

Theory overview of flow measurement using differential pressure devices based on ISO-5167 standard.

Arian FL40 flow computer description.

Flow Cad software users manual.

<b>Introduction</b> .....	<b>3</b>
<b>1.0 Basic theory</b> .....	<b>4</b>
<i>1.1 Origin of differential pressure flow measurements</i> .....	<i>4</i>
<i>1.2 ISO-5167 standard and its mass flow rate formula</i> .....	<i>7</i>
<b>2.0 The FL40 flow computer</b> .....	<b>10</b>
<b>3.0 Arian ISO-5167 Flow Cad software</b> .....	<b>11</b>
<i>3.1 Software Installation</i> .....	<i>11</i>
<i>3.2 Start up</i> .....	<i>12</i>
<i>3.3 Fluid selection</i> .....	<i>14</i>
<i>3.4 Primary device</i> .....	<i>18</i>
<i>3.5 Flow conditions set up</i> .....	<i>20</i>
<i>3.6 Calculating results</i> .....	<i>22</i>
<i>3.7 Instrument parameters</i> .....	<i>25</i>
<b>References</b> .....	<b>27</b>

# Introduction

Differential pressure flow measurement is old and reliable. With the aid of microprocessor technology now discharge coefficient calculations can be done in real time. Even more, properties of the fluid can be stored on the instrument and measuring temperature and absolute pressure allows to correct fluid parameters such as density and viscosity and then to obtain the mass flow rate. This are called multivariable mass flow meters.

By other side years of research and experiments had been done obtaining better characterization of typical differential pressure devices (nozzles, orifice plate , etc). The ISO5167 standard condenses all this experimental information giving the formulas and procedures for manufacturing a differential pressure flow measurement device of the standard types with a predictable uncertainty.

## 1.0 Basic theory.

This overview intention is only to refresh the knowledge you already have from your technical studies. Also can be a introduction to the problem, but reader must have some knowledge on fluid dynamics.

### 1.1 Origin of differential pressure flow measurements.

Bernoulli equation represents energy conservation for a fluid element:

$$Const = \rho \cdot g \cdot h + \frac{1}{2} \rho \cdot v^2 + P \quad (1)$$

$\rho$	Fluid Density
$v$	Linear velocity of the fluid element
$P$	Pressure

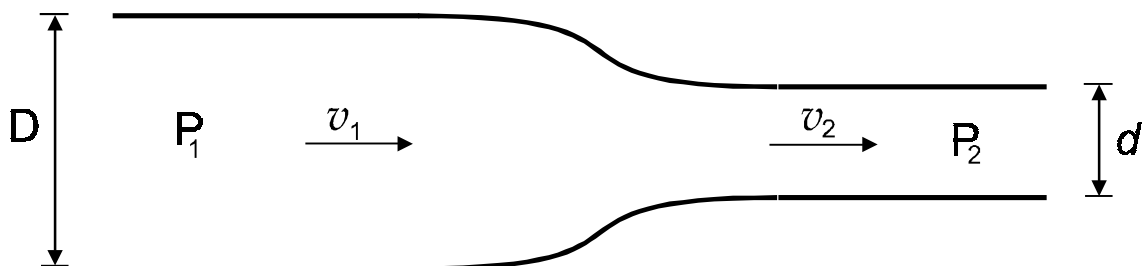
The first term  $\rho \cdot g \cdot h$  is the potential energy coming from height on the gravitational field. For our development we will suppose constant height of our fluid, so this term is discarded and the equation is:

$$Const = \frac{1}{2} \rho \cdot v^2 + P \quad (2)$$

The term  $\frac{1}{2} \rho \cdot v^2$  is kinetic energy, here the density replaces mass.

Pressure  $P$  can be understand as a potential energy. Work is stored in compressing the fluid the same way as a compressed string stores energy.

We apply this equation to a circular cross section pipe that is reduced in diameter as it goes down stream in horizontal direction



$$\frac{1}{2} \rho_1 \cdot v_1^2 + P_1 = \frac{1}{2} \rho_2 \cdot v_2^2 + P_2 \quad (3)$$

$\rho_1, v_1, P_1$  Up stream density, velocity and pressure

$\rho_2, v_2, P_2$  Down stream density, velocity and pressure

By other side mass is conserved (not created nor destroyed) as it flows along the pipe, this is represented by the formulas

$$Q_M = \rho_2 \cdot v_2 \cdot A_2 = \rho_1 \cdot v_1 \cdot A_1 \quad (4)$$

$Q_M$  Mass flow rate along the pipe, units are e.g. Kg/sec

$A_2, A_1$  Up and down stream cross sectional area of the pipe

Squaring both sides of (4), and solving for  $v_2^2$  we have

$$v_2^2 = v_1^2 \cdot \left( \frac{\rho_1 \cdot A_1}{\rho_2 \cdot A_2} \right)^2 \quad (5)$$

From (3), we have

$$2 \cdot (P_1 - P_2) = \rho_2 \cdot v_2^2 - \rho_1 \cdot v_1^2$$

Substituting  $v_2^2$  from (5) into this equation

$$2 \cdot (P_1 - P_2) = v_1^2 \cdot \left( \rho_2^2 \left( \frac{\rho_1 \cdot A_1}{\rho_2 \cdot A_2} \right)^2 - \rho_1^2 \right) = v_1^2 \cdot \frac{(\rho_2^2 \cdot (\rho_1 \cdot A_1)^2 - \rho_1^2 \cdot (\rho_2 \cdot A_2)^2)}{(\rho_2 \cdot A_2)^2}$$

