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Orifice, Nozzle and Venturi Flow Rate Meters

The orifice, nozzle and venturi flow rate meters use the Bernoulli Equation to calculate the fluid flow rate using pressure difference through obstructions in the flow

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In a flow metering device based on [the Bernoulli Equation](#) the downstream pressure after an obstruction will be lower than the upstream pressure before. To understand orifice, nozzle and venturi meters it's therefore necessary to explore the Bernoulli Equation.

The Bernoulli Equation

Assuming a horizontal flow (neglecting minor elevation differences between measuring points) [the Bernoulli Equation](#) can be modified to:

$$p_1 + 1/2 \rho v_1^2 = p_2 + 1/2 \rho v_2^2 \quad (1)$$

where

p = pressure

ρ = density

v = flow velocity

The equation can be adapted to vertical flow by adding elevation heights h_1 and h_2 .

Assuming uniform velocity profiles in the upstream and downstream flow - [the Continuity Equation](#) can be expressed as

$$q = v_1 A_1 = v_2 A_2 \quad (2)$$

where

q = flow rate

A = flow area

Combining (1) and (2), assuming $A_2 < A_1$, gives the "ideal" equation:

$$q = A_2 [2(p_1 - p_2) / \rho(1 - (A_2 / A_1)^2)]^{1/2} \quad (3)$$

For a given geometry (A), the flow rate can be determined by measuring the pressure difference $p_1 - p_2$.

The theoretical flow rate q will in practice be smaller (2 - 40%) due to geometrical conditions.

The ideal equation (3) can be modified with a discharge coefficient:

$$q = c_d A_2 [2(p_1 - p_2) / \rho(1 - (A_2 / A_1)^2)]^{1/2} \quad (3b)$$

where

c_d = discharge coefficient

The discharge coefficient c_d is a function of the jet size - or orifice opening - the

area ratio = A_{vc} / A_2

where

A_{vc} = area in "vena contracta"

"Vena Contracta" is the minimum jet area that appears just downstream of the restriction. The viscous effect is usually expressed in terms of the nondimensional parameter [Reynolds Number - Re](#).

Due to the Bernoulli and Continuity Equation the velocity of the fluid will be at its highest and the pressure at the lowest in "Vena Contracta". After the metering device the velocity will decrease to the same level as before the obstruction. The pressure recovers to a pressure level lower than the pressure before the obstruction and adds a head loss to the flow.

Equation (3) can be modified with diameters to:

$$q = c_d \pi/4 D_2^2 [2(p_1 - p_2) / \rho(1 - d^4)]^{1/2} \quad (4)$$

where

D_2 = orifice, venturi or nozzle inside diameter

D_1 = upstream and downstream pipe diameter

$d = D_2 / D_1$ diameter ratio

$\pi = 3.14$

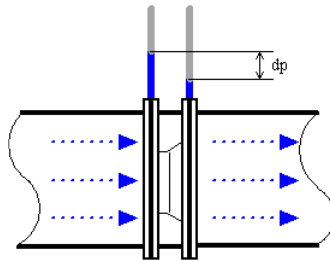
Equation (4) can be modified to mass flow for fluids by simply multiplying with the density:

$$m = c_d \pi/4 D_2^2 \rho [2(p_1 - p_2) / \rho(1 - d^4)]^{1/2} \quad (5)$$

When measuring the mass flow in gases, it's necessary to considerate the pressure reduction and change in density of the fluid. The formula above can be used with limitations for applications with relatively small changes in pressure and density.

The Orifice Plate

The orifice meter consists of a flat orifice plate with a circular hole drilled in it. There is a pressure tap upstream from the orifice plate and another just downstream. There are in general three methods of placing the taps. The coefficient of the meter depends upon the position of taps.



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- Flange location - Tap location *1 inch* upstream and *1 inch* downstream from face of orifice
- "Vena Contracta" location - Tap location 1 pipe diameter (actual inside) upstream and 0.3 to 0.8 pipe diameter downstream from face of orifice
- Pipe location - Tap location 2.5 times nominal pipe diameter upstream and 8 times nominal pipe diameter downstream from face of orifice

The discharge coefficient - c_d - varies considerably with changes in area ratio and the [Reynolds number](#). A discharge coefficient $c_d = 0.60$ may be taken as standard, but the value varies noticeably at low values of the Reynolds number.

Diameter Ratio $d = D_2 / D_1$	Discharge Coefficient - c_d			
	Reynolds Number - Re			
	10^4	10^5	10^6	10^7
0.2	0.60	0.595	0.594	0.594
0.4	0.61	0.603	0.598	0.598
0.5	0.62	0.608	0.603	0.603
0.6	0.63	0.61	0.608	0.608
0.7	0.64	0.614	0.609	0.609

The pressure recovery is limited for an orifice plate and the permanent pressure loss depends primarily on the area ratio. For an area ratio of 0.5, the head loss is about 70 - 75% of the orifice differential.

