	None
ΔP	Pa	$0 < \Delta p$	None	None	None
β	-	$0 < \beta$	varies with primary element type		$\beta < 1$
ϕ	°	$0 < \phi$	varies with primary element type		None
$\Delta\varpi$	Pa	$0 < \Delta\varpi$	None	None	None

C5.11.2 Calculations

C5.11.2.1 Orifice Plates (§7.4)

The orifice plate calculation is:

$$\Delta\varpi \approx \Delta P \left(\frac{\sqrt{1 - \beta^4} - C\beta^2}{\sqrt{1 - \beta^4} + C\beta^2} \right)$$

The above equation may generate negative permanent pressure loss. If the calculated $\Delta\varpi$ is too low, the following equation will be used:

$$\Delta\varpi \approx \Delta P \left(1-\beta^{1.9}\right)$$

C5.11.2.2 Nozzles

C5.11.2.2.1 ISA 1932 Nozzle (§8.1.8)

The ISA 1932 nozzle calculation is:

$$\Delta\varpi \approx \Delta P \left(\frac{\sqrt{1-\beta^4} - C\beta^2}{\sqrt{1-\beta^4} + C\beta^2}\right)$$

C5.11.2.2.2 Long Radius Nozzle (§8.2.7)

The long radius nozzle calculation is:

$$\Delta\varpi \approx \Delta P \left(\frac{\sqrt{1-\beta^4} - C\beta^2}{\sqrt{1-\beta^4} + C\beta^2}\right)$$

C5.11.2.3 Classical Venturi Tubes and Venturi Nozzles

C5.11.2.3.1 Classical Venturi Tubes (§9.1.9.2)

ISO 5167 provides graphs of pressure loss for guidance only. The ASME MFC-3M-1989 methods will be used to calculate the pressure loss.

For the divergent angle, $\phi = 15°$:

$\zeta = 0.436 - 0.86\,\beta + 0.59\,\beta^2$ (ASME MFC-3M-1989, p.42)

For the divergent angle, $\phi = 7°$:

$\zeta = 0.218 - 0.42\,\beta + 0.38\,\beta^2$ (ASME MFC-3M-1989, p.42)

For a divergent angle, $7° \le \phi \le 15°$, assume that linear interpolation will provide an accurate pressure loss value.

$$\zeta_\phi = \zeta_7 + \left(\zeta_{15} - \zeta_7\right)\left(\frac{\phi - 7°}{15° - 7°}\right)$$

$\Delta\varpi = \zeta\,\Delta p$ (ASME MFC-3M-1989, p.42)

C5.11.2.3.2 Venturi Nozzles (§9.2.6)

Although §9.2.1.3 allows the divergent angle to be as large as 30°, the permanent pressure loss calculation will use a maximum of 15° as limited in §9.2.6.

ISO 5167 provides graphs of pressure loss for guidance only. The ASME MFC-3M-1989 methods will be used to calculate the pressure loss.

For the divergent angle, ϕ = 15°:

$\zeta = 0.436 - 0.86\ \beta + 0.59\ \beta^2$ (ASME MFC-3M-1989, p.42)

For the divergent angle, ϕ = 7°:

$\zeta = 0.218 - 0.42\ \beta + 0.38\ \beta^2$ (ASME MFC-3M-1989, p.42)

For a divergent angle, $7° \le \phi \le 15°$, assume that linear interpolation will provide an accurate pressure loss value.

$$\zeta_\phi = \zeta_7 + \left(\zeta_{15} - \zeta_7\right)\left(\frac{\phi - 7°}{15° - 7°}\right)$$

$\Delta\varpi = \zeta\,\Delta p$ (ASME MFC-3M-1989, p.42)

C5.12 Uncertainties

This section intentionally left blank.

§

C6 International Standard ISO 5167-1-1991 (E)

C6.1 Flow Element Applicability

The ISO standard is defined for the following flow measurement elements:

- orifice plates with:
  - flange taps
  - D and D/2 (radius) taps
  - corner taps
- nozzles:
  - ISA 1932 nozzle
  - long radius nozzles, including:
    - high β ratio nozzles
    - low β ratio nozzles
- venturi tubes:
  - venturi-nozzle
  - classical venturi tubes, including:
    - as-cast convergent section
    - machined convergent section
    - fabricated (welded) convergent section

The standard applies to liquid, vapor, or gas flows which are homogenous (single phase), turbulent, subsonic and steady with time (a slow pulsation can be acceptable).

C6.2 Calculation of Reynolds Numbers

C6.2.1 Symbol Table

The symbol table for the calculation of Reynolds Numbers is shown below.

Table C-1 Calculation of Reynolds Numbers Symbol Table

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain
d	m	0 < d	0 < d	None	d < D
D	m	0 < D	0 < D	None	None

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain
U_1	m/s	$0 \leq U_1$	$0 \leq U_1$	None	None
ν_1	m^2/s	$0 < \nu_1$	$0 < \nu_1$	None	None
R_d	-	$0 < R_d$	$0 < R_d$	None	None
R_D	-	$0 < R_D$	$0 < R_D$	None	None
β	-	$0 < \beta$	$0 < \beta$	$\beta \leq 1$	$\beta \leq 1$
μ_1	kg/m-sec	$0 < \mu$	$0 < \mu$	None	None

C6.2.2 Reynolds Number Based on the Upstream Condition of the Fluid and the Upstream Diameter of the Pipe (§3.3.2)

The calculation for the Reynolds Number based on the upstream condition of the fluid and the upstream diameter of the pipe is:

$$\mathrm{Re}_D = \frac{U_1 D}{\nu_1} = \frac{4q_m}{\pi \mu_1 D}$$

C6.2.3 Reynolds Number Based on the Orifice or Throat Diameter of the Primary Device (§3.3.2)

The calculation for the Reynolds Number based on the orifice or throat diameter of the primary device is:

$$\beta = \frac{d}{D}$$

$$R_d = \frac{R_D}{\beta}$$

C6.3 Orifice Plate Discharge Coefficients

C6.3.1 Symbol Table

The symbol table for the orifice plate discharge coefficients is shown below.

Table C-2 Orifice Plate Discharge Coefficients Symbol Table

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain	Ref
β	-	$0 < \beta$	varies with pressure tappings		$\beta < 1$	§8.3.1
R_D	-	$0 < R_D$	varies with pressure tappings		None	§8.3.1
k	m	$0 < k$	None	None	None	

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain	Ref
D	m	0 < D	varies with pressure tappings		None	§8.3.1
C	-	0 < C	0 < C	C < 1	None	

C6.3.2 Calculations

C6.3.2.1 Base Discharge Coefficients (§8.3.2.1)

The calculation for base discharge coefficients is:

$$C = 0.5959 + 0.0312\beta^{2.1} - 0.1840\beta^{8} + 0.0029\beta^{2.5}\left[\frac{10^6}{\mathrm{Re}_D}\right]^{0.75}$$
$$+\ 0.0900L_1\beta^4(1-\beta^4)^{-1} - 0.0337L_2'\beta^3$$

Where:

$$L_1 = \frac{l_1}{D}$$

$$L_2' = \frac{l_2'}{D}$$

$$If: \quad L_1 \geq 0.4333 \quad \text{then } 0.0900L_1 \equiv 0.0390$$

- l_1 - distance of upstream pressure tap from upstream face of orifice plate
- l_2 - distance of downstream pressure tap from downstream face of orifice plate
- E - thickness of orifice plate

The valid tap arrangements are defined in paragraphs 8.2. It is not permitted to enter into equation pairs of values L_1 and L'_2 which do not match one of the three standardized tap arrangements.

C6.3.2.2 Corner Taps

C6.3.2.2.1 Limits (§8.3.1)

The corner taps limits are:

- $d \geq 0.0125$
- $0.050 \leq D \leq 1.0$
- $0.2 \leq \beta \leq 0.45$ $\beta > 0.45$
- $R_D \geq 5000$ $R_D \geq 10{,}000$

The roughness upper limits for the corner taps are shown below.

Table C-3 Corner Tap Roughness Upper Limits

β	≤0.3	0.32	0.34	0.36	0.38	0.4	0.45	0.5	0.6	0.75
10^4k/D	25	18.1	12.9	10.0	8.3	7.1	5.6	4.9	4.2	4.0

C6.3.2.2.2 Tap Spacing (§8.3.2.1)

The tap spacing calculation is:

$L_1 = L'_2 = 0$

C6.3.2.3 Flange Taps

C6.3.2.3.1 Limits (§8.3.1)

The flange tap limits are:

- $d \geq 0.0125$
- $0.050 \leq D \leq 1.000$
- $0.2 \leq \beta \leq 0.75$
- $R_D \geq 1260\beta^2 Dx10^3$

The roughness upper limits for the flange taps are shown below.

Table C-4 Flange Taps Roughness Upper Limits

β	≤0.3	0.32	0.34	0.36	0.38	0.4	0.45	0.5	0.6	0.75
10^4k/D	25	18.1	12.9	10.0	8.3	7.1	5.6	4.9	4.2	4.0

C6.3.2.3.2 Tap Spacing, D > 58.62mm (§8.3.2.1)

The tap spacing calculation is:

$L_1 = L'_2 = 0.0254D\text{-}1$

C6.3.2.3.3 Tap Spacing, 50.8mm ≤ D ≤ 58.62mm (§8.3.2.1)

The tap spacing calculations are:

$L_1 = 0.4333$

$L'_2 = 0.0254D\text{-}1$

C6.3.2.4 Radius Taps (D and D/2)

C6.3.2.4.1 Limits (§8.3.1)

The radius taps limits are:

- $d \geq 0.0125$

- $0.050 \le D \le 1.000$
- $0.2 \le \beta \le 0.75$
- $R_D \ge 1260\beta^2 D$

Note: D is in mm.

The roughness upper limits for the radius taps are shown below.

Table C-5 Radius Taps Roughness Upper Limits

β	≤ 0.3	0.32	0.34	0.36	0.38	0.4	0.45	0.5	0.6	0.75
$10^4 k/D$	25	18.1	12.9	10.0	8.3	7.1	5.6	4.9	4.2	4.0

C6.3.2.4.2 *Tap Spacing (§8.3.2.1)*

The tap spacing is:

Since $L_1 \ge 0.4333$, $0.0090L_1 \equiv 0.0390$

$L'_2 = 0.47$

C6.4 *Nozzles*

C6.4.1 *Symbol Table*

The symbol table for nozzles is shown below.

Table C-6 Nozzles Symbol Table

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain
β	-	$0 < \beta$	varies with design		$\beta < 1$
Re_D	-	$0 < R_D$	varies with design		None
k	m	$0 < k$	None	None	None
D	m	$0 < D$	varies with design		None
C	-	$0 < C$	None	$C < 1$	None

C6.4.2 *Calculations*

C6.4.2.1 ISA 1932 Nozzle

C6.4.2.1.1 *Limits (§9.1.6.1)*

The ISA 1932 nozzle limits are:

- $0.050 \le D \le 0.500$

- $0.3 \leq \beta < 0.44$ $0.44 \leq \beta \leq 0.80$
- $70{,}000 \leq R_D \leq 10^7$ $20{,}000 \leq R_D \leq 10^7$

The roughness upper limits for the ISA 1932 nozzle are shown in the table below.

Table C-7 ISA 1932 Nozzle Roughness Upper Limits

β	≤0.35	0.36	0.38	0.40	0.42	0.44	0.46	0.48	0.50	0.60	0.70	0.77	0.80
10^4 k/D	25	18.6	13.5	10.6	8.7	7.5	6.7	6.1	5.6	4.5	4.0	3.9	3.9

C6.4.2.1.2 Discharge Coefficients (§9.1.6.2)

The discharge coefficient calculation is:

$$C = 0.9900 - 0.2262\beta^{4.1} - \left[0.00175\beta^{2} - 0.0033\beta^{4.15}\right]\left[\frac{10^6}{\mathrm{Re}_D}\right]^{1.15}$$

C6.4.2.1.3 Expansibility (§9.1.6.3)

The expansibility calculation is:

$$\varepsilon_1 = \left[\left(\frac{\kappa\tau^{2/\kappa}}{\kappa-1}\right)\left(\frac{1-\beta^4}{1-\beta^4\tau^{2/\kappa}}\right)\left(\frac{1-\tau^{(\kappa-1)/\kappa}}{1-\tau}\right)\right]^{1/2}$$

(for $p_2/p_1 \geq 0.75$)

C6.4.2.2 Long-Radius Nozzles

The long radius nozzles include:

- high ratio nozzles, $0.25 \leq \beta \leq 0.8$, and (§9.2.1)
- low ratio nozzles, $0.20 \leq \beta \leq 0.5$ (§9.2.1)

C6.4.2.2.1 Limits (§9.2.6.1)

The long radium nozzle limits are:

- $0.050 \leq D \leq 0.630$
- $0.2 \leq \beta \leq 0.8$
- $10^4 \leq R_D \leq 10^7$
- $k/D \leq 10 \times 10^{-4}$

C6.4.2.2.2 *Discharge Coefficients (§9.2.6.2)*

The discharge coefficients calculation is:

$$C = 0.9965 - 0.00653\beta^{0.5}\left[\frac{10^6}{R_D}\right]^{0.5}$$ (for upstream Reynolds Number)

or

$$C = 0.9965 - 0.00653\left[\frac{10^6}{R_d}\right]^{0.5}$$ (for throat R_d)

C6.5 Venturi Tubes and Venturi Nozzles

C6.5.1 Symbol Table

The symbol table for venturi tubes and venturi nozzles is shown below.

Table C-8 Venturi Tubes/Nozzles Symbol Table

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain
β	-	$0 < \beta$	varies with design		$\beta < 1$
Re_D	-	$0 < Re_D$	varies with design		None
D	m	0 < D	varies with design		None
C	-	C > 0	None	$C \leq 1$	None

The standard applies to 3 types of venturi tubes (§10.1) and Venturi Nozzle (§10.2):

1. Venturi with an as-cast convergent,
2. Venturi with a machined convergent, and
3. Venturi with a fabricated (welded) sheet-iron convergent.

C6.5.2 Calculations

C6.5.2.1 Classical Venturi Tube With an As-Cast Convergent (§10.1.5.2)

C6.5.2.1.1 *Limits*

The limits for the classical venturi tube with an as-cast convergent are:

- $0.100 \leq D \leq 0.800$
- $0.3 \leq \beta \leq 0.75$
- $2 \times 10^5 \leq R_D \leq 2 \times 10^6$

C6.5.2.1.2 *Discharge Coefficient*

The discharge coefficient is:

$C = 0.984$

C6.5.2.2 Classical Venturi Tubes With a Machined Convergent (§10.1.5.3)

C6.5.2.2.1 *Limits*

The limits for the classical venturi tube with a machined convergent are:

- $0.050 \leq D \leq 0.250$
- $0.4 \leq \beta \leq 0.75$
- $2 \times 10^5 \leq R_D \leq 1 \times 10^6$

C6.5.2.2.2 *Discharge Coefficient*

The discharge coefficient is:

$C = 0.995$

C6.5.2.3 Classical Venturi Tubes With a Rough Welded Convergent (§10.1.5.4)

C6.5.2.3.1 *Limits*

The limits for the classical venturi tube with a rough welded convergent are:

- $0.200 \leq D \leq 1.200$
- $0.4 \leq \beta \leq 0.7$
- $2 \times 10^5 \leq Re_D \leq 2 \times 10^6$

C6.5.2.3.2 *Discharge Coefficient*

The discharge coefficient is:

$C = 0.985$

C6.5.2.4 Venturi Nozzle

C6.5.2.4.1 *Limits (§10.2.4.1)*

The limits for the venturi nozzle are:

- $0.065 \leq D \leq 0.500$
- $d \leq 0.050$
- $0.316 \leq \beta \leq 0.775$
- $1.5 \times 10^5 \leq R_D \leq 2 \times 10^6$

C6.5.2.4.2 Discharge Coefficient (§10.2.4.2)

The discharge coefficient is:

$$C = 0.9858 - 0.196\beta^{4.5}$$

C6.6 Orifice Plate Expansion Factors

C6.6.1 Symbol Table

The symbol table for orifice plate expansion factors is shown below.

Table C-9 Orifice Plate Expansion Factors Symbol Table

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain	Ref.
β	-	$0 < \beta$	varies with design		$\beta < 1$	§7.3.1
κ	-	$0 < \kappa$	None	None	None	
p_1	Pa	$0 < p_1$	$0 < p_1$	None	None	§5.3.3
p_2	Pa	$0 < p_2$	$0.75\ p_1 < p_2$	$p_2 < p_1$	None	§5.3.3
Δp	Pa	$0 \le \Delta p$	$0 \le \Delta p$	None	None	
Y	-	$0 < Y$	None	$Y \le 1$	None	§2.4.7

C6.6.2 Gas Expansion Factor based on Upstream Conditions (§8.3.2.2)

The calculation for gas expansion factors based on upstream conditions is:

$$Y_1 = 1 - (0.41 + 0.35\beta^4)\frac{\Delta p}{\kappa p_1}$$

In addition to other limit conditions, the above equation is only applicable for $p_2/p_1 \ge 0.75$.

This formula is a result of testing on air, steam, and natural gas. There are no known objections to applying it to other gases.

C6.6.3 Gas Expansion Factor based on Downstream Conditions (§8.3.2.2)

The calculation for gas expansion factors based on downstream conditions is:

$$Y_2 = Y_1\sqrt{1 + \frac{\Delta P}{P_2}}$$

C6.6.4 Liquid Expansion Factor (§3.3.5)

The liquid expansion factor is:

Y = 1

C6.7 Nozzles Expansion Factors

C6.7.1 Symbol Table

The symbol table for nozzles expansion factors is shown below.

Table C-10 Nozzles Expansion Factors Symbol Table

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain	Ref
β	-	$0 < \beta$	varies with	design	$\beta < 1$	
κ	-	$0 < \kappa$	None	None	None	
P_1	Pa	$0 < P_1$	$0 < P_1$	None	None	
P_2	Pa	$0 < P_2$	$0.75\ P_1 < P_2$	$P_2 < P_1$	None	
ΔP	Pa	$0 \le \Delta P$	$0 \le \Delta P$	None	None	
τ		$0 < \tau$	$0.75 \le \tau$	None	$\tau < 1$	
Y	-	$0 < Y$	None	$Y \le 1$	None	§2.4.7

C6.7.2 Calculations

C6.7.2.1 ISA 1932 Nozzle

C6.7.2.1.1 Gas Expansion Factor (§8.1.6.3)

The gas expansion factor calculations are:

$$\tau = \frac{p_2}{p_1}, \qquad \tau \ge 0.75$$

$$Y = \left[\left[\frac{\kappa \tau^{\frac{2}{\kappa}}}{\kappa - 1} \right] \left[\frac{1 - \beta^4}{1 - \beta^4 \tau^{\frac{2}{k}}} \right] \left[\frac{1 - \tau^{\frac{\kappa - 1}{\kappa}}}{1 - \tau} \right] \right]^{\frac{1}{2}}$$

C6.7.2.1.2 Liquid Expansion Factor (§2.4.7)

The liquid expansion factor is:

Y = 1

C6.7.2.2 Long Radius Nozzles

C6.7.2.2.1 Gas Expansion Factor (§8.2.5.3)

The gas expansion factor calculations are:

$$\tau = \frac{p_2}{p_1}, \quad \tau \geq 0.75$$

$$Y = \left[\left[\frac{\kappa \tau^{\frac{2}{\kappa}}}{\kappa - 1} \right] \left[\frac{1-\beta^4}{1-\beta^4 \tau^{\frac{2}{k}}} \right] \left[\frac{1-\tau^{\frac{\kappa-1}{\kappa}}}{1-\tau} \right] \right]^{\frac{1}{2}}$$

C6.7.2.2.2 Liquid Expansion Factor (§2.4.7)

The liquid expansion factor is:

Y = 1

C6.8 Classical Venturi Tubes and Venturi Nozzles Expansion Factor

C6.8.1 Symbol Table

The symbol table for the classical venturi tubes and venturi nozzles expansion factor is shown below.