From this equations,  $v_1$  can be written as

$$v_1 = \sqrt{2 \cdot (P_1 - P_2)} \cdot \sqrt{\frac{(\rho_2 \cdot A_2)^2}{(\rho_2^2 \cdot (\rho_1 \cdot A_1)^2 - \rho_1^2 \cdot (\rho_2 \cdot A_2)^2)}}$$

This value of  $v_1$  is substituted on (4)

$$Q_M = \rho_1 \cdot v_1 \cdot A_1 = \sqrt{2 \cdot (P_1 - P_2)} \cdot \sqrt{\frac{(\rho_1 \cdot A_1)^2 \cdot (\rho_2 \cdot A_2)^2}{(\rho_2^2 \cdot (\rho_1 \cdot A_1)^2 - \rho_1^2 \cdot (\rho_2 \cdot A_2)^2)}} \quad (4a)$$

Those who are familiar with orifice plates, will recognize the pressure difference square root dependence of the mass flow .  
Now since the pipes are circular with diameters

$D$  Up stream diameter  
 $d$  Down stream diameter

Circular cross areas are

$$A_2 = \left(\frac{d}{2}\right)^2 \cdot \pi$$

$$A_1 = \left(\frac{D}{2}\right)^2 \cdot \pi$$

Substituting on (4a) and ordering terms we obtain finally

$$Q_M = \sqrt{\frac{1}{\left(\frac{\rho_1}{\rho_2}\right) - \beta^4}} \cdot \frac{\pi}{4} \cdot d^2 \cdot \sqrt{2 \cdot (P_1 - P_2) \cdot \rho_1} \quad (4b)$$

with,  $\beta = \left(\frac{d}{D}\right)$

The equation (4b) was obtained only from Bernoulli and mass conservation.

Is very similar to the equation (1) on page 6 of ISO 5167-1:1991(E) document, (from now on ref-1 document).

In fact for a uncompressible fluid (liquid),  $\left(\frac{\rho_1}{\rho_2}\right) = 1$  gets even more similar.

This equation (4b) comes only from a theoretic analysis, does not take consider turbulent flow or thermo-dynamical energy conservation for the fluid in order to be used in a practical flow rate measurement.  
It is useful only to get some insight on the ISO5167 equations.

## 1.2 ISO-5167 standard and its mass flow rate formula.

The general equation for mass flow rate measurement used by ISO5167 standard is:

$$Q_M = \frac{C}{\sqrt{1-\beta^4}} \cdot \varepsilon_1 \cdot \frac{\pi}{4} \cdot d^2 \cdot \sqrt{2 \cdot \Delta p \cdot \rho_1}$$

You will find it on section 5.1 of ref-1, this formula is obtained in part from additional complex theoretic analysis but comes mostly from experimental research done along years and presented in several publications.

What is interesting about ISO5167 standard is that condenses all the experimental research and gives it in a simple and practical form (well not so simple but useful).

We will classify the parameters on the formula by 3 different groups, this will help us understanding the formula and also on using Arian flow software.

### *Fluid property,*

This are intrinsic fluid properties, e.g. density or viscosity at given temperature or pressure.

### *Primary device parameter*

This are the primary device physical properties such as: pipe diameter, bore size, device material temperature expansion coefficient.

### *Flow conditions*

This are the specific flow conditions, e.g., pressure, temperature, differential pressure.

$Q_M$

Mass flow rate, in (mass)/(time) units

$\Delta p$  Differential pressure  $\Delta p = (p_1 - p_2)$

Difference between the (static) pressures measured at the wall pressure tapings, one of which is on the upstream side and the other of which is on the downstream side of a primary device (or in the throat for a Venturi tube) inserted in a straight pipe through which flow occurs, when any difference in height between the up-stream and downstream tapings has been taken into account.

$\rho_1$  Up stream fluid density.

$d$  Bore diameter

$D$  Pipe diameter

$\beta$  Diameter ratio

This is a geometric parameter of the device, that is calculated using

$$\beta = \frac{d}{D}$$

$\varepsilon_1$  Expansion factor. (Up stream evaluated)

Coefficient used to take into account the compressibility of the fluid. The numerical values of  $\varepsilon_1$  for orifice plates given in ISO5167 are based on data determined experimentally. For nozzles and Venturi tubes they are based on the thermodynamic general energy equation.

For liquids (incompressible fluids), is always  $\varepsilon_1 = 1$

For steam and gases (compressible fluids)  $\varepsilon_1 < 1$ .

Is calculated with different formulas depending on the device geometry.

For example for a orifice plate, ISO5167-1:1991(E) section 8.3.2.2 gives on the following formula:

$$\varepsilon_1 = 1 - (0.41 + 0.35 \cdot \beta^4) \cdot \frac{\Delta p}{k \cdot p_1}$$

Where  $k$  is the isentropic exponent, a "Fluid property" that depends on fluid pressure and temperature. Is related with adiabatic expansion of the fluid in the bore zone.

$C$  Discharge coefficient

Is a coefficient, defined for an incompressible fluid flow, which relates the actual flow-rate to the theoretical flow-rate through a device. Is related with turbulent flow and the restriction the devices makes to the flow.

Again the formula for evaluating it, comes from empirical data, for example for a orifice plate, the formula used by ISO5167-1:1991 section 8.3.2.1 on page 22.

$$C = 0.5959 + 0.0312 \cdot \beta^{2.1} - 0.184 \cdot \beta^8 + 0.0029 \cdot \beta^{2.5} \cdot \left(\frac{10^6}{Re_D}\right)^{0.75} + 0.09L_1 \cdot \beta^4 \cdot (1 - \beta^4)^{-1} - 0.0337L_2' \cdot \beta^3$$

Where,

$L_2'$ ,  $L_1$  are geometrical parameters of the orifice plate as described on same page of the document.

$$Re_D = \frac{\rho_1 \cdot v_1 \cdot D}{\mu_1} \quad \text{is the Reynolds number for up stream flow}$$

$v_1$ ,  $\mu_1$

Are the Up stream velocity and viscosity of the fluid. The viscosity is fluid property that depend on pressure and mostly on temperature.

