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General description: FlowCalc32 CE.

General

One common method to measure the flow rate in pipe is to insert an orifice plate, nozzle or venturi tube and measure the drop of pressure that arises when the media passes.

The formula for the relation between flow and differential pressure can very simplified be stated as: $Q=C\sqrt{h}$ where Q =flow C =constant and h =differential pressure.

The method of measuring flow with orifices is old and very well documented. The standardized orifices have been studied for many years by independent experts. Probably no other flow measurement method has been as firmly studied and documented. This huge research effort means that all calculation formulas and data such as accuracy, rules of installation etc are very precise.

The information required for installation, calculation and construction is documented in the standards ISO 5167. Generally for orifice plates, the expected accuracy is better then 0.8 % if you follow the rules of installation in the standard.

The different primary devices have different characteristics and some are better suited for a specific application then others:

- Orifice plate with corner tapping. This is the most common primary device. Corner tapping represents an orifice plate with the pressure taps immediately before and after the orifice plate.
- Orifice plate with flange tapping. This is orifice plates with pressure tapping in the pipe flanges.
- Orifices with “D-D/2 tapping”. This orifice has its pressure tapping, one pipe diameter before and ½ pipe diameter after the orifice plate.
- Venturi tubes can be used when the remaining loss of pressure is to be minimized. These devices are also very hard to wear out and are sometimes used for measurement of steam.



- Nozzles have a similar field of use.
- Classical venturi tubes are most often used in larger pipes for gas and air.

The advantages of orifice plates are that you attain high accuracy and that they can be used for widely different operation conditions. The limitations are most often found in the difficulties to measure very small differential pressures in liquids

Possibilities with FlowCalc32 CE

With FlowCalc32 you can do accurate calculations of orifice plates, nozzles or venturi tubes in quick and easy. You will have full control over your calculated gauges and can easily see how a change of process data (temperature etc.) will affect the measurement of the flow.

It is also possible to control how variation in pressure and temperature affect the measurement and to find out the accuracy for the compensation formulas used in practice.

Specifications:

Variables that are solved:

- Orifice bore diameter
- Flow
- Differential pressure.

Orifice devices that FlowCalc32 CE handles:

- Orifice plates with different pressure tapping.
- Venturi nozzles
- Classical venturi in different materials
- ISA-1932 nozzles.
- Long radius nozzles.

Media that FlowCalc32 CE calculates:

- Gas
- Liquid
- Steam
- Water

Unit conversions that FlowCalc32 CE handles:

- Pressure
- Differential pressure
- Volume flow
- Mass flow
- STP (standardized condition for gas)
- Dynamic viscosity



- Density
- Temperature

Performance

The program calculates density and viscosity for steam and water according to IFC: s formulas for industrial use with an accuracy that in tests has been found to be better then 0.05 %.

All data is saved in a database and FlowCalcs file manager makes it easy to search for and edit old calculations, make copies or new calculations.

FlowCalc32 CE checks that the primary device parameters are within the limits specified in the standards. If any parameter is out of range there is a clear warning and this warning is also included on printouts. You can manually adjust your data to get the primary device within the limits of the standard.

The program uses a standardized windows interface.

All data required for a calculation is entered on a single form. The form adjusts itself depending on previously entered values.

FlowCalc32 CE supports all printers installed in Windows.

You can enter text as information for every primary device. This text will also be included in printouts.

Copyrights

The documentation and software for FlowCalc32 CE is protected by international laws.

The documentation and software may not be copied, altered, reproduced, translated or in any way converted to any other medium without written permission from Control Engineering Sweden AB.



Licenses:

The calculation program FlowCalc32 CE is property of Bengt Rapp.

Control Engineering Sweden AB handles licenses.

A standard single user license gives the right for one user (1 workstation) to use the program. The owner of a license is responsible for making sure that only one workstation can use the program.

Copying and use of copies is illegal for other purpose then evaluation of the software.

FlowCalc32 Version 4.xx can be tested during one month for free.

This does however only grant user to use the program for evaluation purpose and calculations must not be used for commercial use.

If the program is not registered within one month, the entry screen at start up will warn users that the trial time has expired. The program is not going to lock up, but you must pay the license fee if you use the software in any kind of business.

Special company licenses are available also.

Although this software is firmly tested the use and functionality are not guaranteed.

Standards

There are many standards for calculations of primary devices, but the dominating ISO 5167 commonly accepted to be reliable.

FlowXalc32 CE calculates conforming to the standard ISO 5167-1:1991 and ISO 5167-1991/Amd.1:1998(E)

Some comments about the standards

We have investigated earlier standard DIN1952 Entwurf oktober 1980 and ISO 5176-1980 without finding any discrepancies.

The formula for ISA 1932 nozzle has changed slightly in the standard ISO 5167-1:1991. We have observed changes about 0.03 % for this type of primary element. The range for validity of the formulas has also changed slightly. Otherwise we have not found any difference.

Addendum ISO 5167-1/Amd.1:1998 introduces new formulas for orifices. Stoltz developed the earlier used formulas, for orifice plates, while the formulas in addendum-1 are based on equations set up by Reader-Harris/Gallagher. Results from calculations made with the new formulas differ around 2/thousands. The uncertainty for the equations has improved slightly.

Other primary devices such as classical venturi and nozzles are not affected in this addendum.

In Flowcalc32 CE user may select to use formulas conforming to ISO 5167-1:1991 or to use formulas from addendum /Amd.1:1998.

Recommendation

Use standard ISO 5167-1/Amd.1:1998 for calculations if you don't have any special reason to use older formulas.

Formulas

Formulas for calculation of different primary devices are not shown specifically in this manual. Users with special questions are advised to obtain the original standards. The formulas further down on the page gives a glimpse of how they may look.

The steam-formulas are available in 'properties of water and steam' (Springer verlag). Note that the



program does not use tables instead the calculations of data for steam and water are made through complex formulas.

Formulas for orifice plates with corner tapping.

Formulas for orifice plates with "corner tapping" conforming to ISO 5167-1991 (Stoltz)
Formulas are simplified as $L'1=L'2=0$

Variables:

χ =isentropic exponent

D_p =differential pressure over pressure tapings.

D =pipe diameter

d =primary device bore

β =diameter ratio

Re =Reynolds number

C =Stoltz constant

e =expansion factor

q =flow

a =alfa

P =pressure ($P1$) =upstream

Limits for range covered by standard:

$50 < D < 1000$ mm.

$d > 12.5$ mm.

$(0.20 < \beta < 0.45$ and $5000 < Re$)

or $(0.45 < \beta < 0.75$ and $10000 < Re$)

Formulas:

$$q_m = (\alpha \epsilon \pi / 4) d^2 (2 D_p \chi R_o)^{0.5}$$

$$\alpha = C E$$

$$E = (1 - \beta^4)^{-0.5}$$

$\epsilon = 1 - \frac{(0.41 + 0.35 \beta^4) D_p}{\chi p_1}$	condition : $\frac{P_2}{P_1} \geq 0.75$
---	---

$$C = 0.5959 + 0.0312 \beta^{2.1} - 0.184 \beta^{2.5} + 0.0029 \beta^{2.5} \left(\frac{10^6}{Re d} \right)^{0.75}$$

Loss of pressure:

$$\Delta p = (1 - \alpha \beta^2) D_p / (1 + \alpha \beta^2)$$

Information required for calculation.

To perform a calculation the following process data must be known:

- Pipe and primary device material are required in order to get a correct compensation for expansion at high temperatures.
For other materials the temperature expansion factor must be known.
- Media-type: gas/ steam/liquid or water.
- Type of primary device: FlowCalc32 CE can calculate orifice plates with corner tapping, orifice plates with flange tapping, orifice plates with D-D/2 tapping, ISA-1932 nozzles, venturi nozzles and classical venturi.
- Pipe diameter (mm).
- Temperature.
- Density. (Not required for steam or water)
- Dynamic viscosity. (Not required for steam)
- Primary device bore¹ (mm)
- Flow¹
- Differential pressure¹ measured over pressure tapings.
- P1 = Pressure before primary device.
- Isentropic exponent. (γ) (A value of 1.30 may be used for steam if you do not have tables available).

Installation

As FlowCalc32 CE uses a database system a runtime version of Borland's database engine will automatically be installed.

FlowCalc32 CE installation:

The complete installation is supplied in one self-extracting file: FlowCalc32engxxx.exe, where xxx is program version.

The installation program guides users through the installation process. Windows resources are automatically restored after the installation.

Remember to make a backup of your old data before you upgrade or make a repair installation.

Install program

Starting install program from CD.

Start Windows. Put in FlowCalc32 CE CD in disc unit. Open: Start Run and enter X:\flowcalc32eng where X is the drive where you have the installation CD. Follow the instructions given by the installation program.

¹ Two of these must be entered. The third is calculated.



Starting the install program with a downloaded file.

Use windows explorer and select the directory where you have saved FlowCalc32engxxx.exe and double-click the file icon.

Installation types

Typical.

Install all files.

Compact. (Reserved for future use)

Installs the minimum required files.

Custom. Allow you to individually install : (Reserved for future use)

- BDE Borland's database engine.
- Calculation data
- Program, program files and help.

Some technical information:

If you previously have the Borland database system: The installation program doesn't alter information earlier stored in the IDAPI configuration for other programs. The alias for FlowCalc32s database tables (ORF6) will be replaced.