Table C-11 Classical Venturi Tubes/Nozzles Expansion Factor Symbol Table

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain	Ref.
β	-	$0 < \beta$	varies with design		$\beta < 1$	
κ	-	$0 < \kappa$	None	None	None	
p_1	Pa	$0 < p_1$	$0 < p_1$	None	None	
p_2	Pa	$0 < p_2$	$0.75\ p_1 < p_2$	$p_2 < p_1$	None	§5.3.3
Δp	Pa	$0 \leq \Delta p$	$0 \leq \Delta p$	None	None	
τ		$0 < \tau$	None	None	$\tau < 1$	
Y	-	$0 < Y$	None	$Y \leq 1$	None	

C6.8.2 Calculations

C6.8.2.1 Classical Venturi Tube

C6.8.2.1.1 Gas Expansion Factor (§9.1.6)

The gas expansion factor calculations are:

$$\tau = \frac{p_2}{p_1}, \qquad \tau \geq 0.75$$

$$Y = \left[\left[\frac{\kappa \tau^{\frac{2}{\kappa}}}{\kappa - 1} \right] \left[\frac{1 - \beta^4}{1 - \beta^4 \tau^{\frac{2}{k}}} \right] \left[\frac{1 - \tau^{\frac{\kappa - 1}{\kappa}}}{1 - \tau} \right] \right]^{\frac{1}{2}}$$

C6.8.2.1.2 Liquid Expansion Factor (§2.4.7)

The liquid expansion factor is:

Y = 1

C6.8.2.2 Venturi Nozzle

C6.8.2.2.1 Gas Expansion Factor (§9.1.6)

The venturi nozzle gas expansion factor calculations are:

$$\tau = \frac{p_2}{p_1}, \qquad \tau \geq 0.75$$

$$Y = \left[\left[\frac{\kappa \tau^{\frac{2}{\kappa}}}{\kappa - 1} \right] \left[\frac{1 - \beta^4}{1 - \beta^4 \tau^{\frac{2}{k}}} \right] \left[\frac{1 - \tau^{\frac{\kappa - 1}{\kappa}}}{1 - \tau} \right] \right]^{\frac{1}{2}}$$

C6.8.2.2.2 Liquid Expansion Factor (§2.4.7)

The nozzle liquid expansion factor is:

Y = 1

C6.8.3 Uncertainties (§8.3.3)

For all three types of tappings, assume that β, D, C, R_D and k/D are known without error, the relative uncertainty of the value of C is equal to:

0.6%	for	$\beta \leq 0.6$
β%	for	$0.6 < \beta \leq 0.75$

uncertainty in Y_1

$$4\frac{\Delta P}{P_1}$$

C6.9 Thermal Expansion Correction

ISO 5167 requires temperature compensation to be applied to d and D, but does not provide a method to do so. Therefore, the corrections stated in ASME MFC-3M-1989 will be applied.

C6.9.1 Symbol Table

The symbol table for thermal expansion correction is shown below.

Table C-12 Thermal Expansion Correction Symbol Table

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain
d_{meas}	m	$0< d_{meas}$	None	None	$d_{meas} \leq D_{meas}$
D_{meas}	m	$0< D_{meas}$	None	None	None
α_{PE}	m/m/°C	$0 < \alpha_{pE}$	None	None	None
α_p	m/m/°C	$0 < \alpha p$	None	None	None
t	°C	$-273.15 < t$	None	None	None
t_{meas}	°C	$-273.15 < t_{meas}$	t_{meas} is usually assumed to be 20°C		
d	m	0<d	None	None	None
D	m	0<D	None	None	None

C6.9.2 Calculations

C6.9.2.1 Bore Diameter, d, Temperature Correction

The bore diameter temperature correction calculation is:

$$d = \left[1+\alpha_{PE}\left[t-t_{meas}\right]\right]d_{meas}$$ (ASME MFC-3M-1989 eq. 19a, p. 12)

C6.9.2.2 Pipe Diameter, D, Temperature Correction

The pipe diameter temperature correction calculation is:

$$D = \left[1 + \alpha_p \left[t - t_{meas}\right]\right] D_{meas}$$ (ASME MFC-3M-1989 eq. 19b, p. 12)

C6.10 Flow Rate Calculation

C6.10.1 Symbol Table

The symbol table for flow rate calculation is shown below.

Table C-13 Flow Rate Calculation Symbol Table

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain
d_{meas}	m	$0 < d_{meas}$	varies with primary element type		$d_{meas} < D_{meas}$
D_{meas}	m	$0 < D_{meas}$	varies with primary element type		None
P_1	Pa	$0 < P_1$	$0 < P_1$	None	None
P_2	Pa	$0 < P_2$	$0.75\ P_1 < P_2$	$P_2 < P_1$	None
t	°C	$-273.15 < t$	None	None	None
t_{meas}	°C	$-273.15 < t_{meas}$	None	None	None
α_P	m/m/°C	$0 < \alpha_P$	None	None	None
α_{PE}	m/m/°C	$0 < \alpha_{PE}$	None	None	None
ρ_1	kg/m^3	$0 < \rho_1$	None	None	None
C	-	$0 < C$	None	$C \leq 1$	None
d	m	$0 < d$	varies with primary element type		None
D	m	$0 < D$	varies with primary element type		None
ΔP	Pa	$0 < \Delta P$	None	None	None
β	-	$0 < \beta$	varies with primary element		$\beta < 1$
Y	-	$0 < Y$	None	$Y \leq 1$	None
q_m	kg/s	$0 < q_m$	None	None	None

C6.10.2 Calculations (§5.3)

The actual flow is found by iteration, since R_D and for some primary elements C are dependent on the flow rate q_m.

$$q_m = \frac{\pi}{4} C\, Y_1\, d^2 \sqrt{\frac{2\ \Delta P\ \rho_1}{1 - \beta^4}} \quad \text{or} \quad q_m = \frac{\pi}{4} C\, Y_2\, d^2 \sqrt{\frac{2\ \Delta P\ \rho_2}{1 - \beta^4}}$$

Where Y_2 and ρ_2 are referred to the downstream conditions; d and D should use the working condition value or with correction terms.

C6.11 Permanent Pressure Loss

C6.11.1 Symbol Table

The symbol table for permanent pressure loss is shown below.

Table C-14 Permanent Pressure Loss Symbol Table

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain
C	-	$0 < C$	None	$C \leq 1$	None
ΔP	Pa	$0 < \Delta P$	None	None	None
β	-	$0 < \beta$	varies with primary element type		$\beta < 1$
ϕ	°	$0 < \phi$	varies with primary element type		None
$\Delta\omega$	Pa	$0 < \Delta\omega$	None	None	None

C6.11.1.1 Calculations

C6.11.2 Orifice Plate (§8.4.1)

The orifice plate calculation is:

$$\Delta \varpi = \Delta P \left(\frac{\sqrt{1 - \beta^4} - C\beta^2}{\sqrt{1 - \beta^4} + C\beta^2} \right)$$

C6.11.3 Nozzles

C6.11.3.1 ISA 1932 Nozzle (§9.1.8)

The ISA 1932 nozzle calculation is:

$$\Delta \varpi = \Delta P \left(\frac{\sqrt{1 - \beta^4} - C\beta^2}{\sqrt{1 - \beta^4} + C\beta^2} \right)$$

C6.11.3.2 Long Radius Nozzle (§9.2.8)

$$\Delta \varpi = \Delta P \left(\frac{\sqrt{1 - \beta^4} - C\beta^2}{\sqrt{1 - \beta^4} + C\beta^2} \right)$$

C6.11.4 Classical Venturi Tubes and Venturi Nozzles

C6.11.4.1 Classical Venturi Tubes (§10.1.9.2)

ISO 5167 provides graphs of pressure loss for guidance only. The ASME MFC-3M-1989 equations will be used to calculate the pressure loss.

For the divergent angle, $\phi = 15°$:

$\zeta = 0.436 - 0.86\ \beta + 0.59\ \beta^2$ (ASME MFC-3M-1989, p.42)

For the divergent angle, $\phi = 7°$:

$\zeta = 0.218 - 0.42\ \beta + 0.38\ \beta^2$ (ASME MFC-3M-1989, p.42)

For a divergent angle, $7° \le \phi \le 15°$, assume that linear interpolation will provide an accurate pressure loss value.

$$\zeta_\phi = \zeta_7 + \left(\zeta_{15} - \zeta_7\right)\left(\frac{\phi - 7°}{15° - 7°}\right)$$

$\Delta\varpi = \zeta\Delta P$ (ASME MFC-3M-1989, p.42)

C6.11.4.2 Venturi Nozzles (§10.2.6)*

ISO 5167 provides graphs of pressure loss for guidance only. The ASME MFC-3M-1989 equations will be used to calculate the pressure loss.

* Note: although §10.2.1.4 allows the divergent angle to be as large as 30°, the permanent pressure loss calculation will use a maximum of 15° since the equations of ζ are not known to be valid outside this range.

For the divergent angle, $\phi = 15°$:

$\zeta = 0.436 - 0.86\ \beta + 0.59\ \beta^2$

For the divergent angle, $\phi = 7°$:

$\zeta = 0.218 - 0.42\ \beta + 0.38\ \beta^2$

For a divergent angle, $7° \le \phi \le 15°$, assume that linear interpolation will provide an accurate pressure loss value.

$$\zeta_\phi = \zeta_7 + \left(\zeta_{15} - \zeta_7\right)\left(\frac{\phi - 7°}{15° - 7°}\right)$$

$\Delta\varpi = \zeta\Delta P$ (ASME MFC-3M-1989, p.42)

§

C7 International Standard ISO 5167-1-2003 (E)

C7.1 Flow Element Applicability

The ISO standard is defined for the following flow measurement elements:

- orifice plates with:
  - flange taps
  - D and D/2 (radius) taps
  - corner taps
- nozzles:
  - ISA 1932 nozzle
  - long radius nozzles, including:
    - high β ratio nozzles
    - low β ratio nozzles
- venturi tubes:
  - venturi-nozzle
  - classical venturi tubes, including:
    - as-cast convergent section
    - machined convergent section
    - fabricated (welded) convergent section

The standard applies to liquid, vapor, or gas flows which are homogenous (single phase), turbulent, subsonic and steady with time (a slow pulsation can be acceptable).

C7.2 Calculation of Reynolds Numbers

C7.2.1 Symbol Table

The symbol table for the calculation of Reynolds Numbers is shown below.

Table C-1 Calculation of Reynolds Numbers Symbol Table

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain
d	m	0 < d	0 < d	None	d < D
D	m	0 < D	0 < D	None	None

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain
U_1	m/s	$0 \le U_1$	$0 \le U_1$	None	None
ν_1	m^2/s	$0 < \nu_1$	$0 < \nu_1$	None	None
R_d	-	$0 < R_d$	$0 < R_d$	None	None
R_D	-	$0 < R_D$	$0 < R_D$	None	None
β	-	$0 < \beta$	$0 < \beta$	$\beta \le 1$	$\beta \le 1$
μ_1	kg/m-sec	$0 < \mu$	$0 < \mu$	None	None

C7.2.2 Reynolds Number Based on the Upstream Condition of the Fluid and the Upstream Diameter of the Pipe (§3.3.2)

The calculation for the Reynolds Number based on the upstream condition of the fluid and the upstream diameter of the pipe is:

$$\mathrm{Re}_D = \frac{U_1 D}{\nu_1} = \frac{4q_m}{\pi \mu_1 D}$$

C7.2.3 Reynolds Number Based on the Orifice or Throat Diameter of the Primary Device (§3.3.2)

The calculation for the Reynolds Number based on the orifice or throat diameter of the primary device is:

$$\beta = \frac{d}{D}$$

$$R_d = \frac{R_D}{\beta}$$

C7.3 Orifice Plate Discharge Coefficient

C7.3.1 Symbol Table

The symbol table for the orifice plate discharge coefficients is shown below.

Table C-2 Orifice Plate Discharge Coefficients Symbol Table

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain	Ref
β	-	$0 < \beta$	varies with pressure tappings		$\beta < 1$	§8.3.1
R_D	-	$0 < R_D$	varies with pressure tappings		None	§8.3.1
k	m	$0 < k$	None	None	None	

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain	Ref
D	m	0 < D	varies with pressure tappings		None	§8.3.1
C	-	0 < C	0 < C	C < 1	None	

C7.3.2 Calculations

C7.3.2.1 Base Discharge Coefficients (§8.3.2.1)

The calculation for base discharge coefficients is:

$$C = 0.5961 + 0.0261\beta^2 - 0.216\beta^8 + 0.000521\left[\frac{10^6\beta}{\mathrm{Re}_D}\right]^{0.7} + \left(0.0188 + 0.0063A\right)\beta^{3.5}\left(\frac{10^6}{\mathrm{Re}_D}\right)^{0.3}$$

$$+\left(0.043 + 0.080e^{-10L_1} - 0.123e^{-7L_1}\right)\left(1 - 0.11A\right)\frac{\beta^4}{1-\beta^4} - 0.031\left(M_2^{'} - 0.8M_2^{'1.1}\right)\beta^{1.3}$$

Where D<71.12 mm (2.8 in.) the following term is added:

$$+0.011\left(0.075 - \beta\right)\left(2.8 - \frac{D}{25.4}\right)$$

Where:

$$L_1 = \frac{l_1}{D}$$

$$L_2' = \frac{l_2'}{D}$$

$$M_2^{'} = \frac{2L_2^{'}}{1-\beta}$$

$$A = \left(\frac{19{,}000\beta}{\mathrm{Re}_D}\right)^{0.8}$$

Where:

- l_1 - distance of upstream pressure tap from upstream face of orifice plate
- l_2 - distance of downstream pressure tap from downstream face of orifice plate

For corner taps:

$$L_1 = L_2^{'} = 0$$

For D and D/2 taps (radius taps):

$$L_1 = 1$$
$$L_2' = 0.47$$

For flange taps:

$$L_1 = L_2' = \frac{25.4}{D}$$

The valid tap arrangements are defined above. It is not permitted to enter into equation pairs of values L_1 and L'_2 which do not match one of the three standardized tap arrangements.

C7.4 Orifice Plate Expansion Factor

The expansion factor is valid where $p_2/p_1 \geq 0.75$.

$$Y = 1 - \left(0.351 + 0.256\beta^4 + 0.93\beta^8\right)\left[1 - \left(\frac{p_2}{p_1}\right)^{\frac{1}{\kappa}}\right]$$

C7.5 Nozzles

C7.5.1 Symbol Table

The symbol table for nozzles is shown below.

Table C-3 Nozzles Symbol Table

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain
β	-	$0 < \beta$	varies with design		$\beta < 1$
Re_D	-	$0 < R_D$	varies with design		None
k	m	$0 < k$	None	None	None
D	m	$0 < D$	varies with design		None
C	-	$0 < C$	None	$C < 1$	None

C7.5.2 Calculations

C7.5.2.1 ISA 1932 Nozzle

C7.5.2.1.1 *Limits (§9.1.6.1)*

The ISA 1932 nozzle limits are:

- $0.050 \leq D \leq 0.500$
- $0.3 \leq \beta < 0.44$ $0.44 \leq \beta \leq 0.80$
- $70{,}000 \leq R_D \leq 10^7$ $20{,}000 \leq R_D \leq 10^7$

The roughness upper limits for the ISA 1932 nozzle are shown in the table below.

Table C-4 ISA 1932 Nozzle Roughness Upper Limits

β	≤0.35	0.36	0.38	0.40	0.42	0.44	0.46	0.48	0.50	0.60	0.70	0.77	0.80
$10^4 k/D$	25	18.6	13.5	10.6	8.7	7.5	6.7	6.1	5.6	4.5	4.0	3.9	3.9

C7.5.2.1.2 *Discharge Coefficients (§9.1.6.2)*

The discharge coefficient calculation is:

$$C = 0.9900 - 0.2262\beta^{4.1} - \left[0.00175\beta^{2} - 0.0033\beta^{4.15}\right]\left[\frac{10^{6}}{\mathrm{Re}_{D}}\right]^{1.15}$$

C7.5.2.1.3 *Expansibility (§9.1.6.3)*

The expansibility calculation is:

$$\varepsilon_1 = \left[\left(\frac{\kappa\tau^{2/\kappa}}{\kappa-1}\right)\left(\frac{1-\beta^4}{1-\beta^4\tau^{2/\kappa}}\right)\left(\frac{1-\tau^{(\kappa-1)/\kappa}}{1-\tau}\right)\right]^{1/2}$$

(for $p_2/p_1 \geq 0.75$)

C7.5.2.2 Long-Radius Nozzles

The long radius nozzles include:

- high ratio nozzles, $0.25 \leq \beta \leq 0.8$, and (§9.2.1)
- low ratio nozzles, $0.20 \leq \beta \leq 0.5$ (§9.2.1)

C7.5.2.2.1 Limits (§9.2.6.1)

The long radius nozzle limits are:

- $0.050 \le D \le 0.630$
- $0.2 \le \beta \le 0.8$
- $10^4 \le R_D \le 10^7$
- $k/D \le 10 \times 10^{-4}$

C7.5.2.2.2 Discharge Coefficients (§9.2.6.2)

The discharge coefficients calculation is:

$$C = 0.9965 - 0.00653\beta^{0.5}\left[\frac{10^6}{R_D}\right]^{0.5}$$

(for upstream Reynolds Number)

or

$$C = 0.9965 - 0.00653\left[\frac{10^6}{R_d}\right]^{0.5}$$

(for throat R_d)

C7.6 Venturi Tubes and Venturi Nozzles

C7.6.1 Symbol Table

The symbol table for venturi tubes and venturi nozzles is shown below.

Table C-5 Venturi Tubes/Nozzles Symbol Table

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain
β	-	$0 < \beta$	varies with design		$\beta < 1$
Re_D	-	$0 < Re_D$	varies with design		None
D	m	$0 < D$	varies with design		None
C	-	$C > 0$	None	$C \le 1$	None

The standard applies to 3 types of venturi tubes (§10.1) and Venturi Nozzle (§10.2):

1. Venturi with an as-cast convergent
2. Venturi with a machined convergent
3. Venturi with a fabricated (welded) sheet-iron convergent

C7.6.2 Calculations

C7.6.2.1 Classical Venturi Tube With an As-Cast Convergent (§10.1.5.2)

C7.6.2.1.1 Limits

The limits for the classical venturi tube with an as-cast convergent are:

- $0.100 \leq D \leq 0.800$
- $0.3 \leq \beta \leq 0.75$
- $2 \times 10^5 \leq R_D \leq 2 \times 10^6$

C7.6.2.1.2 Discharge Coefficient

The discharge coefficient is:

$C = 0.984$

C7.6.2.2 Classical Venturi Tubes With a Machined Convergent (§10.1.5.3)

C7.6.2.2.1 Limits

The limits for the classical venturi tube with a machined convergent are:

- $0.050 \leq D \leq 0.250$
- $0.4 \leq \beta \leq 0.75$
- $2 \times 10^5 \leq R_D \leq 1 \times 10^6$

C7.6.2.2.2 Discharge Coefficient

The discharge coefficient is:

$C = 0.995$

C7.6.2.3 Classical Venturi Tubes With a Rough Welded Convergent (§10.1.5.4)

C7.6.2.3.1 Limits

The limits for the classical venturi tube with a rough welded convergent are:

- $0.200 \leq D \leq 1.200$
- $0.4 \leq \beta \leq 0.7$
- $2 \times 10^5 \leq Re_D \leq 2 \times 10^6$

C7.6.2.3.2 Discharge Coefficient

The discharge coefficient is:

$C = 0.985$

C7.6.2.4 Venturi Nozzle

C7.6.2.4.1 Limits (§10.2.4.1)

The limits for the venturi nozzle are:

- $0.065 \leq D \leq 0.500$
- $d \leq 0.050$
- $0.316 \leq \beta \leq 0.775$
- $1.5 \times 10^5 \leq R_D \leq 2 \times 10^6$

C7.6.2.4.2 Discharge Coefficient (§10.2.4.2)

The discharge coefficient is:

$$C = 0.9858 - 0.196\beta^{4.5}$$

C7.7 Orifice Plate Expansion Factors

C7.7.1 Symbol Table

The symbol table for orifice plate expansion factors is shown below.

Table C-6 Orifice Plate Expansion Factors Symbol Table

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain	Ref.
β	-	$0 < \beta$	varies with design		$\beta < 1$	§7.3.1
κ	-	$0 < \kappa$	None	None	None	
p_1	Pa	$0 < p_1$	$0 < p_1$	None	None	§5.3.3
p_2	Pa	$0 < p_2$	$0.75\ p_1 < p_2$	$p_2 < p_1$	None	§5.3.3
Δp	Pa	$0 \leq \Delta p$	$0 \leq \Delta p$	None	None	
Y	-	$0 < Y$	None	$Y \leq 1$	None	§2.4.7

C7.7.2 Gas Expansion Factor based on Upstream Conditions (§8.3.2.2)

The calculation for gas expansion factors based on upstream conditions is:

$$Y_1 = 1 - (0.41 + 0.35\beta^4)\frac{\Delta p}{\kappa p_1}$$

In addition to other limit conditions, the above equation is only applicable for $p_2 / p_1 \geq 0.75$.

This formula is a result of testing on air, steam and natural gas. There are no known objections to applying it to other gases.

C7.7.3 Gas Expansion Factor based on Downstream Conditions (§8.3.2.2)

The calculation for gas expansion factors based on downstream conditions is:

$$Y_2 = Y_1\sqrt{1+\frac{\Delta P}{P_2}}$$

C7.7.4 Liquid Expansion Factor (§3.3.5)

The liquid expansion factor is:

$Y = 1$

C7.8 Nozzles Expansion Factors

C7.8.1 Symbol Table

The symbol table for nozzles expansion factors is shown below.