This formula for discharge coefficient is named the Stolz equation and on 1998 ISO5167 amendment, ref-2, was substituted for the larger Reader-Harris/Gallagher formula (not included here because of space lack).

As you may see, this formulas are large but, there is no problem since you will use our flow software for evaluating them with just one mouse click.

You may notice that here seems to be a problem related to self reference of the formula :

You need	To calculate
$v_1$	$Re_D$
$Re_D$	$C$
$C$	$Q_M$
$Q_M$	$v_1$ (using density and area of the pipe)

This problem is solved by iteration searching for self consistent results and is done automatically by Arian Flow Cad software.

Also is to be considered that the formulas given by ISO5167 have certain validity range, depending on  $\beta$ ,  $Re_D$  values.

Take a look for example at ISO5167-1 section 8.3.1.

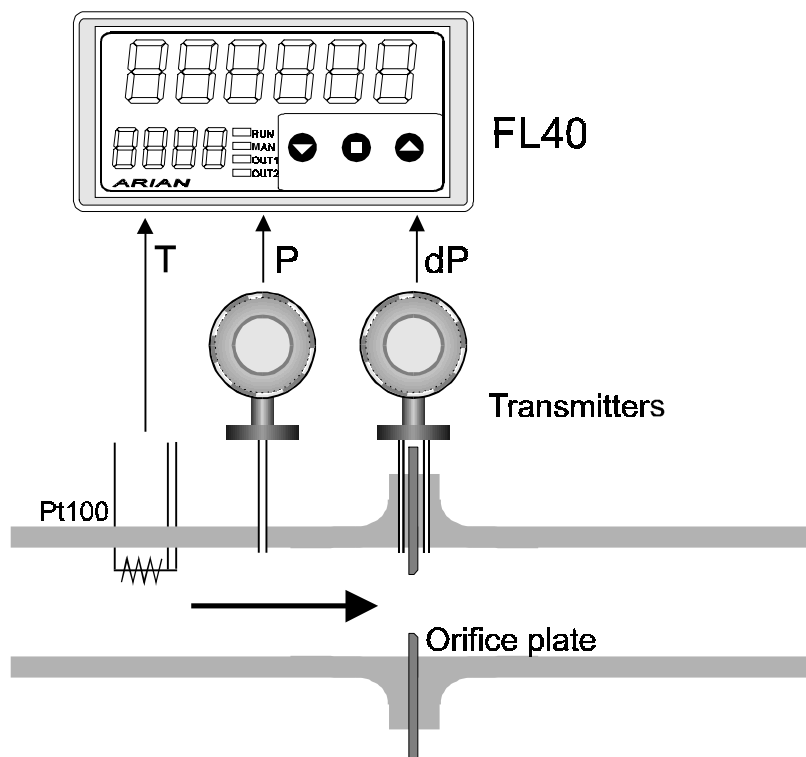
Again the Arian Flow Cad will help advising if flow conditions are out the norm.

## 2.0 The FL40 flow computer.

The FL40 is a powerful multivariable flow computer specifically designed for use on primary devices designed under the ISO5167 standard.

Calculates actual mass flow from the 3 following parameters measured continuously

- dP Differential pressure input (e.g. 4-20ma, 0-10V,..)
- P1 Up stream fluid pressure input (e.g. 4-20ma, 0-10V,..)
- T1 Up stream fluid temperature input (Pt100, thermocouples)



The fluid physical properties are stored on the FL40 so it calculates actual mass flow rate or volumetric flow if you prefer.

Additionally has a 6 digit flow totalizer with alarms and communications functionalities that are described in detail in it's user manual.

Here we will concentrate on describing the input configuration for the FL40 witch is done with the help of the Arian Flow Cad software.

## 3.0 Arian ISO-5167 Flow Cad software.

The Arian Flow Cad software is used for calculating discharge coefficient and expansion factor as ISO5167 describes.

The software generates a configuration file that is downloaded to the FL40 with the RPS PC configuration system. So you don't need to introduce manually a large set of configuration parameters.

Is strongly recommend to have a copy of the ISO 5167 document while you read this manual.

### 3.1 Software Installation.

You need a PC computer with

- windows 95 operating system or better.
- svga 800x600 color monitor.

Uncompress it in any empty folder of your PC. That is all what you need to do, you are ready for start up.

Since the program does not make any change on windows registry, for removing it just delete all the files on the folder.

### 3.2 Start up.

Execute application ArianIso5167FlowCad\_V1.exe.  
Within the program go to [File / Open] in the upper context menu.  
Open the example file air.flw as an example

The screenshot shows the 'Arian Iso5167 Flow Cad' application window. The interface includes a menu bar with 'File', 'Fluid', 'Device', 'Notes', 'Instrument', and 'Help'. The main workspace is divided into several sections:

- Flow Conditions:** A table with columns for 'Min', 'Max', and 'Units'.

	Min	Max	Units
P	1	2	Atm
T	0	30	C
dP	800	24000	Pa
- Flow Units:** Three rows of dropdown menus for 'Q mass', 'Q volume', and 'Velocity', each followed by '/ per' and a 'Sec' dropdown.
- Standard Conditions:** A sub-section with 'Pressure (absolute)' and 'Temperature' dropdowns, and a text field for 'Density at conditions (Kg/m3) = \_\_\_'.

A 'Calculate' button is located at the bottom left of the main workspace. The status bar at the bottom of the window displays the file path: 'D:\dsgn\flow\v4\files\example\_Air.flw'.