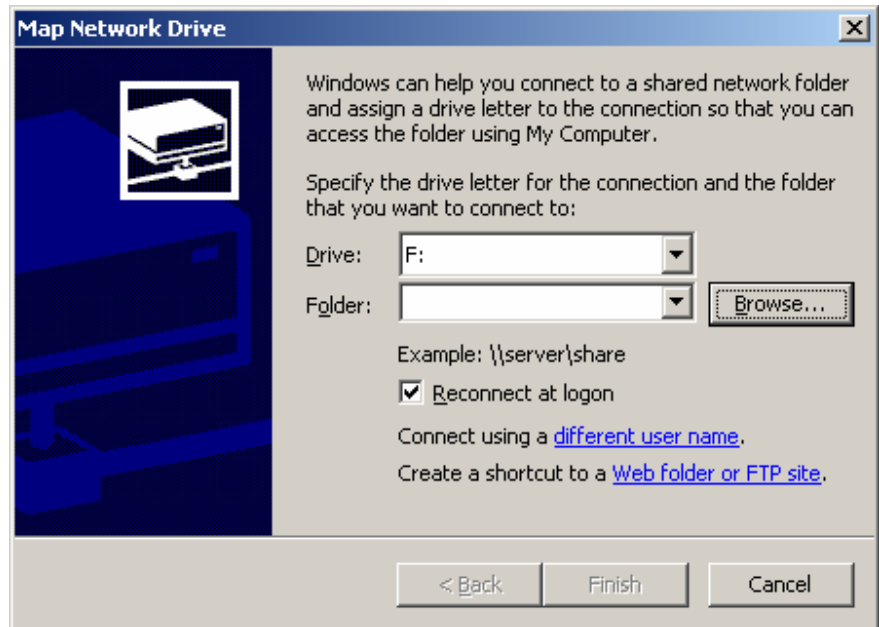


Networking FlowCalc32 CE

FlowCalc32 uses a database to store the calculations.
It is possible for users to set up their system to use shared data on a server.

Instruction:

1. Create a common directory on the server and give different FlowCalc32 users read and write access to that directory. If you are not a network expert, use windows explorer on each FlowCalc32 workstation and map a network drive to the newly created directory.



2. Copy all data files from **one** workstation to that newly created directory. The needed files are all files found in [CommonAppDataFolder]\Control Engineering\Flowcalc\data\
The CommonAppDataFolder is the application data folder for all users, its location varies with different operating systems and languages.

On Windows XP:

C:\Documents and Settings\All Users\Application Data\Control Engineering\Flowcalc\data\

On Windows Vista and Windows 7:

C:\ProgramData\Control Engineering\Flowcalc\data\

If you do not find it you can continue to the next step where the path is shown before you change it.

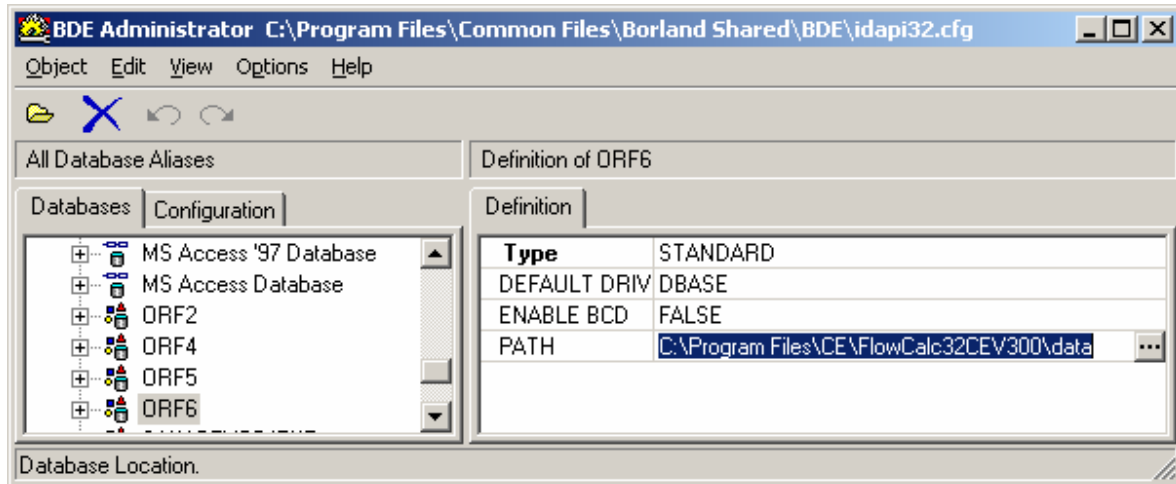


3. Open the program “BDE Administrator” which will be found in the Control Panel.

Click on ORF6 (might be higher number in newer versions).

Click on the PATH entry field.

Click on the button to the right of the path.



Select the mapped network drive and click OK.

Network expert users may enter a common network directory directly in the text field.

Click Object - Apply first, and thereafter OK to save all edits.

Shut down BDE Administrator.

All users who have mapped same data do now have access to each other's calculations.

Starting the program.

Select: Start, Programs, FlowCalc32 CE and FlowCalc32 CE.

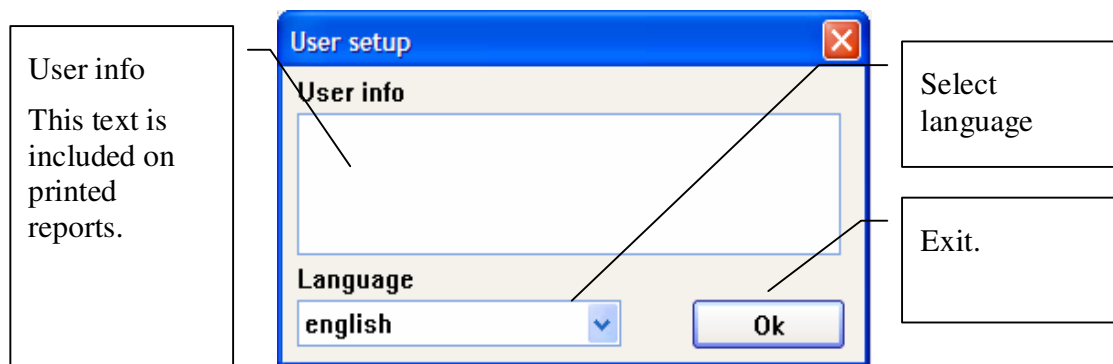
User set-up

At the first session users are advised to take a minute and setup their user information.

Select File->User Setup to from the menu to open the User Setup.

Here you can enter information that will be included on every printout you make.

This information is not related to specific calculations but is saved separately and used for all calculations.



Calculation session.

An appropriate method for calculating a primary device is as follows.

Copy a similar application or choose a new empty form.

Enter the changed values for a copied form or new values for the empty form.

Perform the calculation for the unknown variable. (See calculation)

If the calculation was good (no error-messages), exit calculation with the OK-button that will save data immediately.

After this you may want to print the calculation result.

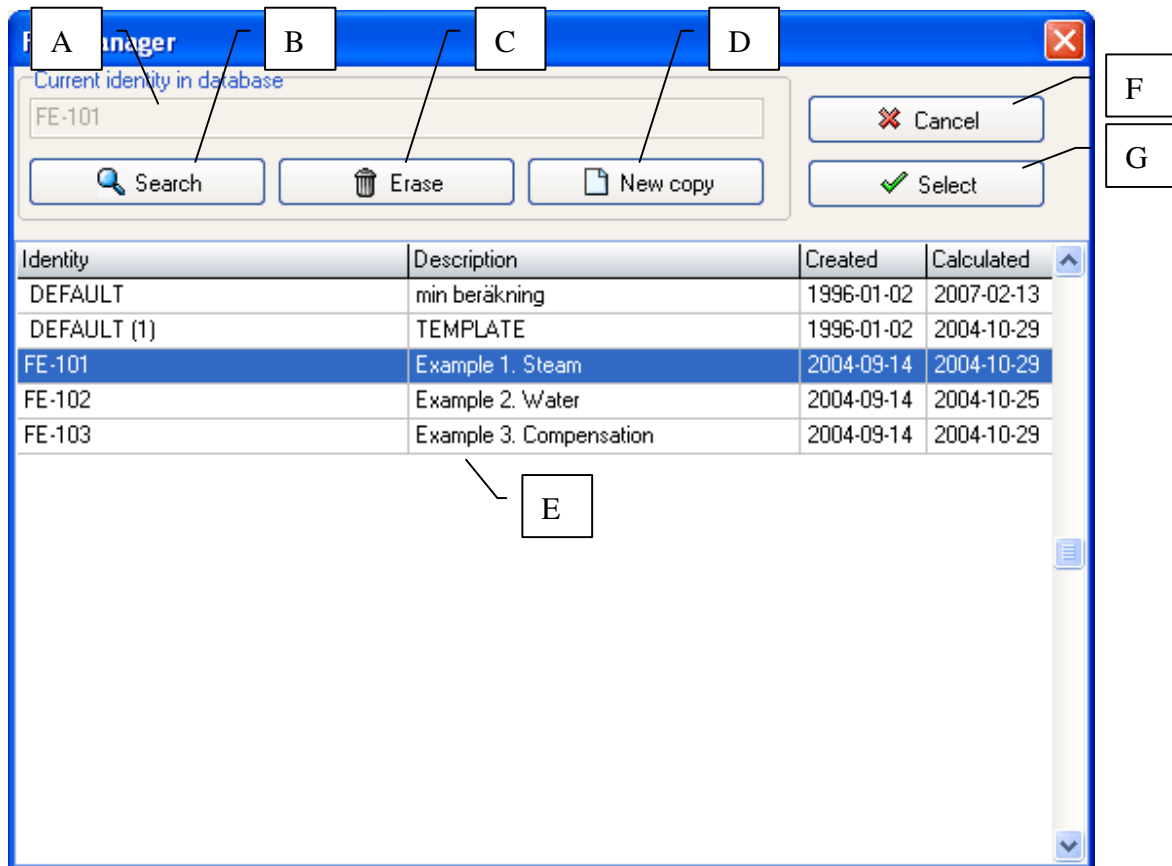
When you have finished calculations quit the program by choosing File Exit.

File manager saved data.

Information for every primary device is stored as a record in a database. Every record has a unique identifier, used to recognize the different primary devices.

With the file manager you can copy, erase or create new empty preset records in the database.