Table C-7 Nozzles Expansion Factors Symbol Table

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain	Ref
β	-	$0 < \beta$	varies with	design	$\beta < 1$	
κ	-	$0 < \kappa$	None	None	None	
P_1	Pa	$0 < P_1$	$0 < P_1$	None	None	
P_2	Pa	$0 < P_2$	$0.75\ P_1 < P_2$	$P_2 < P_1$	None	
ΔP	Pa	$0 \le \Delta P$	$0 \le \Delta P$	None	None	
τ		$0 < \tau$	$0.75 \le \tau$	None	$\tau < 1$	
Y	-	$0 < Y$	None	$Y \le 1$	None	§2.4.7

C7.8.2 Calculations

C7.8.2.1 ISA 1932 Nozzle

C7.8.2.1.1 Gas Expansion Factor (§8.1.6.3)

The gas expansion factor calculations are:

$$\tau = \frac{p_2}{p_1}, \qquad \tau \geq 0.75$$

$$Y = \left[\left[\frac{\kappa \tau^{\frac{2}{\kappa}}}{\kappa - 1} \right] \left[\frac{1 - \beta^4}{1 - \beta^4 \tau^{\frac{2}{k}}} \right] \left[\frac{1 - \tau^{\frac{\kappa - 1}{\kappa}}}{1 - \tau} \right] \right]^{\frac{1}{2}}$$

C7.8.2.1.2 Liquid Expansion Factor (§2.4.7)

The liquid expansion factor is:

Y = 1

C7.8.2.2 Long Radius Nozzles

C7.8.2.2.1 Gas Expansion Factor (§8.2.5.3)

The gas expansion factor calculations are:

$$\tau = \frac{p_2}{p_1}, \qquad \tau \geq 0.75$$

$$Y = \left[\left[\frac{\kappa \tau^{\frac{2}{\kappa}}}{\kappa - 1} \right] \left[\frac{1 - \beta^4}{1 - \beta^4 \tau^{\frac{2}{k}}} \right] \left[\frac{1 - \tau^{\frac{\kappa - 1}{\kappa}}}{1 - \tau} \right] \right]^{\frac{1}{2}}$$

C7.9 Classical Venturi Tubes and Venturi Nozzles Expansion Factor

C7.9.1 Symbol Table

The symbol table for the classical venturi tubes and venturi nozzles expansion factor is shown below.

Table C-8 Classical Venturi Tubes/Nozzles Expansion Factor Symbol Table

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain	Ref.
β	-	$0 < \beta$	varies with design		$\beta < 1$	
κ	-	$0 < \kappa$	None	None	None	
p_1	Pa	$0 < p_1$	$0 < p_1$	None	None	
p_2	Pa	$0 < p_2$	$0.75\ p_1 < p_2$	$p_2 < p_1$	None	§5.3.3
Δp	Pa	$0 \le \Delta p$	$0 \le \Delta p$	None	None	
τ		$0 < \tau$	None	None	$\tau < 1$	
Y	-	$0 < Y$	None	$Y \le 1$	None	

C7.9.2 Calculations

C7.9.2.1 Classical Venturi Tube

C7.9.2.1.1 Gas Expansion Factor (§9.1.6)

The gas expansion factor calculations are:

$$\tau = \frac{p_2}{p_1}, \qquad \tau \ge 0.75$$

$$Y = \left[\left[\frac{\kappa \tau^{\frac{2}{\kappa}}}{\kappa - 1} \right] \left[\frac{1 - \beta^4}{1 - \beta^4 \tau^{\frac{2}{k}}} \right] \left[\frac{1 - \tau^{\frac{\kappa - 1}{\kappa}}}{1 - \tau} \right] \right]^{\frac{1}{2}}$$

C7.9.2.1.2 Liquid Expansion Factor (§2.4.7)

The liquid expansion factor is:

Y = 1

C7.9.2.2 Venturi Nozzle

C7.9.2.2.1 Gas Expansion Factor (§9.1.6)

The venturi nozzle gas expansion factor calculations are:

$$\tau = \frac{p_2}{p_1}, \qquad \tau \ge 0.75$$

$$Y = \left[\left[\frac{\kappa \tau^{\frac{2}{\kappa}}}{\kappa - 1} \right] \left[\frac{1 - \beta^4}{1 - \beta^4 \tau^{\frac{2}{k}}} \right] \left[\frac{1 - \tau^{\frac{\kappa - 1}{\kappa}}}{1 - \tau} \right] \right]^{\frac{1}{2}}$$

C7.9.2.2.2 Liquid Expansion Factor (§2.4.7)

The nozzle liquid expansion factor is:

$Y = 1$

C7.9.3 Uncertainties (§8.3.3)

For all three types of tappings, assume that β, D, C, R_D and k/D are known without error, the relative uncertainty of the value of C is equal to:

0.6%	for	$\beta \leq 0.6$
β%	for	$0.6 < \beta \leq 0.75$

uncertainty in Y_1

$$4 \frac{\Delta P}{P_1}$$

C7.10 Thermal Expansion Correction

ISO 5167 requires temperature compensation to be applied to d and D, but does not provide a method to do so. Therefore, the corrections stated in ASME MFC-3M-1989 will be applied.

C7.10.1 Symbol Table

The symbol table for thermal expansion correction is shown below.

Table C-9 Thermal Expansion Correction Symbol Table

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain
d_{meas}	m	$0 < d_{meas}$	None	None	$d_{meas} \leq D_{meas}$
D_{meas}	m	$0 < D_{meas}$	None	None	None
α_{PE}	m/m/°C	$0 < \alpha_{PE}$	None	None	None
α_p	m/m/°C	$0 < \alpha_p$	None	None	None
t	°C	$-273.15 < t$	None	None	None
t_{meas}	°C	$-273.15 < t_{meas}$	t_{meas} is usually assumed to be 20°C		
d	m	$0<d$	None	None	None
D	m	$0<D$	None	None	None

C7.10.2 Calculations

C7.10.2.1 Bore Diameter, d, Temperature Correction

The bore diameter temperature correction calculation is:

$$d = \left[1 + \alpha_{PE}\left[t - t_{meas}\right]\right] d_{meas}$$ (ASME MFC-3M-1989 eq. 19a, p. 12)

C7.10.2.2 Pipe Diameter, D, Temperature Correction

The pipe diameter temperature correction calculation is:

$$D = \left[1 + \alpha_{p}\left[t - t_{meas}\right]\right] D_{meas}$$ (ASME MFC-3M-1989 eq. 19b, p. 12)

C7.11 Flow Rate Calculation

C7.11.1 Symbol Table

The symbol table for flow rate calculation is shown below.

Table C-10 Flow Rate Calculation Symbol Table

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain
d_{meas}	m	$0 < d_{meas}$	varies with primary element type		$d_{meas} \leq D_{meas}$
D_{meas}	m	$0 < D_{meas}$	varies with primary element type		None
P_1	Pa	$0 < P_1$	$0 < P_1$	None	None
P_2	Pa	$0 < P_2$	$0.75\ P_1 < P_2$	$P_2 < P_1$	None
t	°C	$-273.15 < t$	None	None	None
t_{meas}	°C	$-273.15 < t_{meas}$	None	None	None
α_P	m/m/°C	$0 < \alpha_P$	None	None	None
α_{PE}	m/m/°C	$0 < \alpha_{PE}$	None	None	None
ρ_1	kg/m^3	$0 < \rho_1$	None	None	None
C	-	$0 < C$	None	$C \leq 1$	None
d	m	$0 < d$	varies with primary element type		None
D	m	$0 < D$	varies with primary element type		None
ΔP	Pa	$0 < \Delta P$	None	None	None
β	-	$0 < \beta$	varies with primary element		$\beta < 1$
Y	-	$0 < Y$	None	$Y \leq 1$	None
q_m	kg/s	$0 < q_m$	None	None	None

C7.11.2 Calculations (§5.3)

The actual flow is found by iteration, since R_D and for some primary elements C are dependent on the flow rate q_m.

$$q_m = \frac{\pi}{4} C Y_1 d^2 \sqrt{\frac{2 \Delta P \rho_1}{1 - \beta^4}}$$

or

$$q_m = \frac{\pi}{4} C Y_2 d^2 \sqrt{\frac{2 \Delta P \rho_2}{1 - \beta^4}}$$

Where Y_2 and ρ_2 are referred to the downstream conditions; d and D should use the working condition value or with correction terms.

C7.12 Permanent Pressure Loss

C7.12.1 Symbol Table

The symbol table for permanent pressure loss is shown below.

Table C-11 Permanent Pressure Loss Symbol Table

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain
C	-	$0 < C$	None	$C \leq 1$	None
ΔP	Pa	$0 < \Delta P$	None	None	None
β	-	$0 < \beta$	varies with primary element type		$\beta < 1$
ϕ	°	$0 < \phi$	varies with primary element type		None
$\Delta\omega$	Pa	$0 < \Delta\omega$	None	None	None

C7.12.1.1 Calculations

C7.12.2 Orifice Plate (§8.4.1)

The orifice plate calculation is:

$$\Delta \varpi = \Delta P \left(\frac{\sqrt{1 - \beta^4} - C \beta^2}{\sqrt{1 - \beta^4} + C \beta^2} \right)$$

C7.12.3 Nozzles

C7.12.3.1 ISA 1932 Nozzle (§9.1.8)

The ISA 1932 nozzle calculation is:

$$\Delta \varpi = \Delta P \left(\frac{\sqrt{1 - \beta^4} - C\beta^2}{\sqrt{1 - \beta^4} + C\beta^2} \right)$$

C7.12.3.2 Long Radius Nozzle (§9.2.8)

$$\Delta \varpi = \Delta P \left(\frac{\sqrt{1 - \beta^4} - C\beta^2}{\sqrt{1 - \beta^4} + C\beta^2} \right)$$

C7.12.4 Classical Venturi Tubes and Venturi Nozzles

C7.12.4.1 Classical Venturi Tubes (§10.1.9.2)

ISO 5167 provides graphs of pressure loss for guidance only. The ASME MFC-3M-1989 equations will be used to calculate the pressure loss.

For the divergent angle, $\phi = 15°$:

$\zeta = 0.436 - 0.86\,\beta + 0.59\,\beta^2$ (ASME MFC-3M-1989, p.42)

For the divergent angle, $\phi = 7°$:

$\zeta = 0.218 - 0.42\,\beta + 0.38\,\beta^2$ (ASME MFC-3M-1989, p.42)

For a divergent angle, $7° \le \phi \le 15°$, assume that linear interpolation will provide an accurate pressure loss value.

$$\zeta_\phi = \zeta_7 + \left(\zeta_{15} - \zeta_7\right)\left(\frac{\phi - 7°}{15° - 7°}\right)$$

$\Delta \varpi = \zeta \Delta P$ (ASME MFC-3M-1989, p.42)

C7.12.4.2 Venturi Nozzles (§10.2.6)

ISO 5167 provides graphs of pressure loss for guidance only. The ASME MFC-3M-1989 equations will be used to calculate the pressure loss.

Note: Although §10.2.1.4 allows the divergent angle to be as large as 30°, the permanent pressure loss calculation will use a maximum of 15° since the equations of ζ are not known to be valid outside this range.

For the divergent angle, $\phi = 15°$:

$\zeta = 0.436 - 0.86\,\beta + 0.59\,\beta^2$

For the divergent angle, ϕ = 7°:

$$\zeta = 0.218 - 0.42\ \beta + 0.38\ \beta^2$$

For a divergent angle, 7° ≤ ϕ ≤ 15°, assume that linear interpolation will provide an accurate pressure loss value.

$$\zeta_\phi = \zeta_7 + \left(\zeta_{15} - \zeta_7\right)\left(\frac{\phi - 7°}{15° - 7°}\right)$$

$$\Delta\varpi = \zeta\Delta P$$ (ASME MFC-3M-1989, p.42)

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C8 American Gas Association Report No.3, Part1, 3rd Ed., 1990

C8.1 Flow Element Applicability

At the time of initial publication, three standards organizations have approved AGA-3 Part 1 (1990) for orifice metering:

1. American Gas Processors Association	Report No. 3, Third Edition
2. American Petroleum Institute	API 14.3
3. Gas Processors Association	GPA 8185-90

In May, 1991, Part 1 was approved by the American National Institute ANSI/API 2350; Part 1.

AGA-3 Part 1 (1990) applies to steady-state mass flow. The flowing fluid has the following properties:

- clean
- single phase
- Newtonian

The standard provides the design, construction, and installation specifications for orifice meters having the following characteristics:

- flange tapped
- concentric
- square-edged

The orifice meters must be nominal 2-inch schedule 160 or larger pipe diameters.

C8.2 Calculation of Reynolds Numbers

C8.2.1 Symbol Table

The symbol table for the calculation of Reynolds Numbers is shown below.

Table C-1 Calculation of Reynolds Numbers

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain
D	m	$0 < D$	$0 < D$	None	None
q_m	kg/s	$0 \leq q_m$	$0 \leq q_m$	None	None
μ	Pa-s	$0 < \mu$	$0 < \mu$	None	None
R_D	-	$0 < Re_D$	$0 < Re_D$	None	None

C8.2.2 Reynolds Number (§1.7.3)

The Reynolds Number calculation is:

$$R_D = \frac{4q_m}{\pi \mu D}$$ (eq. 1-20, p. 14)

C8.3 Orifice Plate Discharge Coefficients

C8.3.1 Symbol Table

The symbol table for orifice plate discharge coefficients is shown below.

Table C-2 Orifice Plate Discharge Coefficients Symbol Table

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain	Ref
β	-	$0 < \beta$	$0.1 < \beta$	$\beta < 0.75$	$\beta < 1$	p.13
R_D	-	$0 < R_D$	$4000 < R_D$	$R_D < 3.6 \times 10^7$	None	p. 12
d	m	$0 < d$	$0.0114 < d$	$d < 0.675$	$d < D$	p.13
D	m	$0 < D$	$0.0429 < D$	$D < 0.9000$	None	p.13
$C_d(FT)$	-	$C_d(FT) > 0$	None	$C_d(FT) \leq 1$	None	

C8.3.2 Calculations

C8.3.2.1 Base Discharge Coefficient (§1.7.2)

The base discharge coefficient calculations are:

$$\beta = \frac{d}{D}$$

$$C_d(FT) = C_i(FT) + 0.000511\left(\frac{10^6 \beta}{R_D}\right)^{0.7} + (0.0210 + 0.0049A)\beta^4 C$$ (eq. 1-9, p.13)

$$C_i(FT) = C_i(CT) + UPSTRM + DNSTRM$$ (eq. 1-10, p.13)

$$C_i(CT) = 0.5961 + 0.0291\beta^2 - 0.2290\beta^8 + 0.003(1 - \beta)M_1$$ (eq. 1-11, p.13)

$$UPSTRM = \left(0.0433 + 0.0712\, e^{-8.5L_1} - 0.1145\, e^{-6.0L_1}\right)\left(1 - 0.23A\right)B \qquad \text{(eq. 1-13, p.13)}$$

$$DNSTRM = -0.0116\left(M_2 - 0.52\, M_2^{\,1.3}\right) \beta^{1.1} \left(1 - 0.14\, A\right) \qquad \text{(eq. 1-14, p.13)}$$

$$B = \frac{\beta^4}{1 - \beta^4} \qquad \text{(eq. 1-15, p.13)}$$

$$M_1 = \max(2.8 - \frac{D}{0.0254}, 0.0) \qquad \text{(eq. 1-16, p.13)}$$

$$M_2 = \frac{2\, L_2}{1 - \beta} \qquad \text{(eq. 1-17, p.13)}$$

$$A = \left(\frac{19000\beta}{R_D}\right)^{0.8} \qquad \text{(eq. 1-18, p.13)}$$

$$C = \left(\frac{10^6}{R_D}\right)^{0.35} \qquad \text{(eq. 1-19, p.13)}$$

$$L_1 = L_2 = \frac{0.0254}{D}$$

C8.4 Orifice Plate Expansion Factors

C8.4.1 Symbol Table

The symbol table for orifice plate expansion factors is shown below.

Table C-3 Orifice Plate Expansion Factors Symbol Table

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain
β	-	$0 < \beta$	varies with fluid state		$\beta < 1$
κ	-	$0 < \kappa$	None	None	None
P_{f1}	Pa	$0 < P_{f1}$	$0 < P_{f1}$	None	None
P_{f2}	Pa	$0 < P_{f2}$	varies with fluid state	$P_{f2} < P_{f1}$	None
ΔP	Pa	$0 < \Delta P$	$0 < \Delta P$	varies with fluid state	None
Y_1	-	$0 < Y_1$	None	None	None

C8.4.2 Calculations

C8.4.2.1 Upstream Gas Expansion Factor (§1.8.1)

The upstream gas expansion factor calculations are:

$$\beta = \frac{d}{D}$$

$0.1 \le \beta \le 0.75$ (p.17)

$0.8P_{f1} < P_{f2}$ (p.17)

$\Delta P < 0.20P_{f1}$ (p.17)

$$Y_1 = 1 - \left(0.41 + 0.35\beta^4\right)\frac{x_1}{\kappa}$$ (eq. 1-24, p. 18)

When the upstream static pressure is measured:

$$x_1 = \frac{\Delta P}{P_{f_1}}$$ (eq. 1-25, p. 18)

When the downstream static pressure is measured:

$$x_1 = \frac{\Delta P}{P_{f_2} + \Delta P}$$ (eq. 1-26, p. 18)

C8.4.2.2 Downstream Gas Expansion Factor (§1.8.2)

The downstream gas expansion factor calculation is:

$$Y_2 = Y_1\sqrt{\frac{P_{f_1}Z_{f_2}}{P_{f_2}Z_{f_1}}} = \left[1-(0.41+.35\beta^4)\frac{x_1}{k}\right]\sqrt{\frac{P_{f_1}Z_{f_2}}{P_{f_2}Z_{f_1}}}$$

where,

$$x_1 = \frac{\Delta P}{P_{f_2} + \Delta P}$$

Z_{f1}, Z_{f2} are fluid compressibility factors at upstream and downstream pressure taps, respectively.

Note: If the user defined the gas mixture and selected a density method, Flowel automatically calculates Z_{f1} and Z_{f2}. These two values are presented on the AGA 3 factors report. If there is no mixture defined for the tag, or no density method defined, Flowel will ask the user to input Z_{f1} and Z_{f2}.

C8.4.2.3 Liquid Expansion Factor (§1.6)

$$Y_1 = 1.000$$

C8.5 Thermal Expansion Correction

AGA 3 provides the following temperature correction factors for the pipe diameter and orifice bore.

C8.5.1 Symbol Table

The symbol table for thermal expansion correction is shown below.

Table C-4 Thermal Expansion Correction Symbol Table

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain
d_r	m	$0< d_r$	None	None	None
D_r	m	$0< D_r$	None	None	None
α_{PE}	m/m/°C	$0 < \alpha_{PE}$	None	None	None
α_P	m/m/°C	$0 < \alpha_P$	None	None	None
t	°C	$-273.15 < t$	None	None	None
t_r	°C	$-273.15 < t_r$	t_r is usually assumed to be 20°C		
d	m	$0<d$	None	None	None
D	m	$0<D$	None	None	None

C8.5.2 Calculations

C8.5.2.1 Bore Diameter, d, Temperature Correction

The bore diameter temperature correction calculation is:

$$d = \left[1+\alpha_{PE}\left[t-t_r\right]\right]d_r$$

(eq. 1-7, p. 11)

C8.5.2.2 Pipe Diameter, D, Temperature Correction

The pipe diameter temperature correction calculation is:

$$D = \left[1+\alpha_{P}\left[t-t_r\right]\right]D_r$$

(eq. 1-8, p. 11)

C8.6 Flow Rate Calculation

C8.6.1 Symbol Table

The symbol table for flow rate calculation is shown below.