On this main form you fill the “Flow conditions”  
The other forms in the context menu are the following

- |              |  |
|--------------|--|
| [Fluid]      | Fluid properties.                          |
| [Device]     | Primary device description and parameters. |
| [Notes]      | Add here comments about the project.       |
| [Instrument] | Configuration of the FL40.                 |

The file menu has the following options:

[File / Open]	Opens a new project file with extension .fld
[File / Save]	Saves the project file.
[File / Save as]	Saves with different name.
[File / Report]	Generates a project report file to be printed later. In this example (air.flw) will generate air_Report.txt and air_Report_Data.csv
[File / Exit]	Quits

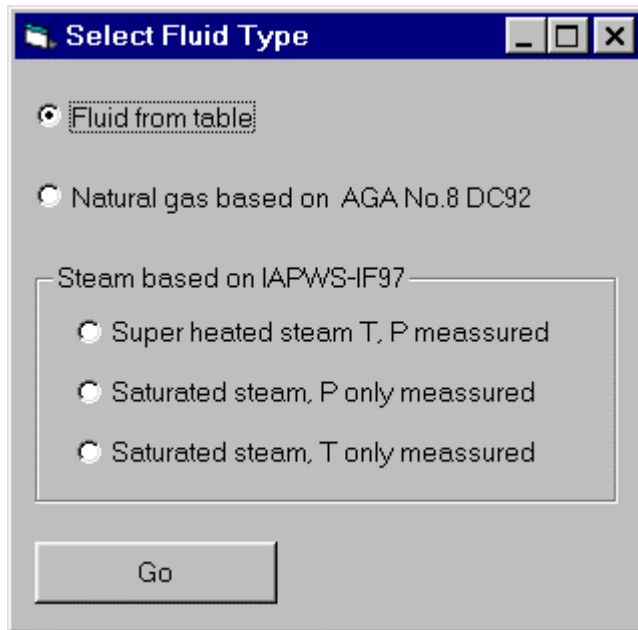
Press now the lower left button “Calculate” and see how calculates the coefficients for the example.

### 3.3 Fluid selection.

The Arian Flow Cad stores about 100 common fluid properties so you simply select from the list the one you will use and if it is liquid or gas.

The internal stored parameter allows to compute the fluid density, viscosity, isentropic constant at operating temperature and pressure conditions.

Go to the [Fluid] menu on top, the following form appears.



Now you have several fluid type options:

#### **Super heated steam T, P measured.**

In this case you are using steam at a temperature higher than the boiling temperature at the working pressure conditions.

Is needed to measure both pressure and temperature.

Properties of steam are calculated with IAPWS-IF97

#### **Saturated steam, P only measured.**

Upstream pressure is the same of the chamber where steam is produced. (water boiled). The steam temperature is inferred by the pressure of the chamber.

Pressure is measured and the steam temperature calculated from tables.

For example at 1Atm water boils at 100C, at 1.2Atm boils at 105C, etc.

Properties of steam are calculated also with IAPWS-IF97

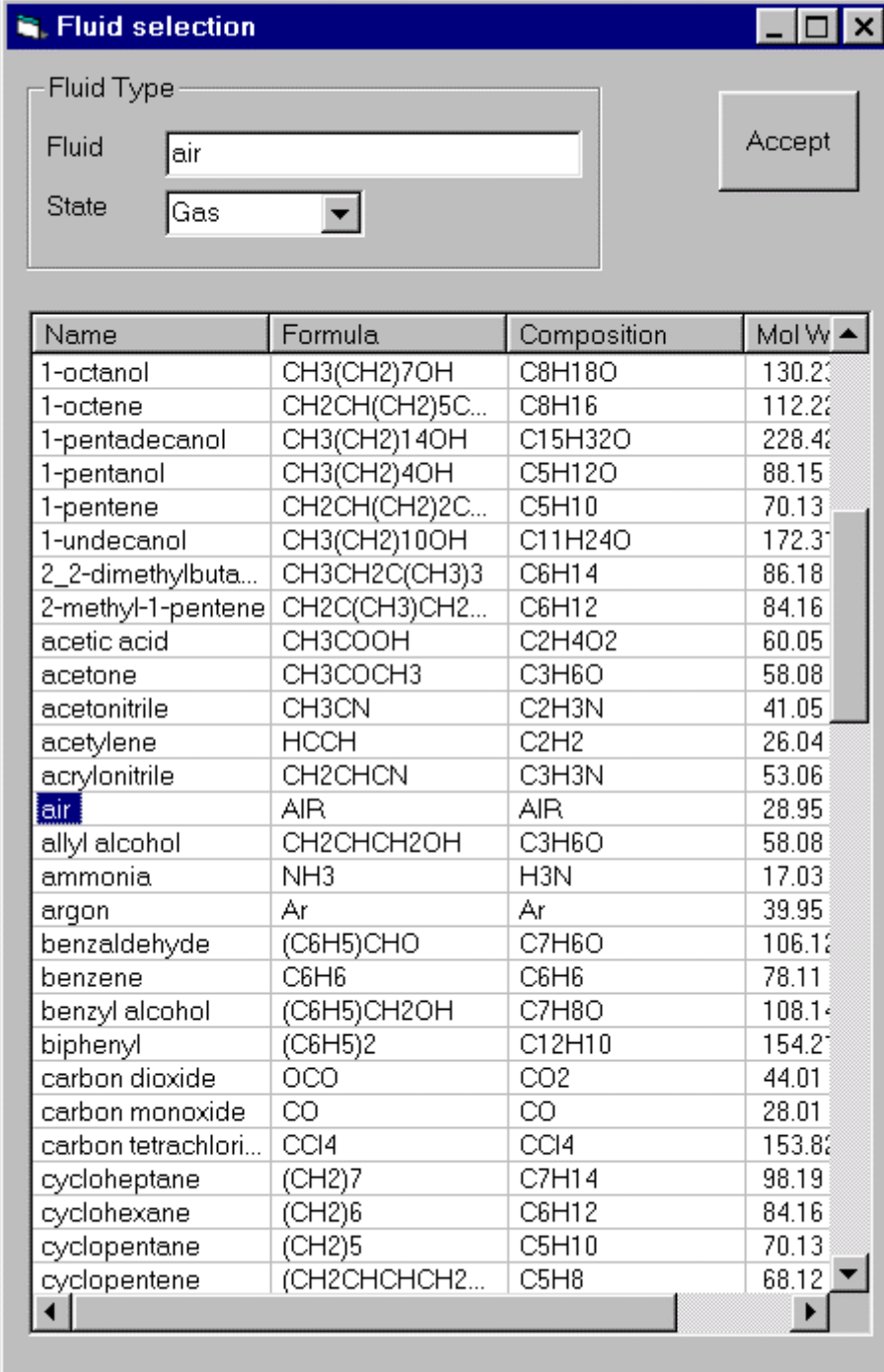
#### **Saturated steam, T only measured.**