To open the file manager click the file manager button located in the tool bar at the top of the main form.



- A: Identity of currently selected record.
- B: Search the database for a specific record.
- C: Deletes the currently selected record from the database.
- D: Creates a new copy of the selected record.
- E: Table showing all records of calculations. Can be used to scroll and select records.
- F: Cancel button. Takes you back to entry form without selecting a new record.
- G: Ok button. Takes you back to entry opens the selected record.

Enter data in the entry form.

When you start the program a form with the default record is automatically selected.

The entry form is used for three purposes:

- Entering the data before calculation.
- To study the result of the calculation
- To modify old calculation data when you want to calculate existing primary devices with changed process data, for example if the temperature has changed. The entry form is directly linked to data saved in databases on the hard drive.

Use the tab key to move the marker between input fields and to step backwards you use Shift Tab. You can also move to a field directly, by clicking on it with the left mouse-button.

All data entered are temporarily stored and are not saved until you click on the save icon or select another primary device either through the database navigator or through the file manager. When a record is changed it is marked in the status-field down on the left of your screen. You can cancel changes in the form by clicking the cancel symbol (looks like an x) on the database navigator.

Each primary device used in the entry form must already be defined in a database. It is recognized with a unique identifier. If you have entered a nonexistent identity you will be informed and have the possibility to go to the File manager where you can create new positions (primary devices).

It is only possible to enter new data that is required. Data fields not required are marked in grey colour.

If you select media liquid the fields for isentropic exponent disappears as in is not used for the calculation.

The STP checkbox is only visible when you have selected gas as media type and a volumetric flow unit.

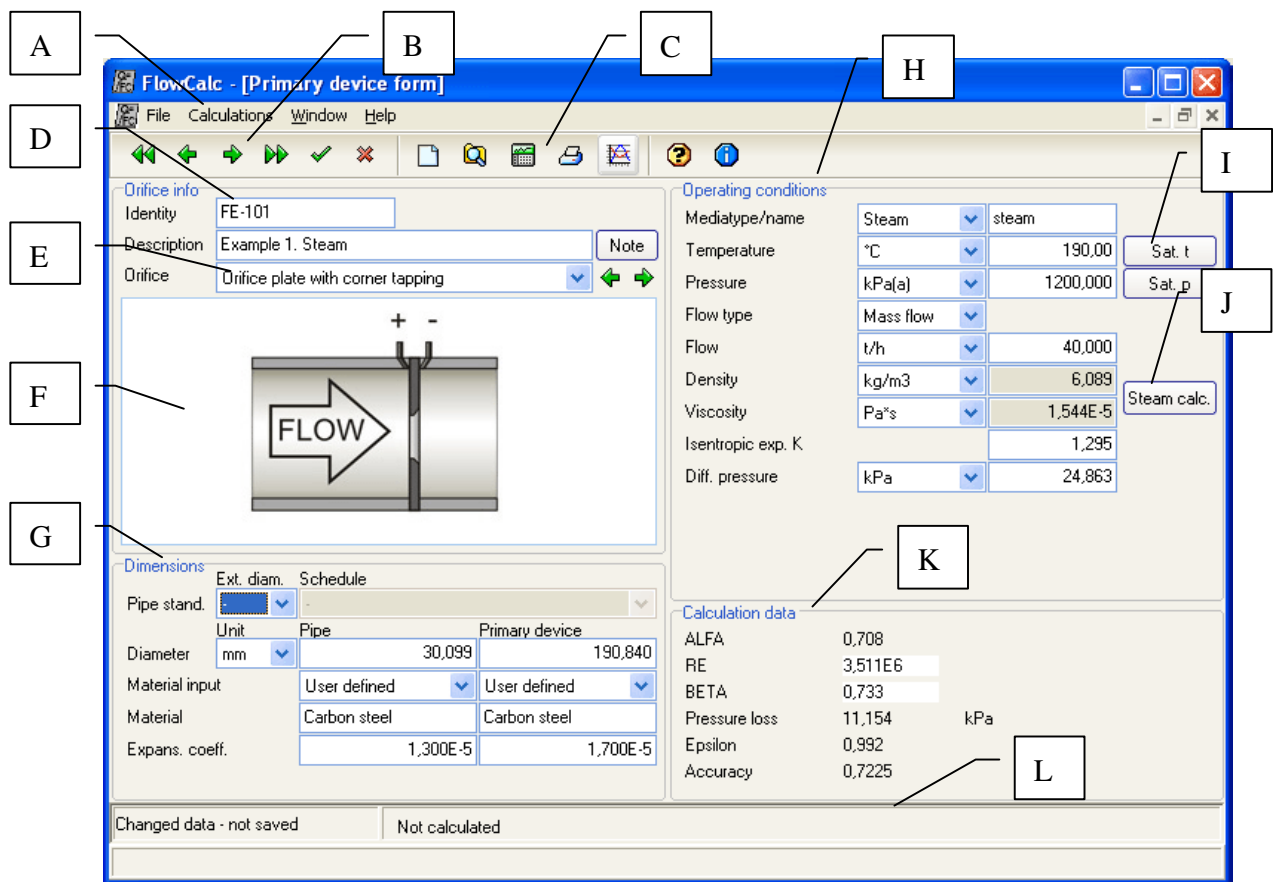
Fields with blue text are extra information and are not used for calculations by the program.

All eligible units have an arrow.

To choose primary device, click the button that shows type of primary device, which will bring up an area for choosing primary device. If you click the button for type again this area is closed.

Choose type by clicking at the desired type of primary device.

Entry form



□A: Menu system. Speed buttons can be used to perform most of these actions.

□B: Navigator. Scroll through earlier calculations.

All entries are stored temporary and will not be saved until you select a new calculation by using this database navigator or if you accept a calculation after it's performed.

> Scroll forward

>> Scroll to last

< Scroll backwards

<< Scroll to first

✓ Save changes.

X Cancel – revert to previously saved data.

□C: Speed buttons



New. Creates a new default calculation



Archive- file. Opens the file (database) manager.



Calculate. Opens the calculation window.



Print. Opens a printable calculation report preview.



Compensation. Opens the compensation analyser.



Help. Opens the help system.



About. Opens the about window.

D: Identity. Every identity must be unique and defined in a database table. If you enters an identity that does not exist a new default calculation will be created otherwise the old calculation with that identity will be opened.

E: Type of primary device. Select the type of primary device in the drop down list or use the two back/forward arrow buttons.

F: Primary device picture.

G: Pipe and orifice device properties. Entry of orifice bore diameter is of course not required if this is the parameter you are going to calculate.

The internal pipe diameter can either be entered manually or calculated by the program for ANSI pipes. To enter the diameter manually select pipe size “-“. To use an ANSI pipe select first the outer dimension (size) and then the schedule. The internal diameter will be set according to your selection of ANSI pipe and can not be changed until you deselect ANSI pipes by selecting size “-“.

The expansion factors can either be entered manually or calculated by the program. To enter them manually select “User defined”. If you select a predefined material then the material can be changed by the “open” button next to the material name that opens a list of available materials. FlowCalc uses tables of expansion numbers for different temperatures and interpolates between the tabulated values.

H: Operating conditions. Here the operating conditions are entered. Move between the fields either with your mouse or tab/shift tab.

FlowCalc handles a large number of units and automatically recalculates values between them on change. To select the right flow unit you must first enter the correct flow type since mass flow units are only available for mass flow and volume flow units for volume flow.

When the media type is set to gas and a volumetric flow unit has been selected a checkbox named STP will appear. If you check this then density and flow is entered at Standard Temperature and Pressure (STP). Flow and density will be recalculated to operational conditions through the ideal gas law for all calculations. When this checkbox is checked/unchecked flow and density will be recalculated to/from STP through the ideal gas law.

Since different regions in the world uses different STP conditions FlowCalc allows you to select between different common STP conditions or define your own.

I: Sat. p. and Sat. t. These buttons are visible only when media is set to steam. They are used to calculate saturate temperature or pressure.

J: Media calculation button. This button is only visible for steam and water. Click this to calculate density and dynamic viscosity. This is automatically done when calculating an orifice.

K: Calculation data. Contains some key values for the calculation. Most users will not need this information.

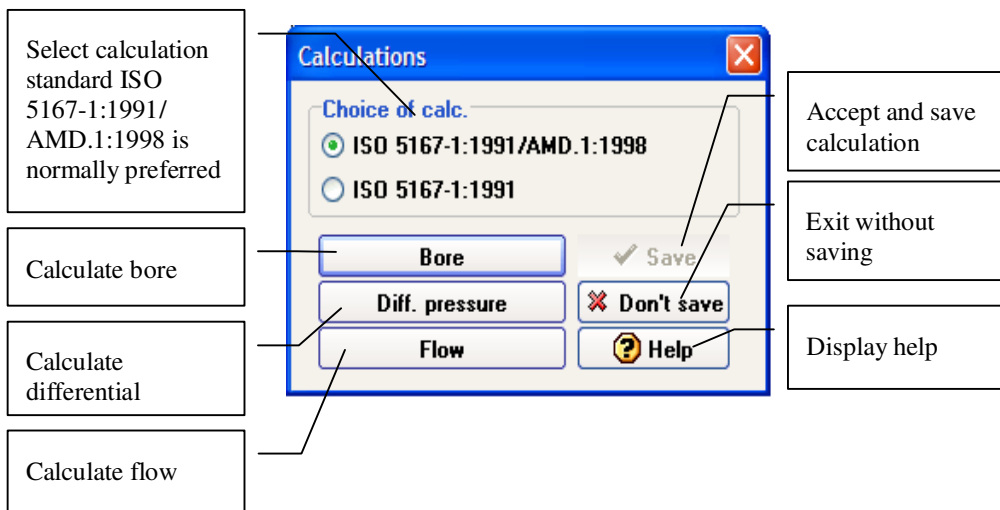
L: Info fields. Below the main work area there are some information fields. The fields contain information on whether the calculation has been edited since last save and if it is calculated. There is also a field for containing mouse over help information for the program.