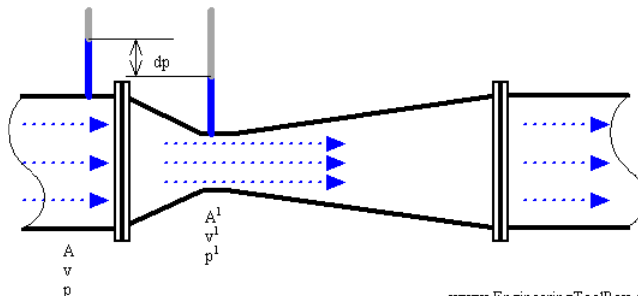
- The orifice meter is recommended for clean and dirty liquids and some slurry services.
- The rangeability is *4 to 1*
- The pressure loss is *medium*
- Typical accuracy is *2 to 4%* of full scale
- The required upstream diameter is *10 to 30*
- The viscosity effect is *high*
- The relative cost is *low*

References

- American Society of Mechanical Engineers (ASME). 2001. Measurement of fluid flow using small bore precision orifice meters. [ASME MFC-14M-2001](#).
- International Organization of Standards ([ISO 5167-1:2003](#)). Measurement of fluid flow by means of pressure differential devices, Part 1: Orifice plates, nozzles, and Venturi tubes inserted in circular cross-section conduits running full. Reference number: [ISO 5167-1:2003](#).
- International Organization of Standards (ISO 5167-1) Amendment 1. 1998. Measurement of fluid flow by means of pressure differential devices, Part 1: Orifice plates, nozzles, and Venturi tubes inserted in circular cross-section conduits running full. Reference number: [ISO 5167-1:1991/Amd.1:1998\(E\)](#).
- American Society of Mechanical Engineers (ASME). [B16.36 - 1996 - Orifice Flanges](#)

The Venturi Meter

In the venturi meter the fluid is accelerated through a converging cone of angle $15-20^\circ$ and the pressure difference between the upstream side of the cone and the throat is measured and provides a signal for the rate of flow.



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The fluid slows down in a cone with smaller angle ($5 - 7^\circ$) where most of the kinetic energy is converted back to pressure energy. Because of the cone and the gradual reduction in the area there is no "Vena Contracta". The flow area is at a minimum at the throat.

High pressure and energy recovery makes the venturi meter suitable where only small pressure heads are available.

A discharge coefficient $c_d = 0.975$ can be indicated as standard, but the value varies noticeably at low values of the [Reynolds number](#).

The pressure recovery is much better for the venturi meter than for the orifice plate.

- The venturi tube is suitable for clean, dirty and viscous liquid and some slurry services.
- The rangeability is *4 to 1*
- Pressure loss is *low*
- Typical accuracy is *1%* of full range

- Required upstream pipe length 5 to 20 diameters
- Viscosity effect is *high*
- Relative cost is *medium*

References

- International Organization of Standards - [ISO 5167-1:2003 Measurement of fluid flow by means of pressure differential devices, Part 1: Orifice plates, nozzles, and Venturi tubes inserted in circular cross-section conduits running full](#). Reference number: [ISO 5167-1:2003](#).
- American Society of Mechanical Engineers [ASME FED 01-Jan-1971. Fluid Meters Their Theory And Application](#)- Sixth Edition

The Nozzle

Nozzles used for determining fluid's flowrate through pipes can be in three different types:

- **The ISA 1932 nozzle** - developed in 1932 by the International Organization for Standardization or ISO. The ISA 1932 nozzle is common outside USA.
- **The long radius nozzle** is a variation of the ISA 1932 nozzle.
- **The venturi nozzle** is a hybrid having a convergent section similar to the ISA 1932 nozzle and a divergent section similar to a venturi tube flowmeter.

Diameter Ratio $d = D_2 / D_1$	Discharge Coefficient - C_d			
	Reynolds Number - Re			
	10^4	10^5	10^6	10^7
0.2	0.968	0.988	0.994	0.995
0.4	0.957	0.984	0.993	0.995
0.6	0.95	0.981	0.992	0.995
0.8	0.94	0.978	0.991	0.995

- The flow nozzle is recommended for both clean and dirty liquids
- The rangeability is 4 to 1
- The relative pressure loss is *medium*
- Typical accuracy is 1-2% of full range
- Required upstream pipe length is 10 to 30 diameters
- The viscosity effect *high*
- The relative is *medium*

References

- American Society of Mechanical Engineers [ASME FED 01-Jan-1971. Fluid Meters Their Theory And Application](#)- Sixth Edition
- International Organization of Standards - [ISO 5167-1:2003 Measurement of fluid flow by means of pressure differential devices, Part 1: Orifice plates, nozzles, and Venturi tubes inserted in circular cross-section conduits running full](#). Reference number: [ISO 5167-1:2003](#).