This is the same last case but is measured the temperature.

Pressure is obtained from "vapor pressure" tables at working (measured) temperature.

## Fluid from table:

This allows to select the fluid (gas or liquid) from a list. Properties of the pure compounds are stored on a data base. Also must be specified the state of the element.



Fluid selection

Fluid Type

Fluid:

State:

Accept

Name	Formula	Composition	Mol Wt
1-octanol	CH <sub>3</sub> (CH <sub>2</sub> ) <sub>7</sub> OH	C <sub>8</sub> H <sub>18</sub> O	130.23
1-octene	CH <sub>2</sub> CH(CH <sub>2</sub> ) <sub>5</sub> C...	C <sub>8</sub> H <sub>16</sub>	112.22
1-pentadecanol	CH <sub>3</sub> (CH <sub>2</sub> ) <sub>14</sub> OH	C <sub>15</sub> H <sub>32</sub> O	228.46
1-pentanol	CH <sub>3</sub> (CH <sub>2</sub> ) <sub>4</sub> OH	C <sub>5</sub> H <sub>12</sub> O	88.15
1-pentene	CH <sub>2</sub> CH(CH <sub>2</sub> ) <sub>2</sub> C...	C <sub>5</sub> H <sub>10</sub>	70.13
1-undecanol	CH <sub>3</sub> (CH <sub>2</sub> ) <sub>10</sub> OH	C <sub>11</sub> H <sub>24</sub> O	172.31
2_2-dimethylbuta...	CH <sub>3</sub> CH <sub>2</sub> C(CH <sub>3</sub> ) <sub>3</sub>	C <sub>6</sub> H <sub>14</sub>	86.18
2-methyl-1-pentene	CH <sub>2</sub> C(CH <sub>3</sub> )CH <sub>2</sub> ...	C <sub>6</sub> H <sub>12</sub>	84.16
acetic acid	CH <sub>3</sub> COOH	C <sub>2</sub> H <sub>4</sub> O <sub>2</sub>	60.05
acetone	CH <sub>3</sub> COCH <sub>3</sub>	C <sub>3</sub> H <sub>6</sub> O	58.08
acetonitrile	CH <sub>3</sub> CN	C <sub>2</sub> H <sub>3</sub> N	41.05
acetylene	HCCH	C <sub>2</sub> H <sub>2</sub>	26.04
acrylonitrile	CH <sub>2</sub> CHCN	C <sub>3</sub> H <sub>3</sub> N	53.06
air	AIR	AIR	28.95
allyl alcohol	CH <sub>2</sub> CHCH <sub>2</sub> OH	C <sub>3</sub> H <sub>6</sub> O	58.08
ammonia	NH <sub>3</sub>	H <sub>3</sub> N	17.03
argon	Ar	Ar	39.95
benzaldehyde	(C <sub>6</sub> H <sub>5</sub> )CHO	C <sub>7</sub> H <sub>6</sub> O	106.12
benzene	C <sub>6</sub> H <sub>6</sub>	C <sub>6</sub> H <sub>6</sub>	78.11
benzyl alcohol	(C <sub>6</sub> H <sub>5</sub> )CH <sub>2</sub> OH	C <sub>7</sub> H <sub>8</sub> O	108.14
biphenyl	(C <sub>6</sub> H <sub>5</sub> ) <sub>2</sub>	C <sub>12</sub> H <sub>10</sub>	154.20
carbon dioxide	OCO	CO <sub>2</sub>	44.01
carbon monoxide	CO	CO	28.01
carbon tetrachlori...	CCl <sub>4</sub>	CCl <sub>4</sub>	153.84
cycloheptane	(CH <sub>2</sub> ) <sub>7</sub>	C <sub>7</sub> H <sub>14</sub>	98.19
cyclohexane	(CH <sub>2</sub> ) <sub>6</sub>	C <sub>6</sub> H <sub>12</sub>	84.16
cyclopentane	(CH <sub>2</sub> ) <sub>5</sub>	C <sub>5</sub> H <sub>10</sub>	70.13
cyclopentene	(CH <sub>2</sub> CHCHCH <sub>2</sub> ...	C <sub>5</sub> H <sub>8</sub>	68.12

**Natural Gas:**

The AGA No.8 DC92 formulas are used for computing the properties of natural gas.

Molar concentration in % of each component must be specified.