Calculation

Selecting calculation.

FlowCalc32 CE allows you to calculate flow, differential pressure or bore.

When you have entered all required parameters click the calculator symbol or choose Calculations One point. Then a window will appear where you choose which value you want to calculate. Note that the other two parameters must already be entered.



Click the button:

- Diff. pressure to calculate Differential pressure.
Bore and flow must already be entered.
- Bore.
Differential pressure and flow must already be entered.
- Flow.
Differential pressure and bore must already be entered

Choosing calculation parameter

This allows you to perform calculations for existing primary devices when for example the operation pressure has changed.

When the calculation is performed the Save button becomes active. Click this to accept and save. If you get an error message you must correct your data for the calculation to succeed.

If you get a warning message you should consider changing your data so that the calculations stay within the limits of the standard. You can for example select a larger bore if the differential pressure is too big. Orifice plate with corner tapping is the primary device that most often stays within its limits. This is due to the great study of this orifice that has resulted in a greater range of the formulas.

Unit conversion

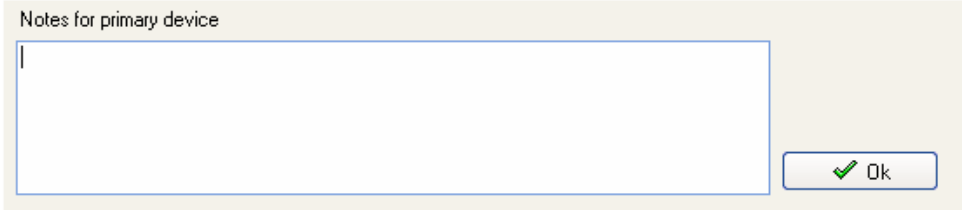
FlowCalc32 CE handles a large number of different units for all process data. This allows you to perform your calculations with your preferred units. To change unit click the arrow next to the unit and a list appears where you can select the unit you want. When you select a new unit the present value will be recalculated to the new unit. Selected units are automatically saved together with all data of the primary device. Calculations can be performed with all different units.

Density	kg/m3	5.293
Viscosity	g/ft3	1.511E-4
Isentropic exp. K	kg/dm3	1.300
Diff. pressure	kg/m3	66.824
	lb/UKgall	
	lb/USgall	
	lb/ft3	

Notes for primary device

Click the button “Note” to write notes for a primary device. This will open a field where you enter your notes.

Notes entry.



Notes for primary device

Ok

The notes are included on prints.

The notes are saved together with other data about the primary device

Printing.

Printing is selected from File Print or by clicking the print icon.

A preview of the print is shown. Click the printer symbol to print a paper copy. If the printer is connected correctly to the computer the print image is sent to windows print manager that executes the printing and you will return to the preview of the print. The preset printer in windows is used.

If you want to change printer, click printer setup.

We have observed that it's best to setup the printer under default system printer in windows. Usually a standing A4 is selected in Europe or legal size for many English-speaking countries.

Click Close to return to the entry form.



System requirement.

As hardware you shall have a PC running under Windows 98, Millennium, NT 4.0, NT5 (W2000 professional workstation) or XP or later version.

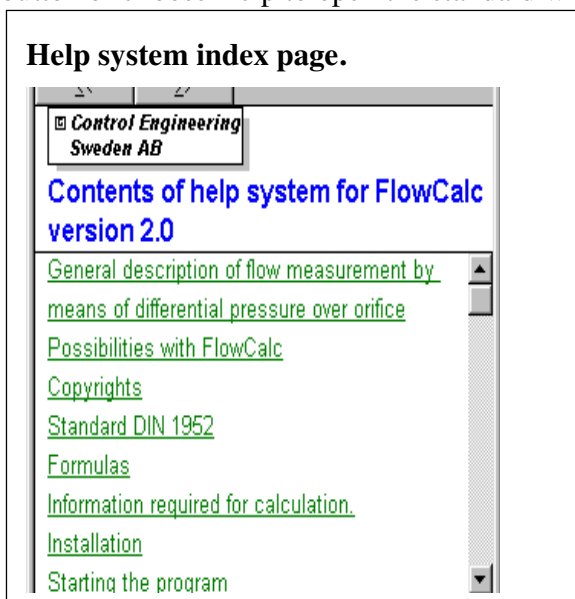
The computer must have at least 32 MB RAM and 12 MB free space on hard drive.

Help system

If you point at a field, a hint text will appear at the line in the bottom of the screen. Let the pointer stay a bit longer and a text with further help will appear by the field.

There is also a help system related to all fields. Press F1 to bring up the windows help system with detailed information about the selected field.

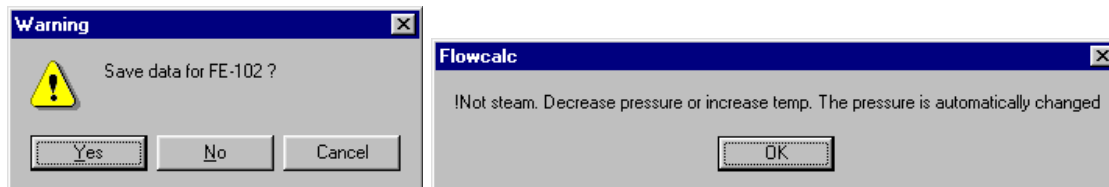
You can also use the traditional help tools such as search and index pages to find help. Press the "?" button or choose Help to open the standard windows help.



Error messages

The program controls that the calculation is executed without errors. However, incorrect usage or data can lead to that the calculation fails or that it is outside the range covered by standard. It is easy to try with new values and see if the error disappears.

Example of error messages:



Sometimes warnings can arise even though the data is correct (in most cases with old pipe systems). This is because there is no documented experience of a similar application within the standard.



In case of error FlowCalc32 CE resets the data so that entered data not will be lost. Furthermore warning or error messages are shown when FlowCalc32 CE doesn't manage a task.

Reynolds number warning.

Check against the range covered by standard. If the difference is small the calculation is usually acceptable. You can try to execute the calculation with decreased flow.

Check the flow value

Check dynamic viscosity.

Enter a larger bore

As orifice plates are the most tested devices they covers the greatest span of Reynolds number. Therefore you can try these devices when the other devices give warnings.

Area ratio / Beta warning.

The standard is only valid within certain area ratios.

Select a new differential pressure to remain within the limits.

Diameter warning.

Try to change type of primary device if you use classical venturi tube. For orifice plates the internal pipe diameter must be larger then or equal to 50 mm to be within range covered by standard.

In practice the calculations have shown to be correct for pipes down to 25 mm.

Bore error.

When you encounter a bore error you can try to change the differential pressure. A suitable method is to first choose a valid bore and then calculate a value for the differential pressure. Use this value and round off. Perform a new calculation with this new differential pressure.

"Calculation total error"

Probably caused by incorrect data.

Check your data and try to calculate again. Keep all values from zero.

If you, after checking you data properly, do not succeed in performing the calculation, contact Control Engineering.

Incorrect date

The date comes from windows clock.

If this date is incorrect you must set the date in Windows.



Compensation analyser

The compensation analyser is only included in FlowCalc32 CE Professional version. If you use either FlowCalc32 CE Standard version or the trial version then the compensation analyser is only available in trial mode. In trial mode the pipe diameter is limited to 200 mm.

To start the compensation analyser, click the Compensation button or select Calculation->Compensation. This will open a new window where compensation formulas can be analysed.

The compensation analyser is available for steam mass flow or gas flows at STP.

Compensation analyser

Usually when you size a primary device using FlowCalc32 you perform a calculation for the primary device under a certain set of operating conditions like temperature, pressure and so on. In FlowCalc32 that set of operating conditions is named the reference point. After calculating the reference point with FlowCalc32 You use the reference point to calibrate a simplified flow formula so that it exactly matches the calculated values in FlowCalc32 in that point. This flow formula is then used in the measurement application. FlowCalc32 can analyse the following flow formulas:

Root formula without compensation

$$Q = k \times dp^{0.5}$$

Root formula with compensation

$$Q = k \frac{dp^{0.5} \times P^{0.5}}{T^{0.5}}$$

Exponential formula with compensation

$$Q = k \frac{dp^{dpExp} \times P^{PExp}}{T^{TExp}}$$

Where

Q = flow

k = calculated constant

dp = differential pressure

P = pressure

T = temperature

dpExp = exponent for dp compensation

PExp = exponent for pressure compensation

TExp = exponent for temperature compensation

In the reference point the accuracy of the flow formula is generally good since it matches the accurate calculation performed by FlowCalc32. Further on the accuracy in that point is known since the accuracy of FlowCalc32's calculations follows ISO-5167 with a well documented accuracy. However when the operating conditions differs from the reference point the flow calculated by the flow formula will differ from the flow calculated by FlowCalc32 for those operating conditions. The reason is that the flow formula is a simplification of the more complex and accurate formulas used in FlowCalc32.

The compensated root formula for example only compensates for temperature and pressure changes by what is known as density compensation. This means that it only compensates for density changes caused by pressure temperature and not for other parameters affected by the temperature such as pipe and



primary device expansion. Further on the root density compensation assumes that the media acts as a natural gas, which is not true for most mediums.

In many cases the accuracy of the standard root compensation formula is good enough and in other cases it is not. It all depends on the operating and reference conditions and the required accuracy. The problem is that you don't know how accurate your flow formula is. This is where FlowCalc32:s compensation analyser comes in handy. The compensation analyser allows you to easily analyse the accuracy of your flow formula. Further on you can obtain a flow formula with a few clicks saving you the hassle of calculating it by hand.

Using the compensation analyser

The compensation analyser works by comparing the output of different flow formulas with the output of FlowCalc32s calculation engine at different operating conditions. The results are presented as graphs that allow the user to easily see the differences between the flow formulas and FlowCalc32s calculations.