Table C-5 Flow Rate Calculation Symbol Table

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain
d_r	m	$0 < d_r$	None	None	$d_r < D_r$
D_r	m	$0 < D_r$	None	None	None
P_1	Pa	$0 < P_1$	$0 < P_1$	None	None
P_2	Pa	$0 < P_2$	$0.8 P_1 < P_2$	$P_2 < P_1$	None
t	°C	$-273.15 < t$	None	None	None
t_r	°C	$-273.15 < t_r$	None	None	None
α_P	m/m/°C	$0 < \alpha_P$	None	None	None
α_{PE}	m/m/°C	$0 < \alpha_{PE}$	None	None	None
ρ_1	kg/m^3	$0 < \rho_1$	None	None	None
C	-	$0 < C$	None	$C \leq 1$	None
d	m	$0 < d$	$0.0114 < d$	None	None
D	m	$0 < D$	$0.0429 < D$		None
ΔP	Pa	$0 < \Delta P$	None	$\Delta P < 0.20 P_1$	None
β	-	$0 < \beta$	$0.1 < \beta$	$\beta < 0.75$	$\beta < 1$
Y	-	$0 < Y$	None	None	None
q_m	kg/s	$0 < q_m$	None	None	None

C8.6.2 Calculations (§1.6)

The actual flow is found by iteration, since C and R_D are dependent on the flow rate q_m.

$$d = \left[1 + \alpha_{PE}\left[t - t_r\right]\right]d_r$$ (eq. 1-7, p. 11)

$$D = \left[1 + \alpha_{PE}\left[t - t_r\right]\right]D_r$$ (eq. 1-8, p. 11)

$$\beta = \frac{d}{D}$$

$$\Delta P = P_1 - P_2$$

The above values of d, D, and β should be used to calculate C and Y.

$$q_m = \frac{\pi}{4} C Y_1 d^2 \sqrt{\frac{2 \Delta P \rho_1}{1 - \beta^4}}$$ (eq. 1-1, p. 10)

or

$$q_m = \frac{\pi}{4} C Y_2 d^2 \sqrt{\frac{2 \Delta P \rho_2}{1 - \beta^4}}$$

C8.7 Permanent Pressure Loss

C8.7.1 Symbol Table

The symbol table for permanent pressure loss is shown below.

Table C-6 Permanent Pressure Loss Symbol Table

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain
C	-	0 < C	None	None	None
ΔP	Pa	$0 < \Delta P$	None	None	None
β	-	$0 < \beta$	None	None	$\beta < 1$
$\Delta \varpi$	Pa	$0 < \Delta \varpi$	None	None	None

C8.7.2 Calculations

AGA 3 does not provide a method to estimate the permanent pressure loss. Therefore, the equation provided by ISO 5167 (1991) is applied.

C8.7.2.1 Orifice Plate (ISO 5167 - 1- 1991 (E) §8.4.1)

The orifice plate calculation is:

$$\Delta \varpi \approx \Delta P \left(\frac{\sqrt{1 - \beta^4} - C\beta^2}{\sqrt{1 - \beta^4} + C\beta^2} \right)$$

C8.8 AGA 3 - 1992 (Part 3) Factors

Volume flow rate:

$$Qv = Fn(Fc + Fse)Y F_{pb} F_{tb} F_{tf} F_{gr} F_{pv} \sqrt{P_f hw} = C' \sqrt{P_f hw}$$

Where:

Fn = numeric conversion factor

Fc + Fse = discharge coefficient

Y = gas expansion factor

F_{pb} = base pressure factor

F_{tf} = flowing temperature factor

F_{gr} = real gas relative density factor

F_{pv} = supercompressibility factor

P_f = *absolute* flowing pressure

Qv = volume flow rate at base condition of Tb and Pb

$$Fn = N\, T_v D^2$$

$$T_v = \frac{1}{\sqrt{1-\beta^4}}$$

Where:

Fc + Fse = discharge coefficient

Y = gas expansion factor

$$F_{pb} = \frac{14.73}{P_b}$$

$$F_{tb} = \frac{T_b}{518.67}$$

$$F_{tf} = \sqrt{\frac{518.67}{T_f}}$$

$$F_{gr} = \sqrt{\frac{1}{Gr}}$$

$$F_{pv} = \sqrt{\frac{Z_b}{Z_f}}$$

Where:

Tb = base temperature in degrees Rankine °R

Tf = flowing temperature in degrees Rankine °R

Pb = base pressure, in pounds force per square inch

Gr = real gas relative density at base conditions

Zb = compressibility factor at base condition

Zf = compressibility at flowing conditions (upstream/downstream)

N = unit conversion factor

Notes:

1. AGA 3 defined the factors approach based upon English (Imperial) unit system. Flowel extended those definitions to any combination of units except mass flow rate units.
2. AGA 3 factors are only applicable for gas (vapor) systems with a volumetric flow rate.

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C9 British Standard BS 1042 – Measurement of Fluid Flow in Closed Conduits: Part 1, Section 1.2

C9.1 Flow Element Applicability

This standard will be applied to liquid, vapor, or gas flows in the following types of orifice plates:

- conical entrance
- quadrant
- eccentric

C9.2 Calculation of Reynolds Numbers

C9.2.1 Symbol Table

The symbol table for the calculation of Reynolds Numbers is shown below.

Table C-1 Calculation of Reynolds Numbers Symbol Table

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain
D	m	0 < D	varies with device		None
q_m	kg/s	0 < q_m	0 < q_m	None	None
μ	Pa-s	0 < μ	0 < μ	None	None
R_D	-	0 < R_D	varies with device		None

C9.2.2 Reynolds Number (§BS 1042, Section 1.1)

The Reynolds Number calculation is:

$$R_D = \frac{4q_m}{\pi \mu D}$$

C9.3 Orifice Plate Limits and Discharge Coefficients

C9.3.1 Symbol Table

The symbol table for orifice plate limits and discharge coefficients is shown below.

Table C-2 Orifice Plate Limits and Discharge Coefficients Symbol Table

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain
β	-	$0 < \beta$	varies with device		$\beta < 1$
R_D	-	$0 < R_D$	varies with device		None
D	m	$0 < D$	varies with device		None
C	-	$0 < C$	varies with device		$C < 1$

C9.3.2 Calculations

C9.3.2.1 Conical Entrance with Corner Taps (§7)

C9.3.2.1.1 Limits (§7.2)

The limits are:

- $d > 0.006$
- $D \leq .500$
- $0.1 \leq \beta \leq 0.316$
- $80 \leq R_D \leq 2x10^5\beta$

C9.3.2.1.2 Discharge Coefficient (§7.5.1)

The discharge coefficient is:

$C = 0.734$

C9.3.2.2 Quadrant Edge with Corner Taps or Flange Taps (§8)

C9.3.2.2.1 Limits (§8.2)

The limits are:

- $d \geq 0.015$
- $D \leq 0.500$
- $0.245 \leq \beta \leq 0.6$
- $R_D \leq 10^5\beta$
- $0.046 \leq C\beta^2(1-\beta^4)^{-0.5} \leq 0.326$
- $R_D\,(\text{min}) = 1000\beta + 9.4 \times 10^6 (\beta - 0.24)^8$

C9.3.2.2.2 Discharge Coefficients (§8.5.1)

The discharge coefficient is:

$$C = 0.73823 + 0.3309\beta - 1.1615\beta^2 + 1.5084\beta^3$$

C9.3.2.3 Eccentric with Corner Taps (§9)

C9.3.2.3.1 Limits (§9.2)

The limits are:

- $d \geq 0.050$
- $0.1 \leq D \leq 1.000$
- $0.46 \leq \beta \leq 0.84$
- $2 \text{ x } 10^5\beta^2 \leq R_D \leq 10^6\beta$

C9.3.2.3.2 Discharge Coefficients (§9.4.1)

The discharge coefficient is:

$$C = 0.9355 - 1.6889\beta + 3.0428\beta^2 - 1.7989\beta^3$$

C9.4 Orifice Plates Expansion Factors

C9.4.1 Symbol Table

The symbol table for orifice plates expansion factors is shown below.

Table C-3 Orifice Plates Expansion Factors Symbol Table

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain
κ	-	$0 < \kappa$	None	None	None
P_{f1}	Pa	$0 < P_1$	$0 < P_1$	None	None
P_{f2}	Pa	$0 < P_2$	$0.75\ P_1 < P_2$	$P_2 < P_1$	None
ΔP	Pa	$0 \leq \Delta P$	$0 \leq \Delta P$	None	None
Y_1	-	$0 < Y_1$	None	None	None
Y_2	-	$0 < Y_2$	None	None	$Y \leq 1$
τ	-	$0 < \tau$	None	None	$\tau < 1$

C9.4.2 Calculations

C9.4.2.1 Conical Entrance (§7.5.2)

C9.4.2.1.1 *Upstream Gas Expansion*

The upstream gas expansion calculation is:

$$\tau = \frac{P_1}{P_2}$$

$$Y_1 = \frac{\left\{ 1-\left(0.41+0.35\beta^4\right)\frac{\Delta P}{\kappa P_1} + \left[\left(\frac{\kappa \tau^{\frac{2}{\kappa}}}{\kappa - 1} \right) \left(\frac{1-\beta^4}{1-\beta^4 \tau^{\frac{2}{\kappa}}} \right) \left(\frac{1-\tau^{\frac{(\kappa-1)}{\kappa}}}{1-\tau} \right) \right]^{\frac{1}{2}} \right\}}{2}$$

C9.4.2.1.2 *Downstream Gas Expansion*

The downstream gas expansion calculation is:

$$Y_2 = Y_1 \sqrt{1+\frac{\Delta P}{P_2}}$$

C9.4.2.1.3 *Liquid*

The liquid calculation is:

$$Y_1 = Y_2 = 1$$

C9.4.2.2 Quadrant with Corner Taps or Flange Taps (§8.5.2) and Eccentric with Corner Taps (§9.4.3)

C9.4.2.2.1 *Upstream Gas Expansion*

The upstream gas expansion calculation is:

$$Y_1 = 1-\left(0.41+0.35\beta^4\right)\frac{\Delta P}{\kappa P_1}$$

C9.4.2.2.2 Downstream Gas Expansion

The downstream gas expansion calculation is:

$$Y_2 = Y_1\sqrt{1+\frac{\Delta P}{P_2}}$$

C9.4.2.2.3 Liquid

$$Y_1 = Y_2 = 1$$

C9.5 Thermal Expansion Correction

C9.5.1 Symbol Table

The symbol table for thermal expansion correction is shown below.

Table C-4 Thermal Expansion Correction Symbol Table

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain
d_r	m	$0< d_r$	None	None	None
D_r	m	$0< D_r$	None	None	None
α_{PE}	m/m/°C	$0 < \alpha_{PE}$	None	None	None
α_P	m/m/°C	$0 < \alpha_P$	None	None	None
t	°C	$-273.15 < t$	None	None	None
t_r	°C	$-273.15 < t_r$	t_r is usually assumed to be 20°C		
d	m	$0<d$	None	None	None
D	m	$0<D$	None	None	None

C9.5.2 Calculations

C9.5.2.1 Bore Diameter, d, Temperature Correction

The bore diameter temperature correction calculation is:

$$d = \left[1+\alpha_{PE}\left[t-t_r\right]\right]d_r$$

C9.5.2.2 Pipe Diameter, D, Temperature Correction

The pipe diameter temperature correction is:

$$D = \left[1+\alpha_p\left[t-t_r\right]\right]D_r$$

C9.6 Flow Rate Calculation

C9.6.1 Symbol Table

The symbol table for flow rate calculation is shown below.

Table C-5 Flow Rate Calculation Symbol Table

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain
d_r	m	$0 < d_{meas}$	varies with primary element type		$d_r < D_r$
D_r	m	$0 < D_{meas}$	varies with primary element type		None
P_1	Pa	$0 < P_1$	$0 < P_1$	None	None
P_2	Pa	$0 < P_2$	varies with fluid state	$P_2 < P_1$	None
t	°C	$-273.15 < t$	None	None	None
t_r	°C	$-273.15 < t_r$	None	None	None
α_P	m/m/°C	$0 < \alpha_P$	None	None	None
α_{PE}	m/m/°C	$0 < \alpha_{PE}$	None	None	None
ρ_1	kg/m^3	$0 < \rho_1$	None	None	None
C	-	$0 < C$	None	None	None
d	m	$0 < d$	varies with primary element type		None
D	m	$0 < D$	varies with primary element type		None
ΔP	Pa	$0 < \Delta P$	None	None	None
β	-	$0 < \beta$	varies with primary element		$\beta < 1$
Y	-	$0 < Y$	None	None	$Y \leq 1$
q_m	kg/s	$0 < q_m$	None	None	None

C9.6.2 Calculations

The actual flow may be found by iteration, since C and R_D may depend on the flow rate q_m.

$$d = \left[1 + \alpha_{PE}\left[t - t_r\right]\right]d_r$$

$$D = \left[1 + \alpha_p\left[t - t_r\right]\right]D_r$$

$$\beta = \frac{d}{D}$$

$$\Delta P = P_1 - P_2$$

The above values of d, D, and β should be used to calculate C and Y.

$$q_m = \frac{\pi}{4} C Y_1 d^2 \beta^2 \sqrt{\frac{2 \Delta P \rho_1}{1 - \beta^4}}$$

C9.7 Permanent Pressure Loss

C9.7.1 Symbol Table

The symbol table for permanent pressure loss is shown below.

Table C-6 Permanent Pressure Loss Symbol Table

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain
C	-	0 < C	None	None	None
ΔP	Pa	$0 < \Delta P$	None	None	None
β	-	$0 < \beta$	Varies with primary element		$\beta < 1$
$\Delta\varpi$	Pa	$0 < \Delta\varpi$	None	None	None

C9.7.2 Calculations

BS 1042 Section 1.2 does not provide a method to estimate the permanent pressure loss. Therefore the equation provided by ISO 5167 (1991) is applied.

C9.7.2.1 Orifice Plate (§7.4)

The orifice plate calculation is:

$$\Delta \varpi \approx \Delta P \left(\frac{\sqrt{1 - \beta^4} - C \beta^2}{\sqrt{1 - \beta^4} + C \beta^2} \right)$$

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C10 ISO TR 15377

C10.1 Flow Element Applicability

The title of this report is “Measurement of fluid flow by means of pressure differential devices – Guidelines for the specification of nozzles and orifice plates beyond the scope of ISO 5167-1.” It contains an update to BS1042, where the devices are not included in ISO 5167-1. Implemented equations from this standard are for the following types of orifice plates:

- conical entrance
- quadrant
- eccentric

C10.2 Calculation of Reynolds Numbers

C10.2.1 Symbol Table

The symbol table for the calculation of Reynolds Numbers is shown below.

Table C-1 Calculation of Reynolds Numbers Symbol Table

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain
D	m	$0 < D$	varies with device		None
q_m	kg/s	$0 < q_m$	$0 < q_m$	None	None
μ	Pa-s	$0 < \mu$	$0 < \mu$	None	None
R_D	-	$0 < R_D$	varies with device		None

C10.2.2 Reynolds Number (§BS 1042, Section 1.1)

The Reynolds Number calculation is:

$$R_D = \frac{4q_m}{\pi\mu D}$$

C10.3 Orifice Plate Limits and Discharge Coefficients

C10.3.1 Symbol Table

The symbol table for orifice plate limits and discharge coefficients is shown below.

Table C-2 Orifice Plate Limits and Discharge Coefficients Symbol Table

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain
β	-	$0 < \beta$	varies with device		$\beta < 1$
R_D	-	$0 < R_D$	varies with device		None
D	m	$0 < D$	varies with device		None
C	-	$0 < C$	varies with device		$C < 1$

C10.3.2 Calculations

C10.3.2.1 Conical Entrance with Corner Taps (§7)

C10.3.2.1.1 Limits (§7.2)

The limits are:

- $d > 0.006$
- $D \leq .500$
- $0.1 \leq \beta \leq 0.316$
- $80 \leq R_D \leq 2x10^5\beta$

C10.3.2.1.2 Discharge Coefficient (§7.5.1)

The discharge coefficient is:

$C = 0.734$

C10.3.2.2 Quadrant Edge with Corner Taps or Flange Taps (§8)

C10.3.2.2.1 Limits (§8.2)

The limits are:

- $d \geq 0.015$
- $D \leq 0.500$
- $0.245 \leq \beta \leq 0.6$
- $R_D \leq 10^5\beta$
- $0.046 \leq C\beta^2(1-\beta^4)^{-0.5} \leq 0.326$
- $R_D\text{ (min)} = 1000\beta + 9.4 \text{ x } 10^6 (\beta - 0.24)^8$

C10.3.2.2.2 Discharge Coefficients (§8.5.1)

The discharge coefficient is:

$C = 0.73823 + 0.3309\beta - 1.1615\beta^2 + 1.5084\beta^3$

C10.3.2.3 Eccentric with Corner Taps (§9)

C10.3.2.3.1 Limits (§9.2)

The limits are:

- $d \geq 0.050$
- $0.1 \leq D \leq 1.000$
- $0.46 \leq \beta \leq 0.84$
- $2 \times 10^5\beta^2 \leq R_D \leq 10^6\beta$

C10.3.2.3.2 Discharge Coefficients (§9.4.1)

The discharge coefficient is:

$C = 0.9355 - 1.6889\beta + 3.0428\beta^2 - 1.7989\beta^3$

C10.4 Orifice Plates Expansion Factors

C10.4.1 Symbol Table

The symbol table for orifice plates expansion factors is shown below.

Table C-3 Orifice Plates Expansion Factors Symbol Table

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain
κ	-	$0 < \kappa$	None	None	None
P_{f1}	Pa	$0 < P_1$	$0 < P_1$	None	None
P_{f2}	Pa	$0 < P_2$	$0.75P_1 < P_2$	$P_2 < P_1$	None
ΔP	Pa	$0 \leq \Delta P$	$0 \leq \Delta P$	None	None
Y_1	-	$0 < Y_1$	None	None	None
Y_2	-	$0 < Y_2$	None	None	$Y \leq 1$
τ	-	$0 < \tau$	None	None	$\tau < 1$

C10.4.2 Calculations

C10.4.2.1 Conical Entrance (§7.5.2)

C10.4.2.1.1 Upstream Gas Expansion

The upstream gas expansion calculation is:

$$\tau = \frac{P_1}{P_2}$$

$$Y_1 = \frac{\left\{ 1 - \left(0.41 + 0.35\beta^4\right)\frac{\Delta P}{\kappa P_1} + \left[\left(\frac{\kappa \tau^{\frac{2}{\kappa}}}{\kappa - 1} \right) \left(\frac{1 - \beta^4}{1 - \beta^4 \tau^{\frac{2}{\kappa}}} \right) \left(\frac{1 - \tau^{\frac{(\kappa-1)}{\kappa}}}{1 - \tau} \right) \right]^{\frac{1}{2}} \right\}}{2}$$

C10.4.2.1.2 Downstream Gas Expansion

The downstream gas expansion calculation is:

$$Y_2 = Y_1 \sqrt{1 + \frac{\Delta P}{P_2}}$$

C10.4.2.1.3 Liquid

The liquid calculation is:

$$Y_1 = Y_2 = 1$$

C10.4.2.2 Quadrant with Corner Taps or Flange Taps (§8.5.2) and Eccentric with Corner Taps (§9.4.3)

C10.4.2.2.1 Upstream Gas Expansion

The upstream gas expansion calculation is:

$$Y_1 = 1 - \left(0.41 + 0.35\beta^4\right)\frac{\Delta P}{\kappa P_1}$$

C10.4.2.2.2 Downstream Gas Expansion

The downstream gas expansion calculation is:

$$Y_2 = Y_1 \sqrt{1 + \frac{\Delta P}{P_2}}$$

C10.4.2.2.3 Liquid

$$Y_1 = Y_2 = 1$$

C10.5 Thermal Expansion Correction

C10.5.1 Symbol Table

The symbol table for thermal expansion correction is shown below.

Table C-4 Thermal Expansion Correction Symbol Table

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain
d_r	m	$0<d_r$	None	None	None
D_r	m	$0<D_r$	None	None	None
α_{PE}	m/m/°C	$0 < \alpha_{PE}$	None	None	None
α_P	m/m/°C	$0 < \alpha_P$	None	None	None
t	°C	$-273.15 < t$	None	None	None
t_r	°C	$-273.15 < t_r$	t_r is usually assumed to be 20°C		
d	m	$0<d$	None	None	None
D	m	$0<D$	None	None	None

C10.5.2 Calculations

C10.5.2.1 Bore Diameter, d, Temperature Correction

The bore diameter temperature correction calculation is:

$$\mathrm{d} = \left[1 + \alpha_{\mathrm{PE}}\left[\mathrm{t} - \mathrm{t_r}\right]\right]\mathrm{d_r}$$

C10.5.2.2 Pipe Diameter, D, Temperature Correction

The pipe diameter temperature correction is:

$$\mathrm{D} = \left[1 + \alpha_{\mathrm{p}}\left[\mathrm{t} - \mathrm{t_r}\right]\right]\mathrm{D_r}$$

C10.6 Flow Rate Calculation

C10.6.1 Symbol Table

The symbol table for flow rate calculation is shown below.