Molar composition			
Name	Formula	Molar %	Fixed
Methane	CH4	96.5	<input checked="" type="checkbox"/>
Nitrogen	N2	.3	<input checked="" type="checkbox"/>
Carbon Dioxide	CO2	.6	<input type="checkbox"/>
Ethane	C2H6	1.8	<input type="checkbox"/>
Propane	C3H8	.45	<input type="checkbox"/>
Water	H2O	0	<input type="checkbox"/>
Hydrogen Sulfide	H2S	0	<input type="checkbox"/>
Hydrogen	H2	0	<input type="checkbox"/>
Carbon Monoxide	CO	0	<input type="checkbox"/>
Oxygen	O2	0	<input type="checkbox"/>
iso-Butane	C4H10	.1	<input type="checkbox"/>
n-Butane	C4H10	.1	<input type="checkbox"/>
iso-Pentane	C5H12	.05	<input type="checkbox"/>
n-Pentane	C5H12	.03	<input type="checkbox"/>
n-Hexane	C6H14	.07	<input type="checkbox"/>
n-Heptane	C7H16	0	<input type="checkbox"/>
n-Octane	C8H18	0	<input type="checkbox"/>
n-Nonane	C9H20	0	<input type="checkbox"/>
n-Decane	C10H22	0	<input type="checkbox"/>
Helium	He	0	<input type="checkbox"/>
Argon	Ar	0	<input type="checkbox"/>

Accept

Total molar %

Normalize 100

Normalize button is used for setting the sum of molar concentrations equal to 100%.

That is done multiplying all concentrations to a fixed constant that modifies each individual concentration in order to be the sum 100%.

Selected components can be set as fixed so they are not changed on normalization.

### 3.4 Primary device.

On the [Device] menu you will have the following form

The screenshot shows a software dialog box titled "Primary device settings". It is divided into three main sections. The first section, "Iso 5167 Formulas", contains two dropdown menus: "Iso Type" (set to "Iso 5167-1:1991 Sec.8 Orifice plates") and "Case" (set to "D and D/2 Taps"). An "Accept" button is located to the right of these dropdowns. The second section, "Bore diameter (d)", includes a text input field with "100", a unit dropdown menu set to "mm", a material dropdown menu set to "316 Stainless Steel", a text input field with "21", and a dropdown menu set to "C". The third section, "Upstream Pipe diameter (D)", includes a text input field with "200", a unit dropdown menu set to "mm", a material dropdown menu set to "316 Stainless Steel", a text input field with "21", and a dropdown menu set to "C".

The options are:

#### **Iso Type**

Select the exact standard under you want to do the calculations.

- Iso 5167-1:1991 Sec.8 Orifice plate
- Iso 5167-1:1991 Sec.9 Nozzle
- Iso 5167-1:1991 Sec.10 Venturi tube
- Iso 5167-1:1991 Sec.10.1 Venturi tube
- Iso 5167-1:1991 Sec.10.2 Venturi nozzle
- Iso 5167-1:1991/Amd.1:1998 Orifice plate
- Iso 5167-2:2003 Orifice plate
- Iso 5167-3:2003 Nozzle
- Iso 5167-4:2003 Venturi tube

#### **Case**

Once the standard is defined, there are usually different cases you must specify.

For example for a orifice plate, you must specify this design options:

- Corner Taps
- D and D/2 Taps
- Flange Taps

Or for a nozzle, cases are:

- ISA 1932 Nozzle
- Long radius Nozzle

**Bore diameter (d)**

You must set the bore diameter and the units (e.g. mm, inch,..)

Optionally you may introduce the bore material and the temperature at which you measured that diameter.

This information is used for example in a situation where the primary device will operate with a gas at 200C. The bore diameter changes by thermal expansion.

The used diameter must be the one at that temperature, but is not easy to put a caliper inside a pipe at 200C.

So you may measure the diameter with a caliper at environmental temperature (e.g. 25C) and specify the bore material and temperature of your measurement.

The software has thermal expansion coefficients tables for typical bore and Pipe material and will correct continuously for the diameter at operating temperature.

**Upstream Pipe diameter (D)**

Here accounts same considerations as for bore diameter.

### 3.5 Flow conditions set up.

Once you have set all the information requested on [Fluid] and [Device] menus, you may set the flow limits in the main form.

Here is an explanation of the parameter to be set:

	Min	Max	Units	Units Type	Atmospheric Pressure	
P	1	2	Atm	Absolute	1	Atm
T	0	30	C			
dP	800	24000	Pa			

#### Flow conditions

In this frame you must set the expected limits (maximum and minimum) for:

##### P

Upstream fluid pressure range. The fluid pressure you will have must be contained within this limits.

If your pressure sensor/transmitter measures absolute pressure (referred to absolute vacuum) then select:

[Units Type] = Absolute

But if the sensor measures relative to atmospheric pressure, then you must specify [Atmospheric pressure] and set:

[Units Type] = Gauge

##### T

Upstream fluid temperature range. The fluid operating temperature must be within this range.

##### dP

Differential pressure range. This is the maximum and minimum differential pressure you expect to have.

The minimum can not be zero, mainly because ISO5167 needs a minimum Reynolds number of about 4000 typically.

With zero differential pressure you have zero fluid linear velocity and zero Reynolds.

## Flow Units

Here you set the rate units for calculated results.

Results will be mass, volumetric and linear velocity flow rate in the specified units.

The image shows a software interface for configuring flow units. It is divided into two main sections: 'Flow Units' and 'Standard Conditions'.

**Flow Units:**

- Q mass:** Unit dropdown is 'Std(Cubic Ft)', 'per' dropdown is 'Sec'.
- Q volume:** Unit dropdown is 'Cubic Meter', 'per' dropdown is 'Sec'.
- Velocity:** Unit dropdown is 'Meter', 'per' dropdown is 'Sec'.