There are three different charts for temperature, pressure and flow variations. Each graph shows the effect of changes in that particular parameter while the other operation conditions are fixed at the reference point values. This means that the errors compared to the ISO calculations can add up to a larger error when more parameters differ from the reference point.

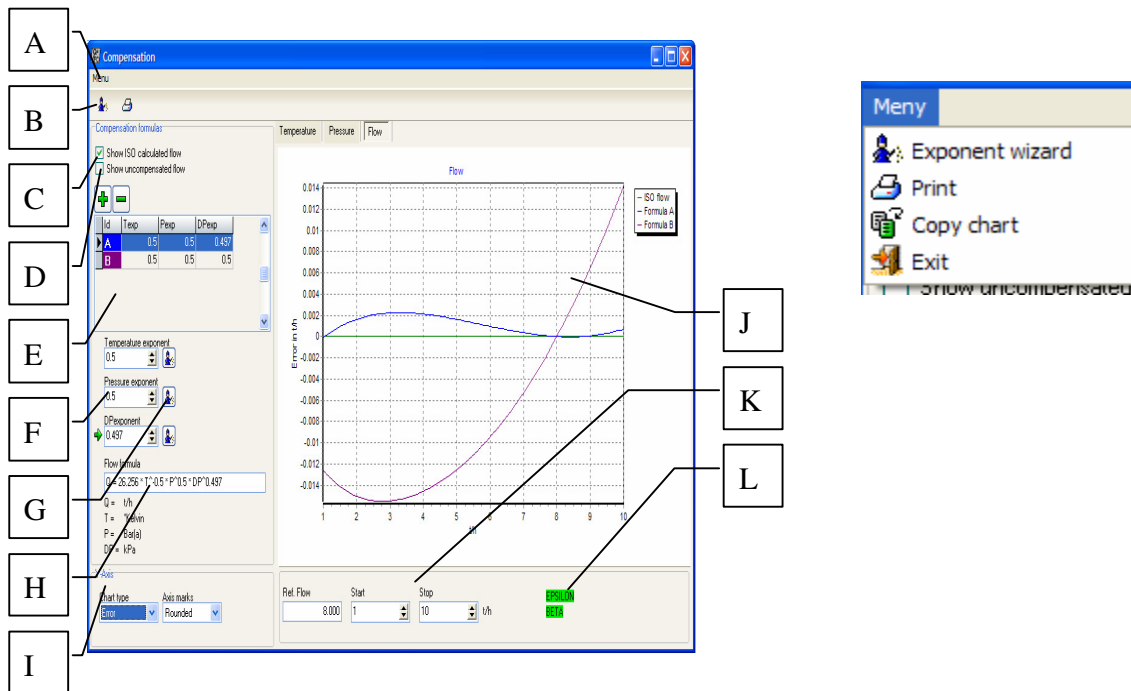
The user set starting and stopping values for the charts and can add, delete or change the flow formulas to plot. Each chart can contain up to five graphs of different flow formulas at the same time and they are redrawn in real time when something changes. In this way you can elaborate with different flow formulas and instantly see the resulting differences towards FlowCalc32s calculations when the operating conditions change.

The user can analyse up to five different flow formulas in the same set of charts. All flow formulas are stated as exponential formulas and the user edits them by changing the compensation exponents. The point calculated in FlowCalc32s main form is used as reference point and the compensation analyser automatically calculates the flow formula resulting from that point and the compensation exponents.

The compensation analyser also contains wizard buttons that automatically searches for the flow formula that gives the minimum error compared to FlowCalc32s formulas.

Follow example 3 in the end of this manual to get a guide on how to use the compensation analyser.

Compensation window



- **A Menu.**
Exponent-wizard: Opens a wizard window to let a flow wizard search for the exponential flow formula that gives the minimum difference compared to FlowCalc32s calculations. To start the search for this formula first enter the start and end values of for the
Print: Creates a report of the compensation analysis. This report can then be printed by clicking the print button.
Copy chart: Copies the selected chart to Windows clipboard. Before the chart is copied a window where you can select the chart dimensions is shown. The chart copy in Windows clipboard can then be pasted in to many other Windows programs such as Microsoft word etc.
Exit: Closes the compensation analyser.
- **B Toolbar:** The toolbar has two buttons; print and exponent-wizard that do exactly the same thing as the menu selections described above.
- **C Show ISO flow:** When this is checked a graph for flow calculated by FlowCalc32 is drawn in all charts.
- **D Show uncompensated flow:** When this is checked a graph for flow calculated without temperature and pressure compensation is drawn in the charts for temperature and pressure.
- **E Flow formulas:** This is a list of all flow formula exponents included in the analysis. The currently selected floe formal has its row marked in blue. Flow formulas can be added and deleted by using the buttons + and -. A maximum if five flow formulas can be used per orifice.
- **F Exponent field:** In these fields the exponents for the selected flow formulas pressure, temperature and dp compensation is entered. When an exponent is changed the chart is

automatically redrawn. This makes it easy to use the up and down buttons to trim the exponent to fit FlowCalc32:s calculations.

If you set the exponent to 0.5 this is equivalent to root compensation.

If you set the exponent to 0 this is equivalent to no compensation.

- **G Exponent field wizard:** The wizard button found left of an exponent field involves the exponent wizard. The wizard will automatically find the exponent that gives the least total flow difference towards FlowCalc32:s calculated flow within the stated parameter span.
- **H Flow formula:** This is the flow formula used to draw the graphs for the selected flow formula. The flow formula is calculated automatically and is written in the following form:

$$Q = kdp^{dpExp} \times P^{PExp} \times T^{-TExp}$$

-

Where

Q = flow

k = calculated constant

dp = differential pressure

P = pressure

T = temperature

dpExp = exponent for dp compensation

PEXp = exponent for pressure compensation

TExp = exponent for temperature compensation. Note that this exponent is negative.

Note that $X^{0.5} = \sqrt{X}$

If the flow formula is to be used in a system that lacks the ability to calculate arbitrary exponential functions it can be useful to rewrite it to the following form:

$$Q = k \times 10^{(-TExp \times \log(T) + PExp \times \log(P) + dpExp \times \log(dp))}$$

This formula is equivalent to the formula presented by the compensation analyser but only contains one exponential function with the base 10.

Or an other equivalent formula as expressed with base E :

$$Q = k \times E^{(-TExp \times \ln(T) + PExp \times \ln(P) + dpExp \times \ln(dp))}$$

- **I Y-axis:** In this box the y-axis properties are set.

Chart type

Flow: The y-axis shows calculated flow.

Error: The y-axis shows the difference between flow calculated by the flow formula and flow calculated by FlowCalc32 in selected flow unit.

Relative error: The y-axis shows the difference between flow calculated by the flow formula and flow calculated by FlowCalc32 in percent of calculated flow

Axis marks

Rounded: The axis marks are only shown at rounded values

Not rounded: The axis marks are shown at not rounded values. Select this option when the axis marks seem to disappear.

- **J Flow chart:** These charts show the calculated graphs. Yellow areas indicate calculations outside range covered by standard or steam calculations at too low temperature or too high pressure.
- **K Reference, start and stop:** Here you can set the start and stop value for the parameter analysed in the chart. In the reference field the value at the reference point is shown.

L Warnings: Beta and epsilon warnings are shown here. If these fields are green then beta and epsilon are ok in all points in the calculation span. If they are yellow then there exists at least one point within the span where epsilon or beta is out of range.



Example

Example 1. Steam media.

Calculation of differential pressure with known flow and bore.

Known data:

Type of primary device:	x orifice plate with corner tapping _ venturi nozzle _ classical venturi tube with machined convergent _ classical venturi tube with sheet-iron convergent _ classical venturi tube with rough cast convergent _ ISA-1932 nozzle. _ Long radius nozzle.	
Media state	: _ liquid _ gas _ water x steam	
Media	: steam	note 2
POSITION	: FE-101	
PRIMARY DEVICE DATA		
Material in primary device	: SS2343	note 2
Expansion. Coeff.	: 1.7E-5	
Primary device bore mm.	: 190.84	note 1
Pipe diameter mm.	: 260.40	
Pipe material	: CARBON STEEL	note 2
Expansion. coeff.	: 1.3E-5	
PROCESS DATA		
Temp	: 190 degrees Celsius	
Density	: calculated by FlowCalc (select unit kg/m3)	note 5
Flow	: 40 t/h	note 1
Differential pressure	: to be calculated select unit kPa	note 1
Isentropic exp.	: 1.295 from steam diagram	note 4
Dyn. visc .	: calculated by FlowCalc (select unit Pa*s)	note 5
Pressure inlet	: 1200 kPa	note 4

Note1: Two of these must be entered. The third is calculated.

Note2: Data not required in FlowCalc32 CE's calculations

Note4: Not required when media is liquid. For steam 1.30 can often be used.

Note5: Not required when media is steam or water.

Calculation

Click file manager symbol in the toolbar to open the file manager.

If the identity FE-101 exists then select this and erase it.

Select the identity "Default" and click "New Copy". Enter the identity "FE-101".

Click "Select". This should take you to the main entry form with the identity "FE-101" selected.

Press tab to get to next field that is Description. Type: Exercise 1. You can now see in status field at the bottom of the screen that the primary device is changed. You can cancel changes by clicking the database navigator symbol cancel (x) but you shall not do that in this exercise.



Press tab to get to notes button. Press enter to write notes for this primary device. Type "Notes for exercise 1".

Press tab to get to the drop down list for selecting type of primary device. Select "orifice plate with corner tapping".

Press tab to get to the drop down list for pipe standard. Since you do not wish to use a standardized pipe select "-".

Press tab to get to the field pipe diameter unit. Select mm.

Press tab to get to the field pipe diameter. Enter 260.40.

Press tab to get to the field pipe material input. Select "User defined".