Table C-5 Flow Rate Calculation Symbol Table

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain
d_r	m	$0 < d_{meas}$	varies with primary element type		$d_r < D_r$
D_r	m	$0 < D_{meas}$	varies with primary element type		None
P_1	Pa	$0 < P_1$	$0 < P_1$	None	None
P_2	Pa	$0 < P_2$	varies with fluid state	$P_2 < P_1$	None
t	°C	$-273.15 < t$	None	None	None
t_r	°C	$-273.15 <$ $_{tr}$	None	None	None
α_P	m/m/°C	$0 < \alpha_P$	None	None	None
α_{PE}	m/m/°C	$0 < \alpha_{PE}$	None	None	None
ρ_1	kg/m^3	$0 < \rho_1$	None	None	None
C	-	$0 < C$	None	None	None
d	m	$0 < d$	varies with primary element type		None
D	m	$0 < D$	varies with primary element type		None
ΔP	Pa	$0 < \Delta P$	None	None	None
β	-	$0 < \beta$	varies with primary element		$\beta < 1$
Y	-	$0 < Y$	None	None	$Y \leq 1$
q_m	kg/s	$0 < q_m$	None	None	None

C10.6.2 Calculations

The actual flow may be found by iteration, since C and R_D may depend on the flow rate q_m.

$$d = \left[1 + \alpha_{PE}\left[t - t_r\right]\right] d_r$$

$$D = \left[1 + \alpha_p\left[t - t_r\right]\right] D_r$$

$$\beta = \frac{d}{D}$$

$$\Delta P = P_1 - P_2$$

The above values of d, D, and β should be used to calculate C and Y.

$$q_m = \frac{\pi}{4} C Y_1 d^2 \beta^2 \sqrt{\frac{2 \Delta P \rho_1}{1 - \beta^4}}$$

C10.7 Permanent Pressure Loss

C10.7.1 Symbol Table

The symbol table for permanent pressure loss is shown below.

Table C-6 Permanent Pressure Loss Symbol Table

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain
C	-	0 < C	None	None	None
ΔP	Pa	0 < ΔP	None	None	None
β	-	0 < β	Varies with primary element		β < 1
Δϖ	Pa	0 < Δϖ	None	None	None

C10.7.2 Calculations

BS 1042 Section 1.2 does not provide a method to estimate the permanent pressure loss. Therefore the equation provided by ISO 5167 (1991) is applied.

C10.7.2.1 Orifice Plate (§7.4)

The orifice plate calculation is:

$$\Delta \varpi \approx \Delta P \left(\frac{\sqrt{1 - \beta^4} - C \beta^2}{\sqrt{1 - \beta^4} + C \beta^2} \right)$$

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C11 American Gas Association Report No.3, Second Ed., 1985

C11.1 Flow Element Applicability

Four standards organizations approved this standard for the orifice metering of natural gas in 1985, these are:

1.	American National Standards Institute	ANSI/API 2530,
2.	American Gas Association	Report No. 3, Second Edition,
3.	American Petroleum Institute	API 2530
4.	Gas Processors Association	GPA 8185-85

The third edition of this standard, issued in 1990, supersedes this edition.

This standard applies to steady-state mass flow. The flowing fluid has the following properties:

- clean
- single phase
- Newtonian

The standard provides the design, construction, and installation specifications for orifice meters having the following characteristics:

- flange tapped or pipe tapped
- concentric
- square-edged

The orifice meters must be nominal 1.6 inch inside diameter or larger.

C11.2 Calculation of Reynolds Numbers

C11.2.1 Symbol Table

The symbol table for the calculation of Reynolds Numbers is shown below.

Table C-1 Calculation of Reynolds Numbers Symbol Table

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain
d	m	$0 < d$	$0 < d$	None	None
V	m/sec	$0 < q_m$	$0 < q_m$	None	None
μ	P_q^{-s}	$0 < \mu$	$0 < \mu$	None	None
ρ_f	kg/m^3	$0 < \rho_f$	$0 < \rho_f$	None	None
R_d	-	$0 < R_d$	$0 < R_d$	None	None

C11.2.2 Bore Reynolds Number (§5.2.2)

The bore Reynolds Number calculation is:

$$R_d = \frac{Vd\rho}{\mu}$$ (eq. 16, p. 27)

C11.3 Flow Coefficients

C11.3.1 Symbol Table

The symbol table for the flow coefficients is shown below.

Table C-2 Flow Coefficients Symbol Table

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain
d	m	$0 < d$	None	None	$d < D$
D	m	$0 < D$	$0.0406 \leq D$	$D \leq 0.762$ (1)	None
R_d	-	$0 < R_d$	$4000 < R_d$ (2)	None	None
β	-	$0 < \beta$	$0.10 < \beta$	$\beta < 0.75$	$\beta < 1$

Notes:

1. Although the standard does not specify an upper limit for pipe diameter, a pipe diameter of 0.762 will generate a warning message. A pipe diameter of 0.762 was selected since the largest pipe diameter used to calculate factors in the appendix was 0.762 nom. (30 inches).
2. Although the standard does not specify a lower limit for Reynolds number, a Reynolds number below 4,000 will generate a warning message. A Reynolds number of 4,000 was selected since this value is generally accepted as the value required for turbulent flow.

C11.3.2 Calculations

C11.3.2.1 Flange Tap Flow Coefficient, K_e, $0.10 < \beta < 0.75$ (§5.2.1)

The flange tap flow coefficient calculations are:

$$\beta = \frac{d_{meas}}{D_{meas}}$$

(eq. 9, p. 26)

$$K_e = 0.5993 + \frac{0.007}{\left(\frac{D}{0.0254}\right)} + \left[0.364 + \frac{0.076}{\left(\frac{D}{0.0254}\right)^{0.5}}\right]\beta^4$$

$$+0.4\left[1.6 - \frac{1}{\left(\frac{D}{0.0254}\right)}\right]^5\left[\left(0.07 + \frac{0.5}{\left(\frac{D}{0.0254}\right)}\right) - \beta\right]^{5/2}$$

$$-\left[0.009 + \frac{0.034}{\left(\frac{D}{0.0254}\right)}\right][0.5 - \beta]^{3/2} + \left[\frac{65}{\left(\frac{D}{0.0254}\right)^2} + 3\right][\beta - 0.7]^{5/2}$$

C11.3.2.2 Pipe Tap Flow Coefficient, K_e, $0.10 < \beta < 0.75$ (§5.2.1)

The pipe tap flow coefficient calculation is:

(eq. 10, p. 26)

$$K_e = 0.5925 + \frac{0.0182}{\left(\frac{D}{0.0254}\right)} + \left[0.440 - \frac{0.06}{\left(\frac{D}{0.0254}\right)}\right]\beta^2$$

$$+\left[0.935 - \frac{0.225}{\left(\frac{D}{0.0254}\right)}\right]\beta^5 + 1.35\beta^{14} + \frac{1.43}{\left(\frac{D}{0.0254}\right)^{0.5}}[0.25 - \beta]^{5/}$$

C11.3.2.3 Flow Coefficient at Infinite Reynolds Number, K_o (§5.2.1)

The flow coefficient at infinite Reynolds Number calculations are:

$$K_o = \frac{K_e}{1 + \dfrac{15E}{d_{meas}(10^6)}} \qquad \text{(eq. 11, p. 27)}$$

Where:

$$E = d\left[830 - 5000\beta + 9000\beta^2 - 4200\beta^3 + B\right] \qquad \text{(eq. 12, p. 27)}$$

Where:

$$B = \frac{530}{\left(\dfrac{D}{0.0254}\right)^{0.5}} \quad \text{(for flange taps)} \qquad \text{(eq. 13, p. 27)}$$

$$B = \frac{875}{\left(\dfrac{D}{0.0254}\right)} + 75 \quad \text{(for pipe taps)} \qquad \text{(eq. 14, p. 27)}$$

C11.3.2.4 Flow Coefficient at Specified Reynolds Number, K (§5.2.1)

The flow coefficient at specified Reynolds Number calculation is:

$$K = K_o\left[1 + \frac{E}{R_d}\right] \qquad \text{(eq. 15, p. 27)}$$

C11.4 Orifice Plates Gas Expansion Factors

C11.4.1 Symbol Table

The symbol table for orifice plate gas expansion factors is shown below.

Table C-3 Orifice Plates Gas Expansion Factors Symbol Table

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain
β	-	$0 < \beta$	varies with pressure taps		$\beta < 1$
κ	-	$0 < \kappa$	None	None	None
P_1	psia	$0 < P_1$	$0 < P_1$	None	None
P_2	psia	$0 < P_2$	$0 < P_2$	$P_2 < P_1$	None
x_1	-	$0 < x_1$	None	None	None
x_2	-	$0 < x_2$	None	None	None
Y_1	-	$0 < Y_1$	None	$Y_1 \leq 1$	
Y_2	-	$0 < Y_2$	None	$Y_2 \leq 1$	None

C11.4.2 Calculations

C11.4.2.1 Upstream Expansion Factor for Flange Taps, 0.1 < β < 0.80 (§5.2.6.1)

The upstream expansion factor for flange taps calculation is:

$$Y_1 = 1 - \left(0.41 + 0.35\beta^4\right)\frac{x_1}{\kappa}$$ (eq. 17, p. 28)

Where:

$$x_1 = \frac{P_1 - P_2}{P_1}$$ (eq. 18, p. 28)

C11.4.2.2 Upstream Expansion Factor for Pipe Taps, 0.1 < β < 0.70 (§5.2.6.1)

The upstream expansion factor for pipe taps calculation is:

$$Y_1 = 1 - \left(0.333 + 1.145\left(\beta^2 + 0.7\beta^5 + 12\beta^{13}\right)\right)\frac{x_1}{\kappa}$$ (eq. 18, p. 28)

Where:

$$x_1 = \frac{P_1 - P_2}{P_1}$$ (eq. 18, p. 28)

C11.4.2.3 Downstream Expansion Factor for Flange Taps, 0.1 < β < 0.80 (§5.2.6.2)

The downstream expansion factor for flange taps calculation is:

$$Y_2 = Y_1\left[\frac{1}{1 - x_2}\right]^{0.5}$$ (eq. 20, p. 29)

$$Y_2 = \left[\left[1 + x_2\right]^{0.5} - \left(0.41 + 0.35\beta^4\right)\frac{x_2}{\kappa\left(1 + x_2\right)^{0.5}}\right]$$ (eq. 21, p. 29)

Where:

$$x_2 = \frac{P_1 - P_2}{P_2}$$ (eq. 23, p. 29)

C11.4.2.4 Downstream Expansion Factor for Pipe Taps, 0.2 < β < 0.67 (§5.2.6.2)

The downstream expansion factor for pipe taps calculation is:

$$Y_2 = Y_1\left[\frac{1}{1 - x_2}\right]^{0.5}$$ (eq. 20, p. 29)

$$Y_2 = \left[1 + x_2\right]^{0.5} - \left(0.333 + 1.145\left(\beta^2 + 0.7\beta^5 + 12\beta^{13}\right)\right)\frac{x_2}{\kappa\left(1 + x_2\right)^{0.5}}$$ (eq. 22, p. 29)

Where:

$$x_2 = \frac{P_1 - P_2}{P_1} \qquad \text{(eq. 23, p. 29)}$$

C11.4.2.5 Liquid Expansion Factor (§5.2)

The liquid expansion factor is:

$$Y_1 = Y_2 = 1.000$$

C11.5 Thermal Expansion Correction

C11.5.1 Symbol Table

The symbol table for thermal expansion correction is shown below.

Table C-4 Thermal Expansion Correction Symbol Table

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain
d_r	m	$0< d_r$	None	None	None
D_r	m	$0<D_r$	None	None	None
α_{PE}	m/m/°C	$0 < \alpha_{PE}$	None	None	None
α_P	m/m/°C	$0 < \alpha_P$	None	None	None
t	°C	$-273.15 < t$	None	None	None
t_r	°C	$-273.15 < t_r$	t_r is usually assumed to be 20°C		
d	m	$0<d$	None	None	None
D	m	$0<D$	None	None	None

C11.5.2 Calculations

C11.5.2.1 Bore Diameter, d, Temperature Correction

The bore diameter temperature correction calculation is:

$$d = \left[1 + \alpha_{PE}\left[t - t_r\right]\right]d_r$$

C11.6 Flow Rate Calculation

C11.6.1 Symbol Table

The symbol table for flow rate calculation is shown below.

Table C-5 Flow Rate Calculation Symbol Table

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain
d_r	m	$0 < d_r$			$d_r < D_r$
D_r	m	$0 < D_r$			None
P_1	Pa	$0 < P_1$	$0 < P_1$	None	None
P_2	Pa	$0 < P_2$	$0.8P_1 < P_2$	$P_2 < P_1$	None
t	°C	$-273.15 < t$	None	None	None
t_r	°C	$-273.15 < t_r$	None	None	None
α_P	m/m/°C	$0 < \alpha_P$	None	None	None
α_{PE}	m/m/°C	$0 < \alpha_{PE}$	None	None	None
ρ_1	kg/m^3	$0 < \rho_1$	None	None	None
C	-	$0 < C$	None	$C \leq 1$	None
d	m	$0 < d$	$0.0114 < d$	None	None
D	m	$0 < D$	$0.0406 \leq D$	$D \leq 0.762$	None
ΔP	Pa	$0 < \Delta P$	None	None	None
β	-	$0 < \beta$	$0.1 < \beta$	$\beta < 0.75$	$\beta < 1$
Y	-	$0 < Y$	None	None	None
q_m	kg/s	$0 < q_m$	None	None	None

C11.6.2 Calculations (§1.6)

The actual flow is found by iteration, since C and R_D are dependent on the flow rate q_m.

$$d = \left[1 + \alpha_{PE}\left[t - t_r\right]\right]d_r$$

$$\beta = \frac{d}{D}$$

$$\Delta P = P_1 - P_2$$

The above values of d, D, and β should be used to calculate C and Y.

$$q_m = \frac{\pi}{4} C Y_1 d^2 \sqrt{\frac{2 \Delta P \rho_1}{1 - \beta^4}}$$

C11.7 Permanent Pressure Loss

C11.7.1 Symbol Table

The symbol table for permanent pressure loss is shown below.

Table C-6 Permanent Pressure Loss Symbol Table

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain
C	-	0 < C	None	None	None
ΔP	Pa	$0 < \Delta P$	None	None	None
β	-	$0 < \beta$	varies with primary element		$\beta < 1$
$\Delta\varpi$	Pa	$0 < \Delta\varpi$	None	None	None

C11.7.2 Calculations

AGA 3 does not provide a method to estimate the permanent pressure loss. The equation provided by ISO 5167 (1991) is applied.

C11.7.2.1 Orifice Plate (§8.4)

$$\Delta\varpi = \Delta P\left(\frac{\sqrt{1 - \beta^4} - C\beta^2}{\sqrt{1 - \beta^4} + C\beta^2}\right)$$

The above equation may generate negative permanent pressure loss under certain conditions (normally with a higher β value or discharge coefficient). If this occurs, the following equation, which is also part of ISO 5167 (1991), standard is used.

$$\Delta\varpi = \Delta P\left(1 - \beta^{1.9}\right)$$

C11.8 AGA 3 Factors

Volume flow rate:

$$Q_v = C'\left[hw\,P_f\right]^{0.5}$$

Where:

Qv = volume flow rate at base conditions
hw = differential pressure
P_f = absolute static pressure; could be measured downstream or upstream

And: $C' = F_b\, F_r\, Y\, F_{pb}\, F_{tb}\, F_{tf}\, F_{gr}\, F_{pv}$

Where:

C' = orifice flow constant
F_b = basic orifice factor
F_r = Reynolds Number factor
Y = gas expansion factor
F_{pb} = pressure base factor
F_{tb} = temperature base factor
F_{tf} = flowing temperature factor
F_{gr} = real gas relative density factor
F_{pv} = supercompressibility factor

$$F_b = Nd^2 K_o$$

Where:

d = bore diameter

$$K_o = \frac{K_e}{1 + \frac{15E}{d(10^6)}}$$

$$F_r = 1 + \frac{E}{R_d}$$

Where:

Y = upstream Y_1
= downstream Y_2

$$F_{pb} = \frac{14.73}{P_b} \qquad F_{tb} = \frac{T_b}{519.67} \qquad F_{tf} = \sqrt{\frac{519.67}{T_f}}$$

$$F_{gr} = \sqrt{\frac{1}{G_r}} \qquad F_{pv} = \sqrt{\frac{Z_b}{Z_f}}$$

Where:

N = unit conversion factor

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C12 General Application

C12.1 Orifice Plate Discharge Coefficients

C12.1.1 Concentric Orifice Plate With Corner Taps, Flange Taps, or Radius Taps

Discharge coefficients for orifice plates using corner taps, flange taps, or radius pressure taps are given in Section C12.5 of this appendix, and are based on ISO 5167 (1991).

C12.1.2 Concentric Orifice Plate With Pipe Taps

C12.1.2.1 Symbol Table

The symbol table for concentric orifice plate with pipe taps is shown below.

Table C-1 Concentric Orifice Plate with Pipe Taps Symbol Table

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain	Ref
D	m	$0 < D$	$0.0428 \leq D$	$D \leq 0.9$	None	Miller, p.9-54
d	m	$0 < d$	$0 < d$	$d < 0.45$	$d < D$	
q_m	kg/s	$0 \leq q_m$	$0 \leq q_m$	None	None	
μ	Pa-s	$0 < \mu$	$0 < \mu$	None	None	
C	-	$0 < C$	$0 < C$	$C \leq 1.0$	None	
R_D	-	$0 < R_D$	$10^4 \leq R_D$	$R_D \leq 10^7$	None	Miller, p.9-54
β	-	$0 < \beta$	$0.2 \leq \beta$	$\beta \leq 0.5$	$\beta < 1$	Miller, p.9-54

C12.1.2.2 Calculations (Miller, p. 9-15)

The concentric orifice plate with pipe taps calculations are:

$$\beta = \frac{d}{D}$$

$$R_D = \frac{4q_m}{\pi\mu D}$$

$$C = 0.5959 + 0.461\,\beta^{2.1} + 0.48\,\beta^{8} + 0.039\left(\frac{\beta^{4}}{1 - \beta^{4}}\right) + \frac{91.71\,\beta^{2.5}}{R_D^{\;0.75}}$$

C12.1.3 Concentric Orifice Plate With Vena Contracta Taps

C12.1.3.1 Symbol Table

The symbol table for concentric orifice plate with vena contracta taps is shown below.

Table C-2 Concentric Orifice Plate with Vena Contracta Taps Symbol Table

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain	Ref
D	m	$0 < D$	$0.0429 \le D$	None	None	*
d	m	$0 < d$	$0 < d$	None	$d < D$	
q_m	kg/s	$0 < q_m$	$0 < q_m$	None	None	
μ	Pa-s	$0 < \mu$	$0 < \mu$	None	None	
C	-	$0 < C$	$0 < C$	$C \le 1$	None	
R_D	-	$0 < R_D$	$10^4\beta < R_D$	None	None	*
β	-	$0 < \beta$	$0.2 < \beta$	$\beta < 0.75$	$\beta < 1$	*

C12.1.3.2 Calculations (Fluid Meters Their Theory and Application, ASME p. 65)*

The calculations for the concentric orifice plate with vena contracta taps are:

$$\beta = \frac{d}{D}$$

$$R_D = \frac{4q_m}{\pi\mu D}$$

$$C = K\sqrt{1 - \beta^4} \qquad \text{(§I-5-37)}$$

$$K = K_o + b\lambda \qquad \text{(§I-5-39)}$$

$$\lambda = 1000/\sqrt{R_D} \qquad \text{(§I-5-39)}$$

$$K_o = 0.5922 + 0.4252\left(\frac{0.0006}{\left(\frac{D}{0.0254}\right)^2 \beta^2 + 0.01\left(\frac{D}{0.0254}\right)} + \beta^4 + 1.25\beta^{16}\right) \qquad \text{(eq. I-5-80)}$$

$$b = 0.00025 + 0.002325\left(\beta + 1.75\beta^4 + 10\beta^{12} + 2D\beta^{16}\right) \qquad \text{(eq. I-5-81)}$$

C12.1.4 Eccentric Orifice Plate With Flange Taps

C12.1.4.1 Symbol Table

The symbol table for the eccentric orifice plate with flange taps is shown below.