**Standard Conditions:**

- Pressure (absolute):** Value is '1', unit dropdown is 'Atm'.
- Temperature:** Value is '21', unit dropdown is 'C'.
- Density at conditions (Kg/m3):** Field is empty, indicated by a small horizontal line.

Mass units can be of the “Volumetric equivalent type” e.g. [Standard Cubic feet] or [Standard Cubic Meter]

If you set “volumetric equivalent” mass flow units for mass flow rate, the you must then specify the Standard conditions (Pressure and Temperature). For example if you are working with air a you set

[Q mass] = [Std(Cubic Ft)]  
[Standard Conditions Pressure] =1 Atm  
[Standard Conditions Temperature] =21 C

Then the mass flow rate will be expressed in units of mass equivalent to the mass contained in 1 cubic feet of air at 1Atm and 21C. That is 33.96 grams.

### 3.6 Calculating results.

Once you have set [Fluid] , [Device] and [flow conditions], then press the calculate button on the lower left corner of the main form.

The screenshot shows the 'Arian Iso5167 Flow Cad' software window. It has a menu bar with 'File', 'Fluid', 'Device', 'Notes', 'Instrument', and 'Help'. The main area is divided into several sections:

- Flow Conditions:** Contains input fields for 'Min', 'Max', and 'Units' for Pressure (P), Temperature (T), and differential pressure (dP). There are also 'Units Type' and 'Atmospheric Pressure' dropdowns.
- Flow Units:** Contains dropdowns for 'Q mass', 'Q volume', and 'Velocity' units, along with 'Standard Conditions' for pressure and temperature, and a calculated density value.
- Results Table:** A table with 8 rows and 8 columns showing calculated values for T, P, dP, Density, Viscosity, Isentropic Exp, and Q mass.
- Calculate Button:** A button labeled 'Calculate' is located at the bottom left.
- File Path:** The bottom of the window shows the file path: 'D:\dsgn\flow\v4\files\example\_Air.flw'.

T [C]	P [Atm]	dP [Pa]	Density [Kg/m...]	Viscosity [Pa.Se...]	Isentropic Exp	Q mass [Kg/Sec]	C
0	1	800	1.29464	1.72481E-05	1.402643	.2232112	.
0	1	24000	1.29464	1.72481E-05	1.402643	1.131781	.
0	2	800	2.590895	1.72481E-05	1.403645	.3157537	.
0	2	24000	2.590895	1.72481E-05	1.403645	1.663418	.
30	1	800	1.166229	1.869872E-05	1.402196	.2121534	.
30	1	24000	1.166229	1.869872E-05	1.402196	1.075255	.
30	2	800	2.333326	1.869872E-05	1.403173	.300035	.
30	2	24000	2.333326	1.869872E-05	1.403173	1.580094	.

The results will be given for the 8 combinations resulting from the 2 limits (min. and max. ) given for P, T, dP.

You may think as 3 dimensional space composed of 3 axes P, T and dP in a cube with 8 corners. The flow conditions must always be kept inside this “cube”.

The calculation results are contained on the 8 lines of the list as follows:

T [C]	P [Atm]	dP [Pa]	Density [Kg/m3]	Viscosity	Isentropic
0	1	800	1.292067	1.724475E-05	1.401914
0	1	24000	1.292067	1.724475E-05	1.401914
0	2	800	2.585746	1.724475E-05	1.401914
0	2	24000	2.585746	1.724475E-05	1.401914
30	1	800	1.163911	1.869568E-05	1.401486
30	1	24000	1.163911	1.869568E-05	1.401486
30	2	800	2.328689	1.869568E-05	1.401486
30	2	24000	2.328689	1.869568E-05	1.401486

$\rho_1$  Density of the fluid at specified T, P limits in MKS units.

$\mu_1$  Viscosity of the fluid at specified T, P limits in Pascal\*Sec units.  
1 Pa\*Sec = 1000 (centi Poise)

Isentropic Const	Q mass [Kg/Sec]	Q vol [Cubic Met...]	Velocity [Meter/...]	Re (D)	C dis
1.401914	.2229897	.1725837	5.496467	82342	.6064
1.401914	1.13061	.8750404	27.86839	417496	.6040
1.401914	.3154401	.1219919	3.885213	116481	.6056
1.401914	1.661688	.642634	20.46668	613605	.6038
1.401486	.211943	.1820956	5.794479	72158	.6067
1.401486	1.074144	.9228755	29.3669	365707	.6041
1.401486	.2997371	.128715	4.095851	102049	.6059
1.401486	1.578453	.6778291	21.56926	537406	.6039

$k$  Isentropic exponent of the fluid at specified T, P limits (dimensionless).

$Q_M$  Mass flow rate in specified units at T, P, dP limits.

$Q_V$  Volumetric flow rate in specified units at T, P, dP limits.

$v_1$  Fluid linear velocity in specified units at T, P, dP limits.

$Re_D$  Reynolds number (upstream)

C discharge	Expansion factor	P loss [Pa]	Uncertainty %	Iso5167 Condition not satisfied
.6058	.99757	583.5853	.601	
.60345	.92707	17529.34	1.121	
.60503	.99879	583.8215	.6	
.6032	.96356	17531.64	.764	
.60614	.99757	583.478	.601	
.60355	.92705	17528.39	1.121	
.6053	.99879	583.7385	.6	
.60328	.96355	17530.93	.764	

$C$  The discharge coefficient

$\varepsilon_1$  The expansion factor (upstream)

#### P loss

The pressure loss is the difference in static pressure between the pressure measured at the wall on the upstream side of the primary device at a section where the influence of the approach impact pressure adjacent to the plate is still negligible (approximately  $D$  upstream of the primary device) and that measured on the downstream side of the primary device where the static pressure recovery by expansion of the jet may be considered as just completed (approximately  $6D$  downstream of the primary device).