Example - Kerosene Flow Through a Venturi Meter

The pressure difference $dp = p_1 - p_2$ between upstream and downstream is 100 kPa ($1 \cdot 10^5 \text{ N/m}^2$). The [specific gravity of kerosene](#) is 0.82.

Upstream diameter is 0.1 m and downstream diameter is 0.06 m.

Density of kerosene can be calculated as:

$$\begin{aligned}\rho &= 0.82 (1000 \text{ kg/m}^3) \\ &= \underline{820} \text{ (kg/m}^3\text{)}\end{aligned}$$

- [Density, Specific Weight and Specific Gravity](#) - An introduction and definition of density, specific weight and specific gravity. Formulas with examples.

Upstream and downstream area can be calculated as:

$$\begin{aligned}A_1 &= \pi ((0.1 \text{ m})/2)^2 \\ &= \underline{0.00785} \text{ (m}^2\text{)} \\ A_2 &= \pi ((0.06 \text{ m})/2)^2 \\ &= \underline{0.002826} \text{ (m}^2\text{)}\end{aligned}$$

Theoretical flow can be calculated from (3):

$$\begin{aligned}q &= A_2 [2(p_1 - p_2) / \rho(1 - (A_2/A_1)^2)]^{1/2} \\ q &= (0.002826 \text{ m}^2) [2 (10^5 \text{ N/m}^2) / (820 \text{ kg/m}^3)(1 - ((0.002826 \text{ m}^2) / (0.00785 \text{ m}^2))^2)]^{1/2} \\ &= \underline{0.047} \text{ (m}^3\text{/s)}\end{aligned}$$

For a pressure difference of 1 kPa ($0.01 \times 10^5 \text{ N/m}^2$) - the theoretical flow can be calculated:

$$\begin{aligned}q &= (0.002826 \text{ m}^2) [2 (0.01 \cdot 10^5 \text{ N/m}^2) / (820 \text{ kg/m}^3)(1 - ((0.002826 \text{ m}^2) / (0.00785 \text{ m}^2))^2)]^{1/2} \\ &= \underline{0.0047} \text{ (m}^3\text{/s)}\end{aligned}$$

The mass flow can be calculated as:

$$\begin{aligned}m &= q \rho \\ &= (0.0047 \text{ m}^3\text{/s}) (820 \text{ kg/m}^3) \\ &= \underline{3.85} \text{ (kg/s)}\end{aligned}$$

Flow Rate and Change in Pressure Difference

Note! - The flow rate varies with the square root of the pressure difference.

From the example above:

- a tenfold increase in the flow rate requires a one hundredfold increase in the pressure difference!

Transmitters and Control System

The nonlinear relationship have impact on the pressure transmitters operating range and requires that the electronic pressure transmitters have the capability to linearizing the signal before transmitting it to the control system.

Accuracy

Due to the non linearity the [turn down rate](#) is limited. The **accuracy strongly increases in the lower part** of the operating range.

- [More about Flow Meters as Orifices, Venturi meters, and Nozzles](#)
- [Fluid Mechanics](#)
- [The Bernoulli Equation](#)
- [The Continuity Equation](#)
- [TurnDown Ratio and Flow Measurement Devices](#) - An introduction to Turn Down Ratio and flow measurement accuracy.

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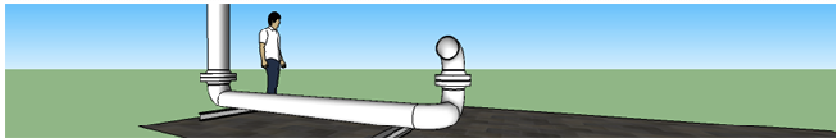
Related Topics

- [Fluid Flow Meters](#) - Flow metering basics - Orifice, Venturi, Flow Nozzles, Pitot Tubes, Target, Variable Area, Positive Displacement, Turbine, Vortex, Electromagnetic, Ultrasonic Doppler, Ultrasonic Time-of-travel, Mass Coriolis, Mass Thermal, Weir V-notch, Flume Parshall and Sluice Gate flow meters and more
- [Fluid Mechanics](#) - The study of fluids - liquids and gases. Involves various properties of the fluid, such as velocity, pressure, density and temperature, as functions of space and time.

Related Documents

- [Equation of Continuity](#) - The Equation of Continuity is a statement of mass conservation
- [Flow of Liquids from Containers](#) - Flow from tanks
- [Flowmeters and Turndown Ratio](#) - An introduction to turndown ratio for flow measurement devices as orifices, venturi meter etc.
- [Nozzles](#) - Gas flow through nozzles - sonic chokes
- [Orifices - Air Discharge](#) - Air volume through orifices

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