Table C-3 Eccentric Orifice Plate with Flange Taps Symbol Table

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain	Ref
D	m	$0 < D$	$0.1 < D$	$D < 0.35$	None	Miller, p.9-137
d	m	$0 < d$	$0.03 < d$	$d < 0.26$	$d < D$	$d < D$
q_m	kg/s	$0 \le q_m$	$0 \le q_m$	None	None	
μ	Pa-s	$0 < \mu$	$0 < \mu$	None	None	
C	-	$0 < C$	None	$C < 1$	None	
R_D	-	$0 < R_D$	$10^4 < R_D$	$R_D < 10^6$	None	Miller, p.9-137
β	-	$0 < \beta$	$0.3 < \beta$	$\beta < 0.75$	$\beta < 1$	Miller, p.9-137

C12.1.4.2 Calculations (Miller, p. 9-15)

The calculations for the eccentric orifice plate with flange taps are:

$$\beta = \frac{d}{D}$$

$$R_D = \frac{4q_m}{\pi \mu D}$$

C12.1.4.2.1 180° Taps (Diametrically Opposed)

The calculation for 180° taps is:

$D \le 0.1$

$$C = 0.5875 + 0.3813\,\beta^{2.1} + 0.6898\,\beta^{8} - 0.1963\left(\frac{\beta^{4}}{1 - \beta^{4}}\right) - 0.3366\,\beta^{3} + \left[\frac{7.3 - 15.7\,\beta + 170.8\,\beta^{2} - 399.7\,\beta^{3} + 332.2\,\beta^{4}}{R_D^{0.75}}\right]$$

$D > 0.1$

$$C = 0.5949 + 0.4078\,\beta^{2.1} + 0.0547\,\beta^{8} + 0.0955\left(\frac{\beta^{4}}{1-\beta^{4}}\right) - 0.5608\,\beta^{3}$$
$$+\left[\frac{-139.7 + 1328.8\,\beta - 4228.2\,\beta^{2} + 5691.9\,\beta^{3} - 2710.4\,\beta^{4}}{R_D^{0.75}}\right]$$

C12.1.4.2.2 90° Taps

The calculation for 90° taps is:

$D \leq 0.1$

$$C = 0.6284 + 0.1462\,\beta^{2.1} - 0.8464\,\beta^{8} + 0.2603\left(\frac{\beta^{4}}{1-\beta^{4}}\right) - 0.2886\,\beta^{3}$$
$$+\left[\frac{69.1 - 469.4\,\beta + 1245.6\,\beta^{2} - 1287.5\,\beta^{3} + 486.2\,\beta^{4}}{R_D^{0.75}}\right]$$

$D > 0.1$

$$C = 0.6276 + 0.0828\,\beta^{2.1} + 0.2739\,\beta^{8} - 0.0934\left(\frac{\beta^{4}}{1-\beta^{4}}\right) - 0.1132\,\beta^{3}$$
$$+\left[\frac{-103.2 + 898.3\,\beta - 2557.3\,\beta^{2} + 2977\,\beta^{3} - 1131.3\,\beta^{4}}{R_D^{0.75}}\right]$$

C12.1.5 Eccentric Orifice Plate With Vena Contracta Taps

C12.1.5.1 Symbol Table

The symbol table for eccentric orifice plate with vena contracta taps is shown below.

Table C-4 Eccentric Orifice Plate with Vena Contracta Taps Symbol Table

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain	Ref
D	m	$0 < D$	$0.1 < D$	$D < 0.35$	None	Miller, p.9-137
d	m	$0 < d$	$0.03 < d$	$d < 0.26$	$d < D$	$d < D$
q_m	kg/s	$0 \leq q_m$	$0 \leq q_m$	None	None	
μ	Pa-s	$0 < \mu$	$0 < \mu$	None	None	
C	-	$0 < C$	None	$C < 1$	None	
R_D	-	$0 < R_D$	$10^4 < R_D$	$R_D < 10^6$	None	Miller, p.9-137
β	-	$0 < \beta$	$0.3 < \beta$	$\beta < 0.75$	$\beta < 1$	Miller, p.9-137

C12.1.5.2 Calculations (Miller, p. 9-15)

The calculations for the eccentric orifice plate with vena contracta taps are:

$$\beta = \frac{d}{D}$$

$$\mathrm{R_D} = \frac{4\mathrm{q_m}}{\pi\mu \mathrm{D}}$$

C12.1.5.2.1 180° Taps (Diametrically Opposed)

The calculations for the 180° taps are:

$D \leq 0.1$

$$\mathrm{C} = 0.6261 + 0.1851\,\beta^{2.1} - 0.2879\,\beta^{8} + 0.1170\left(\frac{\beta^{4}}{1-\beta^{4}}\right) - 0.2845\,\beta^{3} + \left[\frac{23.3 - 207\,\beta + 821.5\,\beta^{2} - 1388.6\,\beta^{3} + 900.3\,\beta^{4}}{\mathrm{R_D}^{0.75}}\right]$$

$D > 0.1$

$$\mathrm{C} = 0.6276 + 0.0828\,\beta^{2.1} + 0.2739\,\beta^{8} - 0.0934\left(\frac{\beta^{4}}{1-\beta^{4}}\right) - 0.1132\,\beta^{3} + \left[\frac{55.7 - 471.4\,\beta + 1721.8\,\beta^{2} - 2722.6\,\beta^{3} + 1569.4\,\beta^{4}}{\mathrm{R_D}^{0.75}}\right]$$

C12.1.5.2.2 90° Taps

The calculations for the 90° taps are:

$D \leq 0.1$

$$\mathrm{C} = 0.5917 + 0.3061\,\beta^{2.1} + 0.3406\,\beta^{8} - 0.1019\left(\frac{\beta^{4}}{1-\beta^{4}}\right) - 0.2715\,\beta^{3} + \left[\frac{-69.3 + 556.9\,\beta - 1332.2\,\beta^{2} + 1303.7\,\beta^{3} - 394.8\,\beta^{4}}{\mathrm{R_D}^{0.75}}\right]$$

$D > 0.1$

Note: Miller, p. 9-16, states the Reynold's number term should be:

$$C = 0.6016 + 0.3312\,\beta^{2.1} - 1.5581\,\beta^{8} + 0.6510\left(\frac{\beta^{4}}{1 - \beta^{4}}\right) - 0.7308\,\beta^{3}$$
$$+\left[\frac{52.8 - 434.2\,\beta + 1571.2\,\beta^{2} - 2460.9\,\beta^{3} + 1420.2\,\beta^{8}}{R_D^{\;0.75}}\right]$$

The previous seven discharge coefficient equations have β^8 as β^4. Therefore, the following equation will be used:

$$C = 0.6016 + 0.3312\,\beta^{2.1} - 1.5581\,\beta^{8} + 0.6510\left(\frac{\beta^{4}}{1 - \beta^{4}}\right) - 0.7308\,\beta^{3}$$
$$+\left[\frac{52.8 - 434.2\,\beta + 1571.2\,\beta^{2} - 2460.9\,\beta^{3} + 1420.2\,\beta^{4}}{R_D^{\;0.75}}\right]$$

C12.1.6 Segmental Orifice Plate With Flange Taps

C12.1.6.1 Symbol Table

The symbol table for the segmental orifice plate with flange taps is shown below.

Table C-5 Segmental Orifice Plate with Flange Taps Symbol Table

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain	Ref
D	m	$0 < D$	$0.15 < D$	$D < 0.35$	None	Miller, p.9-36
d	m	$0 < d$	$0 < d$	None	$d < D$	
q_m	kg/s	$0 \le q_m$	$0 \le q_m$	None	None	
μ	Pa-s	$0 < \mu$	$0 < \mu$	None	None	
C	-	$0 < C$	$0 < C$	$C < 1$	None	
D_C	m	$0 < D_C$	None	None	$D_C < D$	
H_S	m	$0 < H_S$	None	None	$H_S < D$	
R_D	-	$0 < R_D$	$10^4 < R_D$	$R_D < 10^6$	None	
β	-	$0 < \beta$	$0.35 < \beta$	$\beta < 0.75$	None	

C12.1.6.2 Calculations

C12.1.6.2.1 Segment Height (Miller, p. 10-40)

The calculations for segment height are:

$$D = \frac{D_C}{0.98}$$

$$\beta_c = \frac{d}{D_c} = \frac{\beta}{0.98} = \left[\frac{1}{\pi} \left[\arccos\left(1 - \frac{2H_s}{D_c}\right) - 2\left(1 - \frac{2H_s}{D_c}\right)\left(\frac{H_s}{D_c} - \left(\frac{H_s}{D_c}\right)^2\right)^{1/2} \right]\right]^{1/2}$$

C12.1.6.2.2 Discharge Coefficient (Miller, p. 9-16)

The calculations for discharge coefficient are:

$D \leq 0.1$

$$C = 0.5866 + 0.3917\,\beta^{2.1} + 0.7586\,\beta^{8} - 0.2273\left(\frac{\beta^{4}}{1 - \beta^{4}}\right) - 0.3343\,\beta^{3}$$

$D > 0.1$

$$C = 0.6037 + 0.1598\,\beta^{2.1} - 0.2918\,\beta^{8} + 0.0244\left(\frac{\beta^{4}}{1 - \beta^{4}}\right) - 0.0790\,\beta^{3}$$

C12.1.7 Segmental Orifice Plate With Vena Contracta Taps

C12.1.7.1 Symbol Table

The symbol table for segmental orifice plate with vena contracta taps is shown below.

Table C-6 Segmental Orifice Plate with Vena Contracta Taps

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain	Ref
D	m	$0 < D$	$0.15 < D$	$D < 0.35$	None	Miller, p.9-36
d	m	$0 < d$	$0 < d$	None	$d < D$	
q_m	kg/s	$0 \leq q_m$	$0 \leq q_m$	None	None	
μ	Pa-s	$0 < \mu$	$0 < \mu$	None	None	
C	-	$0 < C$	$0 < C$	$C < 1$	None	
D_C	m	$0 < D_C$	None	None	$D_C < D$	

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain	Ref
H_S	m	$0 < H_S$	None	None	$H_S < D$	
R_D	-	$0 < R_D$	$10^4 < R_D$	$R_D < 10^6$	None	
β	-	$0 < \beta$	$0.35 < \beta$	$\beta < 0.75$	None	

C12.1.7.2 Calculations

C12.1.7.2.1 Segment Height (Miller, p. 10-40)

The calculations for segment height are:

$$D = \frac{D_C}{0.98}$$

$$\beta_c = \frac{d}{D_c} = \frac{\beta}{0.98} = \left[\frac{1}{\pi} \left[\arccos\left(1 - \frac{2H_s}{D_c}\right) - 2\left(1 - \frac{2H_s}{D_c}\right)\left(\frac{H_s}{D_c} - \left(\frac{H_s}{D_c}\right)^2\right)^{1/2} \right] \right]^{1/2}$$

C12.1.7.2.2 Discharge Coefficient (Miller, p. 9-16)

The calculations for discharge coefficient are:

$D \leq 0.1$

$$C = 0.5925 + 0.3380\,\beta^{2.1} + 0.4016\,\beta^{8} - 0.1046\left(\frac{\beta^{4}}{1 - \beta^{4}}\right) - 0.3212\,\beta^{3}$$

$D > 0.1$

$$C = 0.5922 + 0.3932\,\beta^{2.1} + 0.3412\,\beta^{8} - 0.0569\left(\frac{\beta^{4}}{1 - \beta^{4}}\right) - 0.4628\,\beta^{3}$$

C12.1.8 Quadrant Orifice Plate With Corner Taps or Flange Taps

C12.1.8.1 Symbol Table

The symbol table for quadrant orifice plate with corner taps or flange taps is shown below.

Table C-7 Quadrant Orifice Plate with Corner/Flange Taps Symbol Table

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain	Ref
D	m	$0 < D$	$0.025 < D$	$D < 0.75$	None	Miller, p.9-136

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain	Ref
d	m	$0 < d$	$0 < d$	None	$d < D$	
q_m	kg/s	$0 \leq q_m$	$0 \leq q_m$	None	None	
μ	Pa-s	$0 < \mu$	$0 < \mu$	None	None	
C	-	$0 < C$	$0 < C$	$C < 1$	None	
R_D	-	$0 < R_D$	$R_D(\min) < R_D$	$R_D < 10^5\beta$	None	Shell, p.68
β	-	$0 < \beta$	$0.24 < \beta$	$\beta < 0.6$	$\beta \leq 1$	

$R_D(\min) = 1000\beta + 9.4 \times 10^6 (\beta - 0.24)^8$

C12.1.8.2 Discharge Coefficient (Miller, p. 9-17)

The calculations for discharge coefficient are:

$D \geq 0.04$

$$\beta = \frac{d}{D}$$

$$C = 0.7746 - 0.1334\,\beta^{2.1} + 1.4098\,\beta^{8} + 0.0675\left(\frac{\beta^{4}}{1 - \beta^{4}}\right) + 0.3865\,\beta^{3}$$

C12.1.9 Conical Orifice with Corner Taps

C12.1.9.1 Symbol Table

The symbol table for the conical orifice with corner taps is shown below.

Table C-8 Conical Orifice with Corner Taps Symbol Table

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain	Ref
D	m	$0 < D$	$0.025 < D$	None	None	Miller, p.9-136
d	m	$0 < d$	$0 < d$	$d < D$	None	
q_m	kg/s	$0 \leq q_m$	$0 \leq q_m$	None	None	
μ	Pa-s	$0 < \mu$	$0 < \mu$	None	None	
C	-	$0 < C$	$0 < C$	$C < 1$	None	
R_D	-	$0 < R_D$	None	None	None	Miller, p.9-136
β	-	$0 < \beta$	$0.1 < \beta$	$\beta < 0.316$	$\beta < 1$	Miller, p.9-136

C12.1.9.2 Discharge Coefficient (Miller, p. 9-17)

The calculations for discharge coefficient are:

D ≥ 0.025 mm

$$\beta = \frac{d}{D}$$

$$R_D = \frac{4q_m}{\pi \mu D}$$

$$250\beta \le R_D \le 5000\beta \quad \Rightarrow C = 0.734$$

$$5000\beta \le R_D \le 200000\beta \quad \Rightarrow C = 0.730$$

C12.1.10 Small Bore Orifice (Small Diameter Orifice) Meter Runs With Flange Taps

C12.1.10.1 Symbol Table

The symbol table for the small bore orifice meter runs with flange taps is shown below.

Table C-9 Small Bore Orifice Meter Runs with Flange Taps Symbol Table

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain	Ref
D	m	0 < D	0.0254 ≤ D	D ≤ 0.0381	None	Fluid Meters, P.214
d	m	0 < d	0 < d	d < D	None	
q_m	kg/s	$0 \le q_m$	$0 \le q_m$	None	None	
μ	Pa-s	0 < μ	0 < μ	None	None	
C	-	0 < C	0 < C	C < 1	None	
R_D	-	$0 < R_D$	$1,000 < R_D$	None	None	Fluid Meters, P.214
β	-	0 < β	0.1 < β	β < 0.8	β < 1	Fluid Meters, P.214

C12.1.10.2 Discharge Coefficient (Fluid Meters, P.214)

The calculations for the discharge coefficient are:

$$\beta = \frac{d}{D}$$

$$R_D = \frac{4q_m}{\pi \mu D}$$

$$C = \left[0.5980 + 0.468\left(\beta^4 + 10\beta^{12}\right)\right]\left(1 - \beta^4\right)^{0.5} + \frac{\left(0.87 + 8.1\beta^4\right)\left(1 - \beta^4\right)^{0.5}}{R_D^{0.5}}$$

C12.1.11 Small Bore Orifice (Small Diameter Orifice) Meter Runs With Corner Taps

C12.1.11.1 Symbol Table

The symbol table for small bore orifice meter runs with corner taps is shown below.

Table C-10 Small Bore Orifice Meter Runs with Corner Taps

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain	Ref
D	m	$0 < D$	$0.0254 \le D$	$D \le 0.0381$	None	Fluid Meters, P.214
d	m	$0 < d$	$0 < d$	$d < D$	None	
q_m	kg/s	$0 \le q_m$	$0 \le q_m$	None	None	
μ	Pa-s	$0 < \mu$	$0 < \mu$	None	None	
C	-	$0 < C$	$0 < C$	$C < 1$	None	
R_D	-	$0 < R_D$	$1{,}000 < R_D$	None	None	Fluid Meters, P.214
β	-	$0 < \beta$	$0.1 < \beta$	$\beta < 0.8$	$\beta < 1$	Fluid Meters, P.214

C12.1.11.2 Discharge Coefficient (Fluid Meters, P.214)

The calculations for the discharge coefficient are:

$$\beta = \frac{d}{D}$$

$$R_D = \frac{4q_m}{\pi\mu D}$$

$$C = \left[0.5991 + \frac{0.11176}{D} + \left(0.3155 + \frac{0.4445}{D}\right)\left(\beta^4 + 2\beta^{16}\right)\right]\left(1 - \beta^4\right)^{0.5} + \left[\frac{13.2}{D} - 0.192 + \left(16.48 - \frac{29.46}{D}\right)\left(\beta^4 + 4\beta^{16}\right)\right]\frac{\left(1 - \beta^4\right)^{0.5}}{R_D^{0.5}}$$

Note: When calculating C, D is in mm.

C12.1.12 Restriction Orifice Plates

The Discharge Coefficient for restriction orifice plates is based on ISO 5167 (1991) for orifice plates with flange taps. Refer to Appendix C6, Section C6.3.2.3.

C12.2 Nozzles

C12.2.1 ISA 1932 Nozzle Discharge Coefficient

The Discharge Coefficient for ISA 1932 nozzles is calculated based on ISO 5167 (1991). Refer to §6.4.2.1 of the appendices.

C12.2.2 Long Radius Nozzle Discharge Coefficient

The Discharge Coefficients for both high-ratio and low-ratio nozzles are based on ISO 5167 (1991). Refer to §6.4.2.2 of the appendices.

C12.3 Classical Venturi Tubes and Venturi Nozzles

C12.3.1 Classical Venturi Tube with as-Cast Convergent Discharge Coefficients

Discharge Coefficients for classical venturi tubes with as-cast convergent is based on ISO 5167 (1991). Refer to §6.5.2.1.1 of the appendices.

C12.3.2 Classical Venturi Tube With a Machined Convergent Discharge Coefficients

Discharge Coefficients for classical venturi tubes with a machined convergent is based on ISO 5167 (1991). Refer to §6.5.2.2.1 of the appendices.

C12.3.3 Classical Venturi Tube With Rough Welded Convergent Discharge Coefficients

Discharge Coefficients for classical venturi tubes with a rough welded convergent is based on ISO 5167 (1991). Refer to §6.5.2.3.1 of the appendices.

C12.3.4 Venturi Nozzle Discharge Coefficients

Discharge Coefficient for a venturi nozzle is based on ISO 5167 (1991). Refer to §6.5.2.4.2 of the appendices.

C12.4 Orifice Plate Thickness Calculation

C12.4.1 Symbol Table

The symbol table for the orifice plate thickness calculation is shown below.

Table C-11 Orifice Plate Thickness Calculation Symbol Table

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain
D	m	0 < D	0 < D	None	None
ΔP	Pa	$0 < \Delta P$	$0 < \Delta P$	None	None
β	-	$0 < \beta$	$0 < \beta$	None	$\beta < 1$
σ_y	Pa	$0 < \sigma_y$	$0 < \sigma_y$	None	None
t_{min}	m	$0 < t_{min}$	$0.003 < t_{min}$	None	None

C12.4.2 Plate Thickness Calculations

The plate thickness calculation is:

$$t_{\min} \geq \left[\frac{(0.681-0.651\beta)\Delta P}{\sigma_y}\right]^{1/2} D$$

(Miller, p. 10-4, eq. 10.2)

Notes:

1. The calculated t_{min} will be compared with the value in the following table and the larger of the two values will be adopted.
   This method is used for all standards.
2. The thickness calculation does not apply to cryogenic applications.

Table C-12 Minimum Recommended Thickness of Orifice Plates (mm)

	Internal Diameter of Pipe (mm)				
Differential Pressure (in kPa)	**76.2 and less**	**150**	**250**	**500**	**800**
	$\beta < 0.5$				
< 249	3.18	3.18	4.76	9.53	12.7
< 49.8	3.18	3.18	3.18	6.35	9.53
< 24.9	3.18	3.18	3.18	6.35	9.53
	$\beta > 0.5$				
< 249	3.18	3.18	4.76	9.53	12.7
< 49.8	3.18	3.18	3.18	4.76	9.53
< 24.9	3.18	3.18	3.18	4.76	6.35

(Application: Part II of Fluid Meters, 6th ed. 1971, ASME p.198)

C12.5 Gas Expansion Factors

C12.5.1 Symbol Table

The symbol table for the gas expansion factors is shown below.

Table C-13 Gas Expansion Factors Symbol Table

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain
β	-	$0 < \beta$	Varies	Varies	$\beta < 1$
κ	-	$0 < \kappa$	$1 < \kappa$	$\kappa < 5$	None
P_1	P_q	$0 < P_1$	$0 < P_1$	None	None
P_2	P_q	$0 < P_2$	$0 < P_2$	$P_2 < P_1$	None
x_1	-	$0 < x_1$	None	None	None
x_2	-	$0 < x_2$	None	None	None
Y_1	-	$0 < Y_1$	None	$Y_1 \leq 1$	None
Y_2	-	$0 < Y_2$	None	$Y_2 \leq 1$	None

C12.5.2 Concentric Orifice Plate With Corner Taps, Flange Taps or Radius Taps

Gas expansion factors for orifice plates using corner taps, flange taps, or radius taps are given in §5.6 of the appendices, and are based on ISO 5167 (1991).