Press tab to get to the field pipe material. Enter "Carbon steel"

Press tab to get to the field pipe expansion factor. Enter 1.3E-5. (All values can be stated with powers of ten. 0.000013 can be entered as 1.3E-5 or as 0.000013.)

Press tab to get to the field primary device diameter. Enter 190.84.

Press tab to get to the field primary device material input. Select "User defined".

Press tab to get to the field primary device material. Enter "SS2343".

Press tab to get to the field primary device expansion factor. Enter 1.7E-5.

Press tab to get to the field media type. Select steam, you can use arrow buttons or your mouse.

Press tab to get to the field text for media type. Type steam.

Press tab to get to the field temperature unit. Select C

Press tab to get to the field temperature. Enter 190.

Press tab twice to get to the field pressure unit. Select kPa(a).

Press tab to get to the field pressure. Enter 1200.

Press tab twice to get to the field flow type. Select mass flow.

Press tab to get to the field flow unit. Select t/h.

Press tab to get to the field flow. Enter 40.0.

Press tab to get to the field density unit. Select kg/m³.

Press tab twice to get to the field dynamic viscosity. Select Pa*s.

Press tab twice to get to steam calculation button and press space. This will calculate density and viscosity

Press tab to get to the field isentropic exponent. Enter 1.295.

Press tab to get to the field Differential pressure unit. Select kPa.

Check that the differential pressure is zero so that you can see changes when the calculation is performed.

Now all data required for calculation of differential pressure is entered

Click the calculator for calculation.

Select standard ISO5167-1:1991/AMD-1:1998



Select differential pressure.

If you followed all instructions correctly no error messages appeared you could see that the differential pressure at current operational data has been calculated to 24.863 kPa.

Save data by clicking ok button.

You can try to change units and see that the calculated values will be recalculated to the new units.

Printing.

Click the printer icon or choose File Print to print the calculation form for this primary device. On the printed form you can also see required straight lengths of pipes.

To print the preview: click the printer icon.



Example 2 water

Calculation of primary device bore with known flow and differential pressure.

Known data:

Type of primary device: x orifice plate with corner tapping
 _ venturi nozzle
 _ classical venturi tube with machined convergent
 _ classical venturi tube with sheet-iron convergent
 _ classical venturi tube with rough cast convergent
 _ ISA-1932 nozzle.
 _ Long radius nozzle.

Media state : _ liquid _ gas x water _ steam

Media : Water note 2
Identity : FE-102 note 2

PRIMARY DEVICE DATA:

Primary device material. : SS2343 note 2
Expansion factor. : 1.7e-5
Bore mm. : to be calculated note 1
Pipe diameter mm. : 200.0
Pipe material : SS2343 note 2
Expansion factor. : 1.7e-5

PROCESS DATA:

Temp : 20 Celsius
Density : 998 kg/m3 note 5
Flow : 200 t/h. note 1
Differential pressure : 25.00 kPa note 1
Isentropic exponent : not used for liquid note 4
Dyn. visc : 0.001000 Pa*s. note 5
Pressure inlet : 200 kPa(a)

Note1: Two of these must be entered. The third is calculated.

Note2: Data not required by FlowCalc32 CE's calculations.

Note4: Not required when media is liquid. For steam 1.30 can often be used

Note5: Not required when media is steam or water.

Calculation



Click file manager symbol in the toolbar to open the file manager.

If the identity FE-102 exists then select this and erase it.

Select the identity "Default" and click "New Copy". Enter the identity "FE-102".

Click "Select". This should take you to the main entry form with the identity "FE-102" selected.

Press tab to get to next field that is Description. Type: Exercise 2. You can now see in status field at the bottom of the screen that the primary device is changed. You can cancel changes by clicking the database navigator symbol cancel (x) but you shall not do that in this exercise.

Press tab to get to notes button. Press enter to write notes for this primary device. Type "Notes for exercise 2".

Press tab to get to the drop down list for selecting type of primary device. Select "orifice plate with corner tapping".

Press tab to get to the drop down list for pipe standard. Since you do not wish to use a standardized pipe select "-".

Press tab to get to the field pipe diameter unit. Select mm.

Press tab to get to the field pipe diameter. Enter 200.0.

Press tab to get to the field primary device diameter. Enter 0, as this is the value to be calculated.

Press tab to get to the field pipe material input. Select "User defined".

Press tab to get to the field primary device material input. Select "User defined".

Press tab to get to the field pipe material. Enter 316SS.

Press tab to get to the field primary device material. Enter 316SS.

Press tab to get to the field pipe expansion factor. Enter 1.7E-5. (All values can be stated with powers of ten. 0.000017 can be entered either as 1.7E-5 or as 0.000017.)

Press tab to get to the field primary device expansion factor. Enter 1.7E-5.

Press tab to get to the field media type. Select water, you can use arrow buttons or your mouse.

Press tab to get to the field text for media type. Type water.

Press tab to get to the field temperature unit. Select C

Press tab to get to the field temperature. Enter 20.

Press tab to get to the field pressure unit. Select kPa(a)..

Press tab to get to the field pressure. Enter 200.

Press tab to get to the field flow type. Select mass flow.

Press tab to get to the field flow unit. Select t/h.

Press tab to get to the field flow. Enter 200.0.

Press tab to get to the field density unit. Select kg/m³.

Press tab twice to get to the field dynamic viscosity. Select Pa*s.

Press tab twice to get to water calculation button and press space. This will calculate density and viscosity.



Press tab to get to the field differential pressure unit. Select kPa.

Press tab to get to the field differential pressure. Enter 25.

Now all data required for calculation of primary device bore is entered

Click the calculator icon for calculation.

Select standard ISO5167-1:1991/AMD-1:1998

Select bore.

If you followed all instructions correctly no error messages appeared and you can click the ok button to save the calculation.

Now you can see that the bore at current operational data has been calculated to 123.47 mm.

Printing

Click the printer icon or choose File Print to print the calculation form for this primary device. On the printed form you can also see required straight lengths of pipes.

To print the preview: click the printer icon.



Example 3 Flow formula analysis

In this example we will look at FlowCalcs compensation analyzer. We will do this using the orifice FE-103 that is included in the database delivered with FlowCalc32.

Orifice data:

Type of primary device: x orifice plate with corner tapping
 _ venturi nozzle
 _ classical venturi tube with machined convergent
 _ classical venturi tube with sheet-iron convergent
 _ classical venturi tube with rough cast convergent
 _ ISA-1932 nozzle.
 _ Long radius nozzle.

Media state : _ liquid _ gas _water x steam

Media : Steam
Identity : FE-103

PRIMARY DEVICE DATA:

Primary device material. : CarbSt
Expansion factor. : 1.3e-5
Bore mm. : 140 mm
Pipe material : CarbSt
Expansion factor. : 1.3e-5
Pipe diameter mm. : 200.0 mm

PROCESS DATA:

Temp : 410 F
Density : 5.745 kg/m³
Flow : 10,000 kg/h.
Differential pressure : 5.904 kPa
Isentropic exponent : 1.295
Dyn. visc : 1.631e-5 Pa*s.
Pressure inlet : 1200kPa(a)

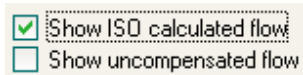
Make sure that the orifice is calculated and then open the compensation analyser by clicking the compensation speed button.



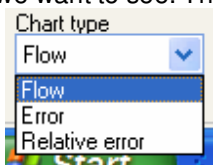
Flow variations at different operating conditions

The first task of this exercise is to produce charts of flow variations as the operating conditions change.

Make sure that the checkbox "Show ISO flow" is checked and that "Show uncompensated flow" is unchecked.



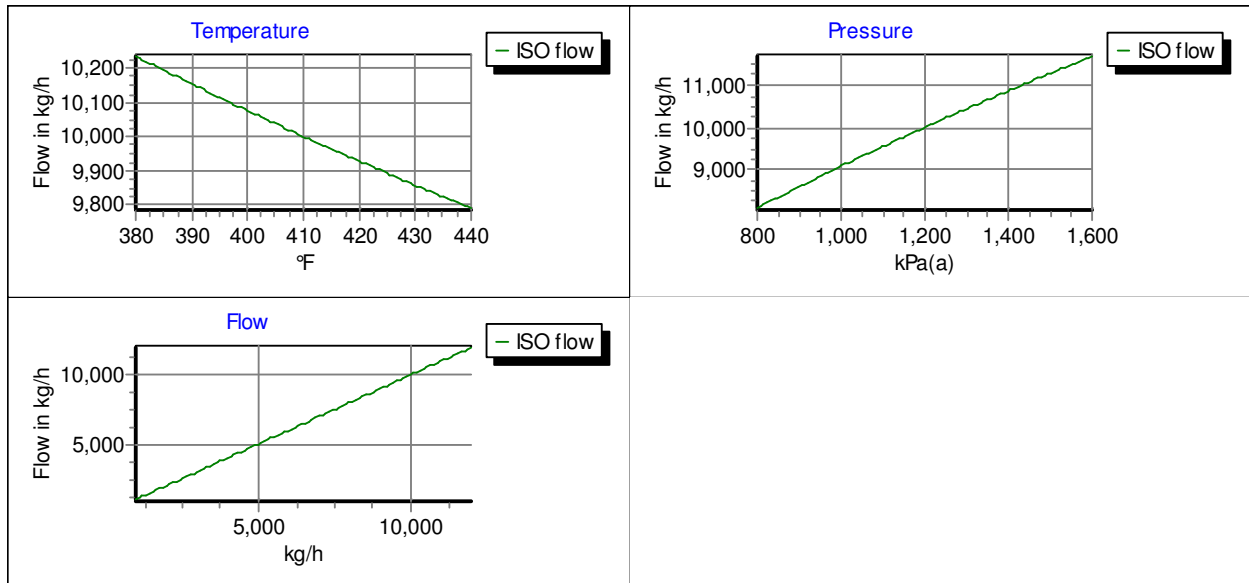
Checking the checkbox "Show ISO flow" means that the all flow charts will contain a graph of flow calculated by FlowCalc32 which is exactly what we want to see. Then check that the option "Flow" is selected in the dropdown



list "Chart type" in the box "Y-Axis".