This is good approximation (not exact) for the effect of the primary device on flow before it is installed.

Must not be confused with  $dP$ , the pressure difference on the primary element walls. In general is expected to have  $dP$  greater than  $P$  loss.

#### Uncertainty %

The quadratic sum for the estimated uncertainty of  $C$  and estimated uncertainty on  $\varepsilon_1$  as predicted by the ISO5167 standard.

This is the uncertainty on the flow rate  $Q_M$ , if no additional errors are made on measurements. For details refer to ISO5167-:1991, Section 11.2.2

#### ISO5167 Condition not satisfied

This last column expresses if the ISO5167 standard is satisfied or not. If you read the document you will find that there are several restrictions on the bore and pipe diameter, the Reynolds number, etc. This restriction comes from the fact that the ISO standard was obtained from experimental results that are bounded under certain limits.

Is important to take care in being within the ISO5167 limits unless you want the uncertainty on  $C$  and  $\varepsilon_1$  to be undetermined.

The ISO standard warranties that errors uncertainties are predicted. So you must change your flow limits or primary device if you find a message in this column. The message will tell you which is the limit or restriction that is not satisfied.

### 3.7 Instrument parameters.

Once you have made the calculations and no restrictions are reported you can prepare the configuration of your FL40 flow computer.

On the [Instrument] menu you have this form:

**Pressure sensor**

Low (4ma / 0 V): 1      High (20ma / 10V): 2      Units: Atm      Units Type: Absolute      Atmospheric Pressure: 1 Atm

**Diferential pressure sensor**

Low (4ma / 0 V): 0      High (20ma / 10V): 30000      Units: Pa

**Flow rate display**

Q mass      K mult: 100      Kg      / per: Min      Dec point: ----

Standard Conditions:  
 Pressure = StndIStdPU  
 Temperature = StndStdTU

T [C]	P [Atm]	dP [Pa]	K*[Kg/Min]	Display
0	1	800	1339.267	1 3 3 9
0	1	24000	6790.685	6 7 9 1
0	2	800	1894.522	1 8 9 5
0	2	24000	9980.51	9 9 8 1
30	1	800	1272.921	1 2 7 3
30	1	24000	6451.532	6 4 5 2
30	2	800	1800.21	1 8 0 0
30	2	24000	9480.567	9 4 8 1

Buttons: Accept      Calculate      Config File

File path: D:\dsgn\flow\v4\files\example\_Air.flw

Pressure sensor frame is for specifying calibrated limits of the up stream pressure sensor been used.  
 Low and high are the pressure value at low and high scale of the sensor (e.g. 4ma-20ma or 0v-10v) . Later on the instrument you will set the input type, but now you must specify only the limits.  
 Set also the units type depending on transmitter type (absolute or gauge units).

The same must be done for the scale settings of the differential pressure transmitter.

On the [Flow rate display] you will set the flow rate type, units and scale on the front display of the instrument.

Set first for Mass or Volumetric flow rate and units to be used.

[K mult] a constant to be multiplied to the flow rate.

[Dec point] is the fixed position of the decimal point on the display

When you press [Calculate], the contents of the bottom list will be calculated. Are listed for the 8 limit flow conditions the 4 digit display reading for the rate flow.

Finally pressing the [Config File] button generates a configuration file and detailed calculations file.

The configuration file , extension .sfg ( e.g. "air.sfg" in this case) is binary format data file containing all the information to be downloaded to the FL40 by the RPS software. Take the air.sfg configuration file that is generated in the same folder of the project file and place a copy of it in "files" subdirectory of the RPS software.

Then run RPS software with the FL40 connected to the PC and go to Menu / Device / FileWrite.

A complete list of calculated coefficients are saved on file in the same folder of the actual file but with extension \*.csv (coma separated variables format) that can be opened as a spread sheet. (e.g. "air.csv")

## References

### **ISO-5167:**

ISO-5167-1:1991(E)

Measurement of fluid flow by means of pressure differential devices.  
Part1: Orifice plates, Nozzles and Venturi tubes inserted in circular cross-section conduits running full. Ref. No.: ISO5167-1:1991(E)

ISO-5167-1:1991/Amd.1:1998(E)      Amendment

ISO-5167: Measurement of fluid flow by means of pressure differential devices inserted in circular cross-section conduits running full-  
Part1: General principles and requirements, Second edition, 2003-03-01, Ref. No.: ISO 5167-1:2003(E).

Part2: Orifice plates, Second edition, 2003-03-01, Ref. No.: ISO 5167-2:2003(E).

Part3: Nozzles and Venturi Nozzles, Second edition, 2003-03-01, Ref. No.: ISO 5167-3:2003(E).

Part4: Venturi tubes, Second edition, 2003-03-01, Ref. No.: ISO 5167-4:2003(E).

### **AGA No.8 DC92:**

Starling, K.E., Savidge, J.L.: "Compressibility Factors for Natural Gas and Other Hydrocarbon Gases", American Gas Association (AGA) Transmission Measurement Committee Report No. 8, American Petroleum Institute (API) MpMS, chapter 14.2, second edition, November 1992.

ISO 12213: Natural gas - Calculation of Compression factor

Part1: Introduction and guidelines

Part2: Calculation using molar-composition analysis

### **IAPWS-IF97:**

Release on the IAPWS Industrial Formulation 1997 for the Thermodynamic Properties of Water and Steam

The International Association for the Properties of Water and Steam, Erlangen, Germany, September 1997, [www.iapws.org](http://www.iapws.org)

### **General:**

Richard W. Miller, Flow Measurement Engineering Handbook. Third edition McGraw-Hill. ISBN0-07-042366-0