C12.5.3 Concentric Orifice Plate With Vena Contracta Taps

(Application: Part II of Fluid Meters, 6th ed. 1971, ASME p.208)

The calculations for the concentric orifice plate with vena contracta taps are:

$$x_1 = \frac{\Delta \mathrm{p}}{\mathrm{P}_1}$$

$$Y_1 = 1 - \left(0.41 + 0.35\beta^4\right) \frac{x_1}{\kappa}$$

$$x_2 = \frac{\Delta \mathrm{p}}{\mathrm{P}_2}$$

$$Y_2 = \sqrt{1+x_2} - \left(0.41 + 0.35\beta^4\right) \frac{x_2}{\kappa} \frac{1}{\sqrt{1+x_2}}$$

C12.5.4 Concentric Orifice Plate With Pipe Taps (Miller, p. 9-56)

The calculations for the concentric orifice plate with pipe taps are:

$$x_1 = \frac{\Delta p}{P_1}$$

$$Y_1 = 1 - \left(0.333 + 1.145\left(\beta^2 + 0.7\beta^5 + 12\beta^{13}\right)\right)\frac{x_1}{\kappa}$$

$$x_2 = \frac{\Delta p}{P_2}$$

$$Y_2 = \sqrt{1 + x_2} - \left[0.333 + 1.145\left(\beta^2 + 0.7\beta^5 + 12\beta^{13}\right)\right]\frac{x_2}{\kappa\sqrt{1 + x_2}}$$

C12.5.5 Eccentric Orifice Plate with Corner Taps, Flange 180° Offset Taps, Flange 90° Offset Taps, Vena Contracta 180° Offset or Vena Contracta 90° Offset (Miller, p. 9-56)

The calculations are:

$$x_1 = \frac{\Delta p}{P_1}$$

$$Y_1 = 1 - \left(0.1926 + 0.574\beta + 0.9675\beta^2 - 4.24\beta^3 + 3.62\beta^4\right)\frac{x_1}{\kappa}$$

$$x_2 = \frac{\Delta p}{P_2}$$

$$Y_2 = \sqrt{1 + x_2} - \left(0.1926 + 0.574\beta + 0.9675\beta^2 - 4.24\beta^3 + 3.62\beta^4\right)\frac{x_2}{\kappa\sqrt{1 + x_2}}$$

C12.5.6 Segmental Orifice Plate with Flange taps or Vena Contracta Taps

The gas expansion equation was determined by curve fitting the data in Application: Part II of Fluid Meters, 6th ed.1971, Figure II-III-12, ASME p.213.

$$x_1 = \frac{\Delta p}{P_1}$$

$$Y_1 = 1 - \left(0.741 + 1.850\beta - 4.940\beta^2 + 5.998\beta^3 - 2.409\beta^4\right)\frac{x_1}{\kappa}$$

$$x_2 = \frac{\Delta p}{P_2}$$

$$Y_2 = Y_1\sqrt{1 + x_2}$$

Note: Y_2 uses the form given in ISO 5167 (1991).

C12.5.7 Quadrant Edged Orifice Plate with Corner Taps or Flange Taps

Gas expansion factors for orifice plates using corner taps or flange taps are given in §6.4 of the appendices, and are based on ISO 5167 (1991).

C12.5.8 Conical Orifice Plate with Corner Taps

Gas expansion factors for orifice plates using corner taps are given in §6.4 of the appendices, and are based on ISO 5167 (1991).

C12.5.9 Small Bore Orifice (Small Diameter) Meter Runs With Flange Taps

Miller (p. 10-35) recommends that the gas expansion factor for a square-edged orifice with pipe taps be used. Refer to §9.5.4. of the appendices.

C12.5.10 Small Bore Orifice (Small Diameter) Meter Runs With Corner Taps

Miller (p. 10-35) recommends that the gas expansion factor for a square-edged orifice with flange, corner or radius taps be used. Refer to §5.6 of the appendices.

C12.5.11 ISA 1932 Nozzle with Corner Taps

Gas expansion factors for the ISA 1932 nozzle are calculated based on ISO 5167 (1991). Refer to §3.8.2.1 of the appendices.

C12.5.12 Long Radius Nozzle with Radius Taps, Wall Taps or Throat Taps

Gas expansion factors for the long radius nozzle are calculated based on ISO 5167 (1991). Refer to §6.5 of this document.

C12.5.13 Classical Venturi Tube with Throat Taps

Gas expansion factors for the classical venturi tube are calculated based on ISO 5167 (1991). Refer to §6.6 of this document.

C12.5.14 Venturi Nozzle with Throat Taps

Gas expansion factors for the venturi nozzle are calculated based on ISO 5167 (1991). Refer to §6.6 of this document.

C12.5.15 Restriction Flow Devices: Concentric Orifice with Pipe Taps

Gas expansion factors for restriction orifice plates are given in §9.5.3 of this document.

C12.6 Correction Factor for Steam Quality (Gas-Liquid) Flows

C12.6.1 Symbol Table

The symbol table for the correction factor for steam quality flows is shown below.

Table C-14 Correction Factor for Steam Quality Flows Symbol Table

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain
ρ_{g1}	kg/m^3	$0 < \rho_{g1}$	None	None	None
ρ_{iq}	kg/m^3	$0 < \rho_l$	None	None	None
ΔP	Pq	$0 < \Delta P$	None	None	None
F_x	-	None	None	None	None
ΔP_g	Pq	$0 < \Delta P$	None	None	None
Y_1		$0 \le Y_1$	$0.98 \le Y$	varies w/device	$Y \le 0$
β	-	$0 < \beta$	$0.25 \le \beta$	$\beta \le 0.5$	$\beta \le 1$
R_D	-	0	$100{,}000 < R_D$	None	None
C_g	-	$0 < C$	varies with device	None	
x	-	$0 < x$	$0.95 < x$	None	None

C12.6.2 Calculations (Miller, p. 9-76)

The two phase correction factor is based on the work of Murdock. The mass flow equation is:

$$q_{M,TC} = \frac{\pi}{4}\frac{Cg}{\sqrt{1-\beta^4}}F_x Y_1\sqrt{\rho_{g1}\Delta P}$$

(Miller, p. 9-77, eq. 9.89)

The quality of a gas/liquid mixture is defined as:

$$X = \frac{\text{Mass of Gas}}{\text{Total Mass of Mixture}}$$

The quality correction factor is defined as:

$$F_x = \frac{1}{X + 1.26\left(1 - X\right)\sqrt{\dfrac{\rho_{g1}}{\rho_{liq}}}}$$ (Miller, p. 9-77, eq. 9.87)

The discharge coefficient is calculated at the Reynolds number defined by the dry gas flow rate. The dry gas flow rate is given as:

$$\left(q_M\right)_g = X\left(q_M\right)_{TC}$$ (Miller, p. 9-77, eq. 9.86)

The gas expansion factor, Y_1, is calculated based on the dry gas differential pressure.

$$\Delta P_g = \frac{\Delta P}{\left[1 + \left[1.26\left(1 - X\right)/X\right]\sqrt{\dfrac{\rho_{g1}}{\rho_{liq}}}\right]^2}$$ (Miller, p. 9-78, eq. 9.91)

C12.7 Drain Hole Correction Factor

C12.7.1 Symbol Table

The symbol table for the drain hole correction factor is shown below.

Table C-15 Drain Hole Correction Factor Symbol Table

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain
d	m	$0 < d$	None	None	$d < D$
d_{DH}	m	$0 < d_{DH}$	None	$d_{DH} < 0.1\ d$	None
β	-	$0 < \beta$	None	None	$\beta < 1$
F_{DH}	-	$0 < F_{DH}$	None	None	None

C12.7.2 Calculations

C12.7.2.1 Square Edged Drain Hole in Orifice Plates

The calculation for the square edged drain hole in the orifice plates is:

$$F_{DH} = 1 + \sqrt{1 - \beta^4}\left(\frac{d_{DH}}{d}\right)^2$$ (Miller, p. 9-79, eq. 9.99)

C12.7.2.2 Square Edged Drain Hole in Nozzles and Venturis

The calculation for the square edged drain hole in nozzles and venturis is:

(Miller, p. 9-79, eq. 9.100)

$$F_{DH} = 1 + 0.6\sqrt{1 - \beta^4}\left(\frac{d_{DH}}{d}\right)^2$$

C12.7.2.3 Round Edged Drain Hole in Orifice Plates

The calculation for the round edged drain hole in orifice plates is:

(Miller, p. 9-79, eq. 9.101)

$$F_{DH} = 1 + 1.66\sqrt{1 - \beta^4}\left(\frac{d_{DH}}{d}\right)^2$$

C12.7.2.4 Round Edged Drain Hole in Nozzles and Venturis

The calculation for the round edged drain hole in nozzles and venturis is:

(Miller, p. 9-80, eq. 9.102)

$$F_{DH} = 1 + \sqrt{1 - \beta^4}\left(\frac{d_{DH}}{d}\right)^2$$

C12.8 Permanent Pressure Loss

C12.8.1 Symbol Table

The symbol table for permanent pressure loss is shown below.

Table C-16 Permanent Pressure Loss Symbol Table

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain
C	-	$0 < C$	None	$C < 1$	None
β	-	$0 < \beta$	varies with device		$\beta < 1$
ΔP	Pa	$0 < \Delta P$	varies with device		None
ϖ	Pa	$0 < \varpi$	None	None	$\varpi < \Delta P$

C12.8.2 Calculations

C12.8.2.1 Square Edged Orifice Plates with Flange Taps, Radius Taps and Corner Taps

Permanent pressure loss is calculated following ISO 5167. Refer to §4.11.2.1 of the appendices.

C12.8.2.2 Square Edged Orifice Plates with Pipe Taps and Quadrant Edged Orifice Plates

Miller recommends the following for square-edged and quadrant-edged orifice plates.

$$\varpi = (1 - 0.24\beta - 0.52\beta^2 - 0.16\beta^3)\Delta P$$ (Miller, p. 6-38)

C12.8.2.3 ISA 1932 Nozzles and Long Radius Nozzles (High and Low Ratios) with Radius Taps

Permanent pressure loss is calculated following ISO 5167 (1991). Refer to Section C2.11.2.3 of the appendices.

C12.8.2.4 Long Radius Low Ratio nozzles with Throat Taps

Permanent pressure loss is calculated following ASME MFC-3M-1989. Refer to Section C2.11.2.2 of the appendices.

C12.8.2.5 Venturi Tubes and Venturi Nozzles

Permanent pressure loss is calculated following ASME Standard MFC-3M-1989. Refer to Section C2.11.2.3 of the appendices.

C12.9 Vena Contracta Location

Note: Currently this calculation is not implemented.

C12.9.1 Symbol Table

The symbol table for vena contracta location is shown below.

Table C-17 Vena Contracta Location Symbol Table

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain
β	-	$0 < \beta$			$\beta < 1$
D	m	0 < D			
x	m	0 < x			

C12.9.2 Vena Contracta Location Calculations

Vena contracta locations for square edged, segmental, and eccentric orifice plates were determined by curve fitting to figure II-III-3 and figure II-III-8, Application Part II of Fluid Meters, AMSE, 6th. ed, 1971.

C12.9.2.1 Concentric Orifice Plates

The concentric orifice plates calculation is:

$$x/D = 1.1265 + \beta\left(-0.7118 + \beta\left(0.9644 - 1.571\beta\right)\right)$$

C12.9.2.2 Eccentric Orifice Plates

The eccentric orifice plates calculation is:

$$x/D = 1.0699 + \beta\left(-1.2443 + \beta\left(3.6310 - 3.651\beta\right)\right)$$

C12.9.2.3 Segmental Orifice Plates

The segmental orifice plates calculation is:

$$x/D = 1.643 + \beta\left(-6.1431 + \beta\left(18.639 + \beta\left(-24.04 + 10.494\beta\right)\right)\right)$$

C12.10 Critical Flow Calculations

C12.10.1 Symbol Table

The symbol table for critical flow calculations is shown below.

Table C-18 Critical Flow Calculations Symbol Table

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain
d	m	$0 < d$	None	None	$d < D$
D	m	$0 < D$	None	None	None
t_p	m	$0 < t_p$	None	None	$t_p < D$
β	-	$0 < \beta$	varies with device		$\beta < 1$
R_d	-	$0 < R_d$	None	None	None
P_1	Pa	$0 < P_1$	$P_2 < P_1$	None	None
P_2	Pa	$0 < P_2$	None	$P_2 < P_1$	None
P_v	Pa	$0 < P_v$	None	None	None
κ	-	$0 < \kappa$	None	None	None
ρ	°	$0 < \rho$	None	None	None
Z	-	$0 < Z$	None	None	None
C	-	$0 < C$	None	$C < 1$	None
Qm	kg/s	$0 < Q$	None	None	None

C12.10.2 Discharge Coefficients

C12.10.2.1 Orifice Plate 1d to 6d Thick

The discharge coefficient for the orifice plate, 1d to 6d thick is:

$d \le t_p \le 6d \qquad C = 0.83932$ (Miller, p. 13-23, eq. 13.23)

C12.10.2.2 Orifice Plate 6d to 20d Thick

The discharge coefficient for the orifice plate, 6d to 20d thick is:

$6\mathrm{d} \le \mathrm{t_p} \le 20\mathrm{d} \qquad \mathrm{C} = 0.899$ (Miller, p. 13-30)

C12.10.3 Liquid Calculations

Liquid choked flow only occurs when a cavitation barrier exists in the flow device. The design pressure drop is given by Miller as:

$\Delta P = P_1 - P_v$ (Miller, p. 13-29, eq. 13.26)

C12.10.4 Critical Flow Function

The critical flow function calculation is:

$$\mathrm{Y_{cr}} = \sqrt{\frac{\kappa}{\mathrm{Z}} \left(\frac{2}{\kappa + 1} \right)^{\left(\frac{\kappa + 1}{\kappa - 1} \right)}}$$

(Miller, p. 13-5, eq. 13.14)

C12.10.5 Flow Rate Calculation

Note: C could be a function of Re and/or β therefore iteration would be required.

$$\mathrm{Qm} = \mathrm{C} \frac{\mathrm{d}^2}{4\pi} \mathrm{Y_{cr}} \sqrt{\mathrm{Z} \rho \mathrm{P}}$$

(ASME/ANSI standard MFC-7M-1987, p. 5)

C12.11 Gas Sonic Flow Rate Check

C12.11.1 Symbol Table

The symbol table for gas sonic flow rate check is shown below.

Table C-19 Gas Sonic Flow Rate Check Symbol Table

Symbol	Units	Lower Domain	Lower Limit	Upper Limit	Upper Domain
k	-	1 < k	None	None	None
P_1	P_q	$0 < P_1$	None	None	None
P_s	P_q	$0 < P_s$	None	$P_s < P_1$	None

C12.11.2 Calculation

Although the following equation applies strictly to ASME long-radius nozzles and a thick square-edged orifice (Miller, p.13-25), the equation has been extended to all the differential pressure devices as a means to provide a check for sonic flow rates.

$$P_s = \frac{P_1\left(\frac{2}{k+1}\right)^{\frac{k}{k-1}}}{\left[1-\frac{k}{2}\left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}\beta^4\right]}$$

(Miller, p. 13-24, eq. 13, 24)

At sonic flow rates and greater, the equations used in this program to calculate flow rate are no longer valid.

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C13 References

Each reference in the text has a name and page number or paragraph number with it. For example, "(Miller, P.49)" would indicate that the entry is referenced from the book by R.W. Miller, on page 49.

The following references are acknowledged as sources, and are directly quoted within this manual:

- AGA Report No.3, Orifice Metering of Natural Gas and Other Related Hydrocarbon Fluids, Part 1, General Equations and Uncertainty Guidelines, Third Edition, Oct. 1990, It's also called API Manual of Petroleum Measurement Standard, Chapter 14.3 and GPA 8185-90.
- AGA Report No.3, Orifice Metering of Natural Gas and Other Related Hydrocarbon Fluids, Part 2, Specifications and Installation Requirements, Fourth Edition, April 2000, It's also called API Manual of Petroleum Measurement Standard, Chapter 14.3 and GPA 8185-92, ANSI/API 2530-92.
- AGA Report No.3, Orifice Metering of Natural Gas and Other Related Hydrocarbon Fluids, Part 3, Natural Gas Applications, Third Edition, Aug. 1992, It's also called API Manual of Petroleum Measurement Standard, Chapter 14.3 and GPA 8185-92, ANSI/API 2530-92.
- AGA Report No.3, Orifice Metering of Natural Gas and Other Related Hydrocarbon Fluids, Second Edition, Aug. 1985, It's also called API Manual of Petroleum Measurement Standard, Chapter 14.3, GPA 8185-85 and ANSI/API 2530.
- AGA Report No. 8, Compressibility Factors of Natural Gas and Other Related Hydrocarbon Gasses, Second Edition Nov. 1992.
- AGA Report No. 10, Speed of Sound in Natural Gas and Other Related Hydrocarbon Gasses, 2003.
- ASME MFC-3M-1989, Measurement of Fluid Flow in Pipes Using Orifice, Nozzle and Venturi, New York, 1990.
- ASME Fluid Meter, 6th Edition, ASME, New York, 1971.
- ASME/ANSI MFC-7M-1987, Measurement of Gas Flow by Means of Critical Flow Venturi Nozzles, New York, 1987.
- ASME MFC 14M-2003, Measurement of Fluid Flow Using Small Bore Precision Orifice Meters, April 2003.
- ANSI/ASME PTC 6-1976, Steam Turbines, Yew York, 1982 (Reaffirmed in 1991).
- BS 1024: Section 1.2, 1989, Measurement of Fluid Flow in Closed Conduit, 1989.

- ISO 5167-1, Measurement of Fluid Flow by Means of Pressure Differential Devices, Part 1: Orifice plates, nozzles and venturi tubes inserted in circular cross-section conduits running full, First Edition, Switzerland, 1991.
- ISO 5168, Measurement of Fluid Flow --Estimation of Uncertainty of Flow Rate Measurement, First Edition, Switzerland, 1978.
- ISO 5167-1, Measurement of Fluid Flow by Means of orifice plates, nozzles and venturi tubes inserted in circular cross-section conduits running full, First Edition, Switzerland, 1980.
- ISO/TR15377:1998, Measurement of Fluid Flow by means of pressure-differential devices – Guidelines for the specification of nozzles and orifice plates beyond the scope of ISO 5167-1.
- R.W. Miller Flow Measurement Engineering Handbook, Second Edition, McGraw-Hill, New York, 1989.
- R.W. Miller Flow Measurement Engineering Handbook, Third Edition, McGraw-Hill, New York, 1996.

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D Other Formulas and Calculations

D.1 Atmospheric Pressure Calculation

The atmospheric pressure is calculated by the following equation:

$$\mathrm{P} = 1.01325 - 1.20155107\times10^{-4}\,y + 5.75887513\times10^{-9}\,y^{2} - 1.27825937\times10^{-13}\,y^{3}$$

Where: P = pressure (bar)
y = altitude (m)

The equation is a curve fitting of the data presented in the CRC Handbook of Chemistry and Physics 64th Edition, 1983-1984, p.F-155 to F-157. In order to convert the pressure into the required unit given the selected units of altitude, appropriate conversion factors are applied.

The atmospheric pressure is used when a gauge flowing pressure unit is selected (designated by the suffix “-g”, i.e., bar-g) to calculate an absolute pressure.

absolute pressure = flowing gauge pressure + atmospheric pressure

The absolute pressure can be required in other calculations.

D.2 Definition of C´

C´ is defined as:

$$C' = \frac{flowrate}{\sqrt{\Delta \mathrm{p}}} \quad \text{(for liquid)}$$

$$C' = \frac{flowrate}{\sqrt{\Delta \mathrm{P}\ \mathrm{P}_f}} \quad \text{(for gas)}$$

Where: $\mathrm{P_f}$ is in absolute units.

If you select a gauge pressure unit (i.e., psig) Flowel automatically converts to the corresponding absolute pressure unit (e.g. psia) before calculating C'.

D.3 Uncertainty

The uncertainty calculation uses the root of sum of squares method. The equation is as follows:

$$E_q = \left[E_C^2 + E_Y^2 + 4E_d^2 \left(\frac{1}{1-\beta^4} \right)^2 + \frac{1}{4} E_\rho^2 + \frac{1}{4} E_{\Delta P}^2 + 4E_D^2 \left(\frac{\beta^4}{1-\beta^4} \right)^2 \right]^{0.5}$$

(eq.15, ISO 5168, 1978, p.19)

Where: E = percentage uncertainty in variable
Q = flow rate
C = discharge coefficient
Y = expansibility coefficient
d = bore diameter of orifice
ρ = density of fluid
ΔP = differential pressure
D = inside pipe diameter
β = beta ratio

The value of E_C and E_Y are determined by the standard (e.g., AGA 3 (1985)). These values depend primarily on the element type selected and cannot be altered by the users. E_d and E_D are initially set to the value given in the standard selected, but they can be re-defined by the user (see Chapter 3, User Reference for details). By default, $E\rho$ and $E_{\Delta P}$ are initially set to zero; however, the user may assign other values.

Notes:

1. A flow calculation must precede an uncertainty calculation.
2. If the limiting variable range is exceeded, no uncertainty is calculated.
3. For critical flow applications, no uncertainty is calculated.