This means that the y-axis of the charts should represent flow.

Now we can study how the flow calculated by FlowCalc32 changes when temperature and pressure changes. The charts are shown under the tabs Temperature, Pressure and Flow. The charts You should see are pictured below:



The charts of interest are Temperature and Pressure. The chart for flow is of no interest since it only displays flow calculated by FlowCalc32 versus flow calculated by FlowCalc32, which is a straight line. In the other two charts you can see the flow calculated by FlowCalc32 when the temperature and pressure changes.

Note that in the reference point (temperature = 410 F and pressure = 1200 kPa) the flow is 10000 Kg/h, which is the reference flow. This point is exactly the point calculated in FlowCalc32s main calculation window.

Start and end limits for the charts can be changed by changing the values in the edit fields Start and Stop. Try to change one of these values and see how the chart changes.

Ref. Temp. Start Stop °F

Flow with uncompensated root formula

Check the checkbox "Show uncompensated flow"

Show ISO calculated flow
 Show uncompensated flow

This adds a graph for uncompensated flow to the charts for temperature and pressure.

$$Q = k \times dp^{0.5}$$

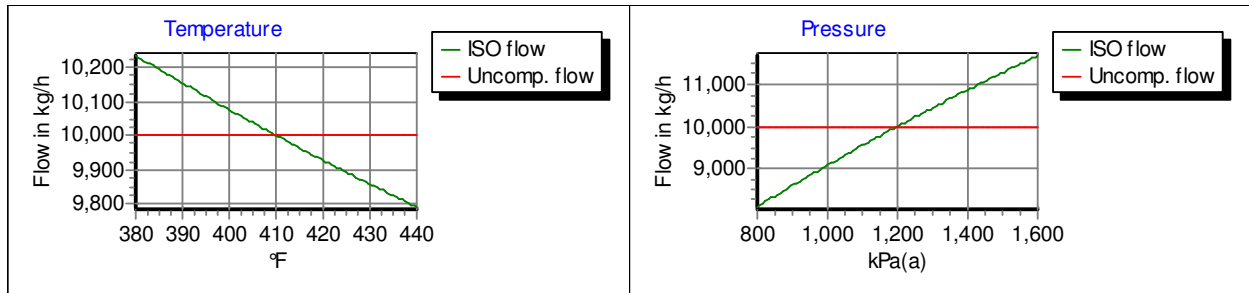
Where

Q = flow

k = calculated constant

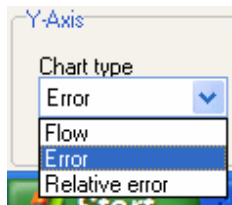
dp = differential pressure

You should now see the following charts for temperature and pressure:

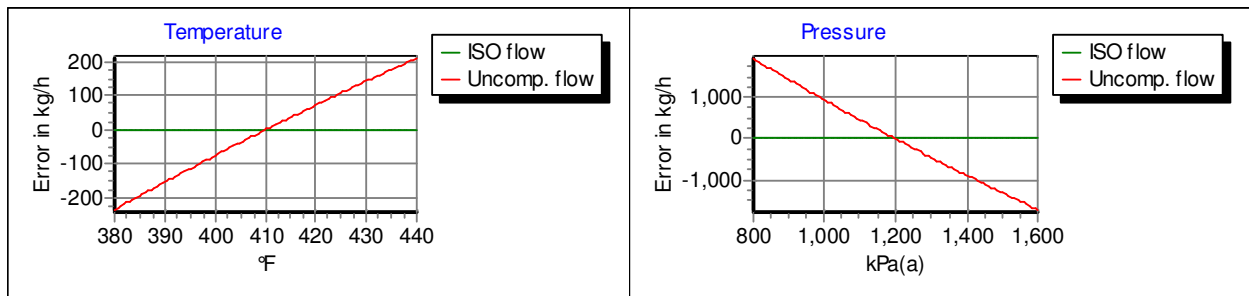


As you can see in the charts above the uncompensated flow is constant at a level of 10000 kg/h. This is the flow in the reference point and since the uncompensated formula doesn't compensate for changes in temperature and pressure the flow graph is only a straight line at this level.

Now set the chart type to error in the Y-axis box.



This changes the y axis of the charts to represent the difference between flow calculated by the flow formulas and FlowCalc32 in selected flow unit, in this case kg/h. Now the charts should look like:



In these charts you can see that the flow calculated by FlowCalc32 (ISO flow) results in an error of 0 kg/h regardless of changes in temperature and pressure. The reason for this is that the error is defined as the difference of the flow calculated by a flow formula and the flow calculated by FlowCalc32s flow formulas. The uncompensated flow on the other hand shows relatively large errors as expected.

You should also try to change the chart type to "relative error". This sets the y-axis to represent the difference towards FlowCalc32s calculated flow in percent.

Flow with compensated root formula

As we saw in the last example there is need to compensate the flow for changes in temperature and pressure. In many measurement applications the root formula with compensation is used.

Root formula with compensation

$$Q = k \frac{dp^{0.5} \times P^{0.5}}{T^{0.5}}$$

Where

Q = flow

k = calculated constant

dp = differential pressure

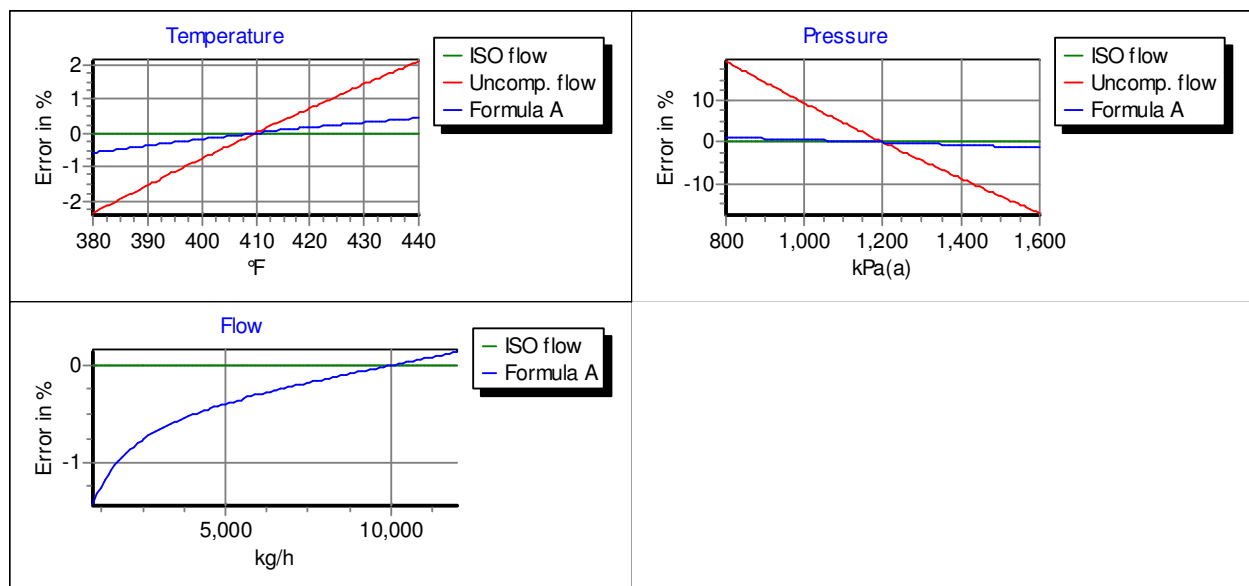
P = pressure
T = temperature

This formula tries to compensate for changes in density caused by temperature and pressure and the compensation is generally named density compensation. Now we will add this flow formula to our charts by clicking the button “+”.



This adds a new exponential flow formula named formula A to the analysis. The default values for its compensation exponents are 0.5, which is equivalent to the root formula with compensation.

Now study how this new formula handles changes in temperature and pressure compared to the previously used uncompensated formula. You can change the parameter spans of the charts and the y-axis properties exactly as we did in the previous example. The picture below shows the charts when the y-axis is set to represent relative error, which is the difference in percent between flow, calculated by FlowCalc32 and the flow formula.



As we can see the errors compared to the uncompensated flow formula are reduced.

The total flow formula for the root formula with temperature and pressure compensation can be found in the field “Flow formula”. If you should decide to use this formula it is ready to use in your flow application.

Flow formula

```
Q = 3503.7 * T^-0.5 * P^0.5 * DP^0.5
```

Flow with compensated exponential formula

Now click the ”+” button one more time. This adds another flow formula (formula B) to the list of flow formulas and the charts. Then set the diagram type to flow in the box Y-Axis and select the tab displaying the temperature chart.

You should now see the temperature flow chart containing the graphs “ISO flow”, “Uncomp. flow”, “Formula A” and “Formula B”. Since formula A and B are identical you cannot separate their graphs.

The added flow formula is an exponential formula with compensation

Exponential formula with compensation

$$Q = k \frac{dp^{dpExp} \times P^{PExp}}{T^{TExp}}$$

Where

Q = flow

k = calculated constant

dp = differential pressure

P = pressure

T = temperature

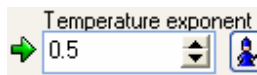
dpExp = exponent for dp compensation

PExp = exponent for pressure compensation

TExp = exponent for temperature compensation

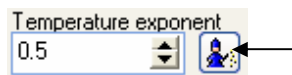
The default values for the exponents are 0.5, which makes it a root formula with compensation. Now we will examine what happens when we change the exponents.

Try using the up and down arrows in the field “Temperature exponent”



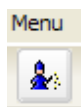
This changes the exponent used for temperature compensation in the selected flow formula and you should instantly see the changes in the flow chart. By using the arrows or typing an exponent in the edit field you can search for a flow formula that matches the flow calculated by FlowCalc32 (ISO flow) as good as possible. In the field “Flow formula” the resulting total flow formula can be seen, this changes in real time according to your changes in the field for the temperature exponent and is ready to be used in your measurement application.

The compensation analyser also includes tools that automatically searches for exponents that give the minimum flow difference towards flow calculated by FlowCalc32. Try to click the button with a wizard icon next to the field “Temperature exponent”.



Now the compensation analyser will perform a search for the temperature exponent best matching the flow calculated by FlowCalc32.

There is also a wizard that tries to find the total flow formula and not only one exponent at a time. This wizard is opened by clicking the wizard button in the toolbar positioned in the top of the compensation analyser window.



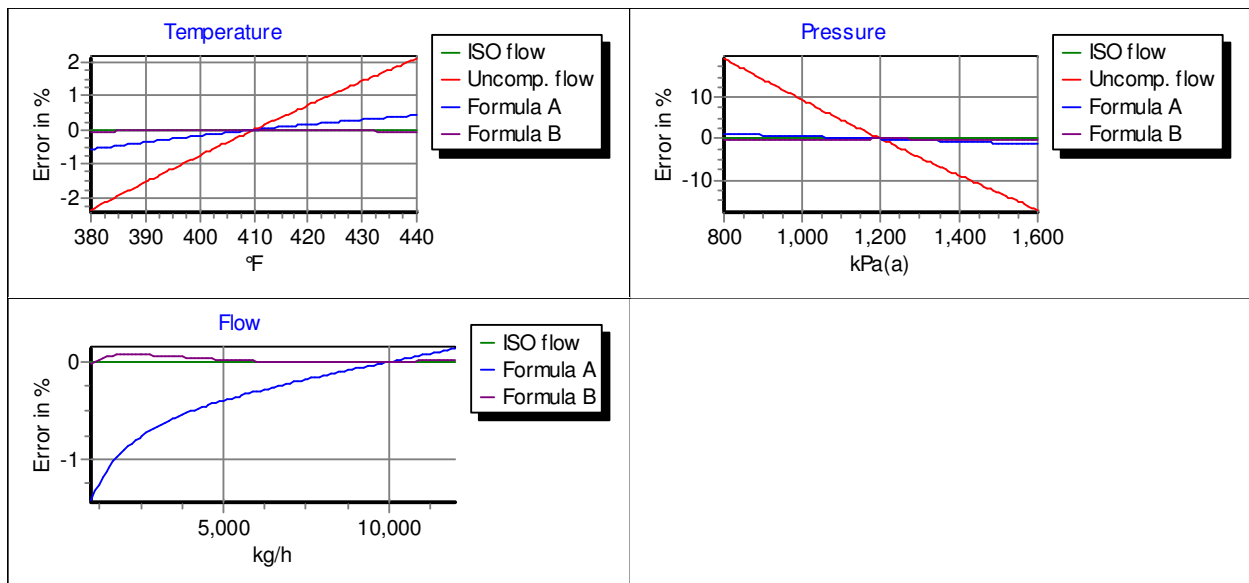
Click this button to open the compensation wizard window.



In this window you can set the parameter span in which the compensation wizard will try to find an optimal flow formula. In our case we don't have to change the limits so we proceed by clicking "Ok"

The compensation wizard will now search for the flow formula that gives the minimum difference towards flow calculated by FlowCalc32 in the desired span for temperature, pressure and flow. When the search is complete the resulting flow formula can be found in the field "Flow formula". Sometimes you may want to adjust your exponents manually after this search to make the flow formula accuracy meet your needs.

Below are flow charts for our newly found exponential flow formula (Formula B), the root compensated root formula (Formula A), the uncompensated formula and flow calculated by FlowCalc32 (ISO flow). The y-axis is set to show relative error.



In the charts above we can see that the exponential formula found by the compensation wizard gives a flow that better matches the flow calculated by FlowCalc32 than the previously studied root formula with compensation. In most cases it is possible to find an exponential formula that gives a better accuracy than the standard compensated root formula but the magnitude of the improvements varies.

Which formula to use in the final measurement application is up to the measurement application designer to decide. The compensation analyser does not give an answer to this but it gives the designer the possibility to base his decision on facts rather than guesses. Further on it quickly calculates flow formulas thereby saving time.

Report

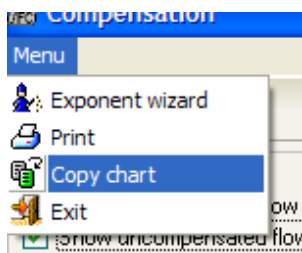


There are two ways of creating a report of the compensation analysis. The first way is to click the printer icon in the toolbar in the top of the window.

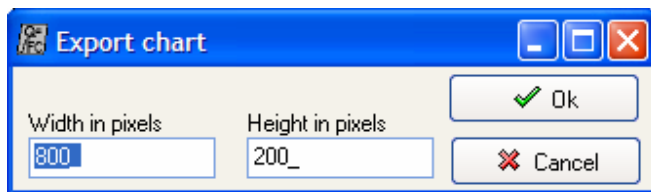


This creates a complete report of the compensation analysis that includes the charts drawn by the compensation analyser. Click this button and see how it looks. The report can then be printed by clicking the print button in the report preview window

The second way of creating a report is to copy the charts produced by the compensation analyser to some other program where you create the report, for example a word processor. To do this select the “Copy chart” from the menu.



This opens a window where you select the dimensions of the chart copy:



After selecting the chart dimensions click “Ok”. Now a copy of the selected chart from the compensation analyser is created in Windows clipboard. From there you can paste it into many other windows programs such as Microsoft Word for example. It is this export chart feature that has been used to copy the charts into this tutorial.

Data entry form, for flow calculation, by means of differential pressure over orifice.

Type of primary device: orifice plate with _corner _flange _D-D/2 tapping”
 _ venturi nozzle
 _ classical venturi tube with machined convergent
 _ classical venturi tube with sheet iron convergent
 _ classical venturi tube with rough cast convergent
 _ ISA-1932 nozzle.
 _ Long radius nozzle.

Media state :_liquid _ gas _water _ steam

Media :_____ Note 2

Identity :_____

PRIMARY DEVICE DATA

Primary device bore. :_____ Note 2

Primary device material :_____

Expansion factor. :_____ Note 1

Pipe diameter. :_____

Pipe material. :_____ Note 2

Expansion factor. :_____

PROCESS DATA

Temperature / unit :_____

Density / unit :_____ Note 5

Flow / unit. :_____ Note 1

Diff. pressure/ unit :_____ Note 1

Isentropic exp. :_____ Note 4

Dyn. visc / unit. :_____ Note 5

Pressure inlet / unit :_____

Note1: Two of these must be entered. The third is calculated.

Note2: Data not required by FlowCalc32 CE's calculations.

Note4: Not required when media is liquid. For steam 1.30 can often be used

Note5: Not required when media is steam or water.



Is orifice flow measurement a suitable choice?

History.

Inserting an orifice plate, nozzle or venturi tube and measure the drop of pressure that arises when the media passes is one method to measurement flow. This method has been used for many years and is now days mostly used for measuring steam and gases

The standardized orifices have been studied for many years and the formulas used are based on a great deal of research. All data such as accuracy, rules of installation, etc is developed by independent specialists and probably no other flow measurement method has been as firmly studied and well documented.

Other methods

Selecting the right type of flow measurement always requires a study of the operational conditions.

Now days other types of flow meters such as magnetic and vortex are becoming more and more popular. Measurement of flow by means of differential pressure over orifice has been criticized by suppliers of other gauges who claims that the accuracy is to low.

Perhaps orifice devices will make a come back as now days, computer calculated primary devices achieve good accuracy. Orifice plates, nozzles and venturi tubes do manage high temperature where other gauges are not suitable.

It is also important to observe that for gas and steam services that it's very important to check how pressure and temperature changes will affect the accuracy. Both vortex and restriction orifices are affected with similar errors if they are not compensated for such changes in operation conditions. Orifice plates, nozzles and venturi tubes are well documented and does not suffer from "teething troubles" as many other gauges has encountered when used in new conditions.

Vortex flow meters are still in many cases sensitive for vibrations and when installed for steam measurements a temporary high temperature can destroy the meter.

Mass flow gauges are complicated to install and some of them are very sensitive for vibrations.

Suppliers of other flow gauges often have guides to help you choosing measurement method.

Don't forget that they may earn some money on whatever type of flow-transmitter they are selling.

Generally speaking flow measurement by means of differential pressure over orifice devices is suitable for pure medias and alternative-measuring methods are better for medias with bigger particles.

Comparing costs, alternative flow meters tend to be inexpensive for smaller pipes and orifice devices have their benefit on larger pipes.

Standardized orifice plates, nozzles and venturi tubes. Advantages and drawbacks

Advantages.

- Accuracies are studied by independent specialists and documented in ISO 5167 and DIN1952. This means that you can trust the formulas and accuracies. No standardized gauges, do mostly have unverified accuracy.
- Larger pipe diameters: Other type flow meters either don't exist or seem to be more expensive. You can also use other not standardized primary devices but with a less documented accuracy.
- It is simple to maintain the differential pressure transmitter. The transmitters can be calibrated without shutting down the process. That gives a good validation of the performance.
- Measurement of steam:
For this type of measurement flow measurement by means of differential pressure over orifice devices

is a good choice as You get a good accuracy and a stable system that will not break down easy. At steady operational conditions or with a compensation unit for pressure and temperature you can most often attain accuracy better then 0.9%.

- Flexible
Can be used for most medias that don't have too big particles.

Drawbacks.

- Can plug up if the media has very solid particles.
- Only manages pipe diameters over 50² mm.

²

50 mm according to the standard but in practice 25 mm is used.