The uncertainty tables for each standard are listed in Table D-1 below.

Table D-1 Uncertainty Tables

Element	Range of Limiting Variable	Variable	Uncertainty in Variable (+/- %)
AGA 3 (1992)			
Orifice Plate – standard	β > 0.175	C	$\left(1+1\left(\frac{4000}{R_D}\right)^{0.8}\right)\left(0.5600-0.255\beta+1.9316\beta^8\right)$
Orifice Plate – standard	β ≤ 0.175	C	$\left(1+1\left(\frac{4000}{R_D}\right)^{0.8}\right)\left(0.7000-1.0550\beta\right)$
Orifice Plate – standard	β ≤ 0.75	Y	$4\left(\frac{\Delta P}{P}\right)$
Orifice Plate – standard		D	0.5
Orifice Plate – standard	d ≤ 0.00635m	d	$\frac{0.00000762\text{m}}{\text{d}}$
Orifice Plate – standard	0.006375m ≤ d ≤ 0.009525m	d	$\frac{0.001016\text{m}}{\text{d}}$
Orifice Plate – standard	0.009527m ≤ d ≤ 0.0254μ	d	$\frac{0.00127\text{m}}{\text{d}}$
Orifice Plate – standard	0.0254m < d	d	0.05
AGA 3 (1985)			
Orifice Plate – standard (flange taps)	0.15 < β < 0.70	$\frac{C}{\sqrt{1-\beta^4}}$	0.5
Orifice Plate – standard (pipe taps)	0.20 < β < 0.67	$\frac{C}{\sqrt{1-\beta^4}}$	0.75
Orifice Plate – standard (flange taps)	0.10 < β < 0.8	Y	0.5
Orifice Plate – standard (pipe taps)	0.10 < β < 0.7	Y	0.5
Orifice Plate – standard (flange taps)	β = 0.75	D	0.5
Orifice Plate – standard (pipe taps)	β = 0.75	D	0.2
Orifice Plate – standard	d ≤ 0.000635m	d	$\frac{0.000762\text{m}}{\text{d}}$
Orifice Plate – standard	0.0006357m ≤ d ≤ 0.009523m	d	$\frac{0.001016\text{m}}{\text{d}}$

Element	Range of Limiting Variable	Variable	Uncertainty in Variable (+/- %)
Orifice Plate – standard	0.009527m ≤ d ≤0.0254μ	d	$\frac{0.00127m}{d}$
Orifice Plate – standard	0.0254μ<d	d	0.05
ISO 5167 (1991)			
Orifice plate – standard (all taps)	$\beta \le 0.6$	C	0.6
Orifice plate – standard (all taps)	$0.6 < \beta \le 0.75$	C	β
Orifice plate – standard (all taps)		Y	$4\left(\frac{\Delta P}{P}\right)$
Orifice plate – standard (all taps)		D	0.3
Orifice plate – standard (all taps)		d	0.05
Nozzle – ISA 1932	$\beta \le 0.6$	C	0.8
Nozzle – ISA 1932	$0.6 < \beta$	C	$2\beta - 0.4$
Nozzle – ISA 1932		Y	$2\left(\frac{\Delta P}{P}\right)$
Nozzle – ISA 1932		D	2
Nozzle – ISA 1932		d	0.05
Nozzle – Long Radius (high or low ratio)	$0.2 < \beta < 0.8$	C	2.0
Nozzle – Long Radius (high or low ratio)		Y	$2\left(\frac{\Delta P}{P}\right)$
Nozzle – Long Radius (high or low ratio)		D	2
Nozzle – Long Radius (high or low ratio)		d	0.05
Venturi (cast)		C	0.7
Venturi (machined)		C	1.0
Venturi (welded)		C	1.5
Venturi (all types)		Y	$\left(4+100\beta^{8}\right)\frac{\Delta P}{P}$
Venturi (all types)		D	2
Venturi (all types)		d	0.1
Venturi Nozzle		C	$1.2+1.5\beta^{4}$
Venturi Nozzle		Y	$\left(4+100\beta^{8}\right)\frac{\Delta P}{P}$

Element	Range of Limiting Variable	Variable	Uncertainty in Variable (+/- %)
Venturi Nozzle		D	2
Venturi Nozzle		c	0.1
ISO 5167 (1980)			
Orifice Plate – Standard (all taps)	$\beta \le 0.6$	C	0.6
Orifice Plate – Standard (corner taps)	$0.6 < \beta < 0.8$	C	β
Orifice Plate – Standard (flange or radius taps)	$0.6 < \beta \le 0.75$	C	β
Orifice Plate – Standard (all taps)	$\beta \le 0.6$	Y	$4\left(\frac{\Delta P}{P}\right)$
Orifice Plate – Standard (corner taps)	$0.75 < \beta \le 0.8$	Y	$8\left(\frac{\Delta P}{P}\right)$
Orifice Plate – Standard (all taps)		D	0.3
Orifice Plate – Standard (all taps)		d	0.05
Nozzle – ISA 1932	$\beta \le 0.6$	C	0.8
Nozzle – ISA 1932	$0.6 < \beta$	C	$2\beta - 0.4$
Nozzle – ISA 1932		Y	$2\left(\frac{\Delta P}{P}\right)$
Nozzle – ISA 1932		D	0.3
Nozzle – ISA 1932		d	0.05
Nozzle – Long Radius (high or low ratio)	$0.2 < \beta < 0.8$	C	2.0
Nozzle – Long Radius (high or low ratio)		Y	$2\left(\frac{\Delta P}{P}\right)$
Nozzle – Long Radius (high or low ratio)		D	0.3
Nozzle – Long Radius (high or low ratio)		d	0.05
Venturi (cast)		C	0.7
Venturi (machined)		C	1.0
Venturi (welded)		C	1.5
Venturi (all types)		Y	$\left(4+100\beta^{8}\right)\frac{\Delta P}{P}$
Venturi (all types)		D	2

Element	Range of Limiting Variable	Variable	Uncertainty in Variable (+/- %)
Venturi (all types)		d	0.1
Venturi Nozzle	$0.065\text{m} \le D \le 0.500\text{m}$ $0.050\text{m} \le d$ $0.316 \le \beta \le 0.775$ $1.5 \times 10^5 \le R_D \le 2 \times 10^6$	$\frac{C}{\sqrt{1-\beta^4}}$	$1.2 + 1.5\beta^4$
Venturi Nozzle		Y	$\left(4+100\beta^8\right)\frac{\Delta P}{P}$
Venturi Nozzle		D	0.3
Venturi Nozzle		d	0.05
ASME MFC-3M			
Orifice plate (all taps)	$10000 < R_D \le 10^8$ $0.2 < \beta \le 0.6$ $0.0429\text{m} \le D \le 0.900\text{m}$	C	0.6
Orifice plate (all taps)	$10000 < R_D \le 10^8$ $0.6 < \beta < 0.75$ $0.0429\text{m} \le D \le 0.900\text{m}$	C	β
Orifice plate (all taps)	$2000 < R_D \le 10000$ $0.2 < \beta < 0.75$ $0.0429\text{m} \le D \le 0.900\text{m}$	C	$0.6 + \beta$
Orifice plate (all taps)		Y	$4\left(\frac{\Delta P}{P}\right)$
Orifice plate (all taps)		D	0.25
Orifice plate (all taps)	$0.025\text{m} \le d$	d	0.05
Orifice plate (all taps)	$0.010\text{m} \le d < 0.025\text{m}$	d	$\frac{0.01}{d}$
Nozzle – long radius (high ratio - wall tap)	$0.1\text{m} \le D \le 0.750\text{m}$ $0.50 \le \beta \le 0.80$ $10^4 \le R_D \le 6\text{x}10^6$ $0.75 \le P_2/P_1$	C	2.0
Nozzle – long radius (low ratio - wall tap)	$0.1\text{m} \le D \le 0.750\text{m}$ $0.20 \le \beta \le 0.50$ $10^4 \le R_D \le 6\text{x}10^6$ $0.75 \le P_2/P_1$	C	2.0
Nozzle – long radius (throat tap)	$0.1\text{m} \le D \le 0.750\text{m}$ $0.25 \le \beta < 0.50$ $10^4 \le R_D \le 6\text{x}10^6$ $0.75 \le P_2/P_1$	C	0.25

Element	Range of Limiting Variable	Variable	Uncertainty in Variable (+/- %)
Nozzle – long radius (all types)		Y	$2\left(\frac{\Delta P}{P_1}\right)$
Nozzle – long radius (throat tap)		D	0.25
Nozzle – long radius (throat tap)		d	0.05
Venturi (all types)		C	1.0
Venturi (all types)		Y	$\left(4+100\beta^{8}\right)\frac{\Delta P}{P}$
Venturi (all types)		D	0.25
Venturi (all types)		d	0.1
BS 1042			
Orifice plate (conical entrance)		C	2
Orifice plate (conical entrance)		Y	33(1-Y)
Orifice plate (conical entrance)		D	0.3
Orifice plate (conical entrance)		d	0.05
Orifice plate (quadrant edged)	$0.316 < \beta$	C	2
Orifice plate (quadrant edged)	$\beta \leq 0.316$	C	2.5
Orifice plate (quadrant edged)	$\beta \leq 0.6$	Y	$4\left(\frac{\Delta P}{P}\right)$
Orifice plate (quadrant edged)		D	0.3
Orifice plate (quadrant edged)		d	0.1
Orifice plate (eccentric)	$\beta \leq 0.75$	C	1
Orifice plate (eccentric)	$0.75 < \beta$	C	2
Orifice plate (eccentric)		Y	$4\left(\frac{\Delta P}{P}\right)$
Orifice plate (eccentric)		D	0.3
Orifice plate (eccentric)		d	0.05

Note: For all general methods, other than those referenced to a standard, the default uncertainty of d and D is zero.

The discharge coefficients and expansion coefficients for general standards are shown in Table D-2 and Table D-3.

Table D-2 Discharge Coefficients – General Standard

Element	Range of Limiting Variable	Variable	Uncertainty in Variable (+/- %)
Orifice plate – Standard (corner, flange or radius taps)	See ISO 5167 (1991)		
Orifice plate – Standard (pipe taps)	$0.0429m \le D \le 0.900m$ $0.2 \le \beta \le 0.5$ $10^4 \le R_D \le 10^7$	C	0.8
Orifice plate – Standard (pipe taps)	$0.0429m \le D \le 0.900m$ $0.51 \le \beta \le 0.7$ $10^4 \le R_D \le 10^7$	C	1.6
Orifice plate – Standard (vena contracta taps)	$0.0429m \le D \le 0.900m$ $0.2 \le \beta \le 0.6$ $10^4 \le R_D \le 10^7$	C	0.6
Orifice plate – Standard (vena contracta taps)	$0.0429m \le D \le 0.900m$ $0.6 \le \beta \le 0.75$ $10^4 \le R_D \le 10^7$	C	β
Orifice plate – Standard (vena contracta taps)	$0.0429m \le D \le 0.900m$ $0.2 < \beta \le 0.75$ $2x10^3 \le R_D \le 10^4$	C	$0.6 + \beta$
Orifice plate – Eccentric (flange or vena contracta taps)	$0.100m \le D \le 0.150m$ $0.35 \le \beta \le 0.75$ $10^4 \le R_D \le 10^6$	C	2
Orifice plate – Eccentric (flange or vena contracta taps)	$0.150m \le D \le 0.350m$ $0.35 \le \beta \le 0.75$ $10^4 \le R_D \le 10^6$	C	1.5
Orifice plate – Segmental (flange or vena contracta taps)	$0.150m \le D \le 0.350m$ $0.35 \le \beta \le 0.75$ $10^4 \le R_D \le 10^6$	C	2
Orifice plate – Quadrant Edged (corner or flange taps)	$0.025m \le D \le 0.750m$ $0.24 \le \beta \le 0.6$		2
Orifice Plate – conical entrance	$0.025m < D$ $0.1 \le \beta \le 0.316$	C	2
Honed Orifice Meter Run	$0.012m \le D \le 0.040m$ $0.1 \le \beta \le 0.8$ $1000 < R_D$	C	0.75
All nozzles and Venturis	See ISO 5167 (1991)		

Table D-3 Expansion Coefficients

Element	Variable	Uncertainty in Variable (+/- %)
Orifice plate – Conical entrance, quadrant edged or honed meter run (all tap types)	Y	$4\left(\frac{\Delta P}{P}\right)$
Orifice plate – Standard (pipe taps)	Y	$8\left(\frac{\Delta P}{P}\right)$
Orifice plate – Standard (vena contracta taps)	Y	$4\left(\frac{\Delta P}{P}\right)$
Orifice plate – Eccentric or Segmental (all tap types)	Y	$8\left(\frac{\Delta P}{P}\right)$

D.4 Conversion Factors

The conversion factors for various volumetric flow rate, mass flow rate, density, temperature, absolute pressure, length, viscosity, gross heating value, and thermal expansion conversions are listed in Table D-4 to Table D-12.

Table D-4 Volumetric Flow Rate Conversions

To Convert From	To	Multiply or Divide[1] By
USGPS	L/sec	3.785412*
NUSGPS	L/sec	3.785412*
SUSGPS	L/sec	3.785412*
USGPM	L/sec	3.785412*60/
NUSGPM	L/sec	3.785412*60/
SUSGPM	L/sec	3.785412*60/
USGPH	L/sec	3.785412*3600/
NUSGPH	L/sec	3.785412*3600/
SUSGPH	L/sec	3.785412*3600/
USGPD	L/sec	3.785412*24/3600/
NUSGPD	L/sec	3.785412*24/3600/
SUSGPD	L/sec	3.785412*24/3600/
USBPH	L/sec	42*3.785412*3600/
NUSBPH	L/sec	42*3.785412*3600/
SUSBPH	L/sec	42*3.785412*3600/
USBPD	L/sec	42*3.785412*24/3600/
NUSBPD	L/sec	42*3.785412*24/3600/
SUSBPD	L/sec	42*3.785412*24/3600/
IMPGPS	L/sec	4.546087*
NIMPGPS	L/sec	4.546087*
SIMPGPS	L/sec	4.546087*

To Convert From	To	Multiply or Divide[1] By
IMPGPM	L/sec	4.546087*60/
NIMPGPM	L/sec	4.546087*60/
SIMPGPM	L/sec	4.546087*60/
IMPGPH	L/sec	4.546087*3600/
NIMPGPH	L/sec	4.546087*3600/
SIMPGPH	L/sec	4.546087*3600/
IMPGPD	L/sec	4.546087*24/3600/
NIMPGPD	L/sec	4.546087*24/3600/
SIMPGPD	L/sec	4.546087*24/3600/
IMPBPH	L/sec	36*4.546087*3600/
NIMPBPH	L/sec	36*4.546087*3600/
SIMPBPH	L/sec	36*4.546087*3600/
IMPBPD	L/sec	36*4.546087*24/3600/
NIMPBPD	L/sec	36*4.546087*24/3600/
SIMPBPD	L/sec	36*4.546087*24/3600/
CFS	L/sec	.03531467/
SCFS	L/sec	.03531467/
NCFS	L/sec	.03531467/
CFM	L/sec	.03531467/60/
SCFM	L/sec	.03531467/60/
NCFM	L/sec	.03531467/60/
CFH	L/sec	.03531467/3600/
SCFH	L/sec	.03531467/3600/
NCFH	L/sec	.03531467/3600/
CFD	L/sec	.03531467/24/3600/
SCFD	L/sec	.03531467/24/3600/
NCFD	L/sec	.03531467/24/3600/
L/sec	L/sec	1*
NL/sec	L/sec	1*
SL/sec	L/sec	1*
L/min	L/sec	60/
NL/min	L/sec	60/
SL/min	L/sec	60/
L/hr	L/sec	3600/
NL/hr	L/sec	3600/
SL/hr	L/sec	3600/
L/day	L/sec	24/3600/
NL/day	L/sec	24/3600/
SL/day	L/sec	24/3600/

To Convert From	To	Multiply or Divide[1] By
m3/sec	L/sec	1000*
Sm3/sec	L/sec	1000*
Nm3/sec	L/sec	1000*
m3/min	L/sec	1000*60/
Sm3/min	L/sec	1000*60/
Nm3/min	L/sec	1000*60/
m3/hr	L/sec	1000*3600/
Sm3/hr	L/sec	1000*3600/
Nm3/hr	L/sec	1000*3600/
m3/day	L/sec	1000*24/3600/
Sm3/day	L/sec	1000*24/3600/
Nm3/day	L/sec	1000*24/3600/
hL/hr	L/sec	100*3600/
NhL/hr	L/sec	100*3600/
ShL/hr	L/sec	100*3600/
hL/day	L/sec	100*24/3600/
NhL/day	L/sec	100*24/3600/
ShL/day	L/sec	100*24/3600/

[1] To determine whether to multiply or divide, identify the last character in this column. If the character is *, multiply; if the character is /, divide.

Mass flow rate conversions are listed below.

Table D-5 Mass Flow Rate Conversions

To Convert From	To	Multiply or Divide[1] By
lb/sec	kg/sec	2.204623/
lb/min	kg/sec	2.204623/60/
lb/hr	kg/sec	2.204623/3600/
lb/day	kg/sec	2.204623/24/3600/
ton/sec	kg/sec	2000*2.204623/
ton/min	kg/sec	2000*2.204623/60/
ton/hr	kg/sec	2000*2.204623/3600/
ton/day	kg/sec	2000*2.204623/24/3600/
kg/sec	kg/sec	1*
kg/min	kg/sec	60/
kg/hr	kg/sec	3600/
kg/day	kg/sec	3600/24/
tonne/sec	kg/sec	1000*
tonne/min	kg/sec	1000*60/
tonne/hr	kg/sec	1000*3600/

To Convert From	To	Multiply or Divide[1] By
tonne/day	kg/sec	1000*3600/24/
[1] To determine whether to multiply or divide, identify the last character in this column. If the character is *, multiply; if the character is /, divide.		

Density conversions are listed in the table below.

Table D-6 Density Conversions

To Convert From	To	Multiply or Divide[1] By
kg/m3	kg/m3	1*
kg/dm3	kg/m3	1000*
g/cm3	kg/m3	1000*
lb/ft3	kg/m3	.06242797/
[1] To determine whether to multiply or divide, identify the last character in this column. If the character is *, multiply; if the character is /, divide.		

Temperature conversions are listed below.

Table D-7 Temperature Conversions

To Convert From	To	Formula
DEG F	DEG C	(DEG F-32)/1.8
DEG R	DEG C	(DEG R-459.67)/1.8
DEG C	DEG C	1
DEG K	DEG C	DEG K -273.15

Absolute pressure conversions are listed in the table below.

Table D-8 Absolute Pressure Conversions

To Convert From	To	Multiply By
mm-H2O (60 Deg F)	kPa	0.00980315*
atm	kPa	101.325*
kPa	kPa	1*
MPa	kPa	1000*
kg/cm2	kPa	6.894757*14.22334*
psia	kPa	6.894757*
in-H2O (60 Deg F)	kPa	0.249*
Bar	kPa	100*

Length conversions are listed in the table below.

Table D-9 Length Conversions

To Convert From	To	Multiply By
mm	mm	1*
cm	mm	10*
m	mm	1000*
micron	mm	0.001*
in	mm	25.4*
ft	mm	304.8*
yd	mm	914.4*

Viscosity conversions are listed in the following table.

Table D-10 Viscosity Conversions

To Convert From	To	Multiply or Divide[1] By
Pa.sec	cP	1000*
mPa.sec	cP	1*
gm/cm.sec	cP	100*
P	cP	100*
cP	cP	1*
kg/m.hr	cP	3.60/
lb/ft.sec	cP	0.000672/
lb/ft.hr	cP	2.419/
lb/in.sec	cP	0.000056/
gmf.sec/cm2	cP	0.0000102/
lbf.sec/in2	cP	0.000000145/
N.sec/m2	cP	1000*
[1] To determine whether to multiply or divide, identify the last character in this column. If the character is *, multiply; if the character is /, divide.		

Gross heating value conversions are listed in the table below.

Table D-11 Gross Heating Value Conversions

To Convert From	To	Multiply or Divide[1] By
kJ/dm3	MJ/m3	1*
kJ/m3	MJ/m3	1000/
MJ/m3	MJ/m3	1*
Btu/ft3	MJ/m3	28.316846592/1.055056*
Btu/in3	MJ/m3	0.016387064/1.055056*
kcal/m3	MJ/m3	1000/4.1841*
[1] To determine whether to multiply or divide, identify the last character in this column. If the character is *, multiply; if the character is /, divide.		

Thermal expansion conversions are listed in the table below.

Table D-12 Thermal Expansion Conversions

To Convert From	To	Multiply or Divide[1] By
mm/(mm C)	mm/(mm C)	1*
in/(in F)	mm/(mm C)	1.8/
[1] To determine whether to multiply or divide, identify the last character in this column. If the character is *, multiply; if the character is /, divide.		

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