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<td>Kolmetz Handbook
of Process Equipment Design

RESTRICTION ORIFICE
SELECTION, SIZING,
AND TROUBLESHOOTING

(ENGINEERING DESIGN GUIDELINES)</td>
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KLM Technology Group has developed highly rated engineering documentation that has many hours of engineering development.

1. Process Engineering Equipment Design Guidelines with examples of sizing,
2. Project Engineering Standards and Specifications,
3. Best Practices
4. Unit Operations Manuals
5. Engineering Practice Magazine

KLM can assist your team in providing Senior Engineering and Operations Staff to provide support for your local team in many areas.

1. Process Equipment Design,
2. Unit Commissioning,
3. Distillation Tower Inspections,
4. HAZOP Facilitation,
5. Facility Siting,
6. Process Engineering Consulting
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KLM provides specialty equipment in

1. Distillation Columns Vessels and Pressure Vessels,
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3. Heat Exchangers and Pumps.

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Process Equipment Design Flaws

Many groups of process equipment follow the "Kolmetz Universal Law of Project Stupidity". A law strictly followed by most engineering and non-engineering projects.

"Save money and poorly design the process equipment by awarding it to the low-cost bidder. Loose money for the next twenty years on plant capacity, maintenance reliability, and excess energy."

According to this law, awarding a process equipment contract to the lowest bidder may save you money in the short term, but it can cost you heavily in the long run. You may end up losing money for the next twenty years on plant capacity, maintenance reliability, and excess energy. So, next time you are tempted to cut corners, remember the Kolmetz Law of Project Stupidity.

Typically, process equipment is awarded to the lowest bidder with very low standards of guarantees. Typical guarantees by the manufacturers are hydraulic capacity only, and this test must be carried out within three to six months, while the process equipment is still clean and new. Typical process guarantees are by the process engineering company which includes capacity and purities, again the performance test must be carried out within three to six months.

Imagine buying a car and receiving a three-to-six-month warranty and only good gas milage for the first six months. You would think the car manufacturer was taking advantage of you, yet this is what we do for heat exchangers, and cars are much more complex than heat exchangers.

What are things that should be included in process equipment design that are not being utilized because of the sweetheart guarantees and low-cost bidders.

1. KLM is a recognized expert in Process Equipment Design, only utilize groups with technical expertise. This guideline has sizing examples in the document and then in an excel spreadsheet.

2. KLM only partners with high quality suppliers, often from the same factories as the Original Equipment Manufacturers (OEM) and has senior inspectors to ensure your equipment is installed correctly

3. Ensure correct metallurgy. Do not use Stainless Steel in Acid or Caustic Solution Servies as some Stainless Steel is not resistant to attack. Many vendors only supply stainless steel even though they know that this might be the wrong metallurgy for your application.

4. Review Galvanic Corrosion Potential for extended life. If you have polar liquids (water, acids, caustics) and a carbon steel vessel, stainless steel will experience bi-metallic corrosion with reduced life.

5. Review the failures of the non-technical suppliers.

KLM can assist your team in providing Senior Engineering and Operations Staff to provide support for your local team in many areas including demister pads, distillation towers, heat exchanger and pump design.

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INTRODUCTION

Scope

A flow restrictor is any device that restricts or limits the flow of a fluid, generally a liquid or a gas. Such devices may also be referred to as flow limiters. Calibrated orifices are one example of flow restrictors. They are used in systems we encounter daily. For example, they control how fast water flows from a faucet, how quickly foam sprays from a bottle of carpet cleaner, and how much fuel is flowing into the engine of a car.

The restriction orifice plate is mostly applied in non-critical flow limitations. This could for instance be after a control valve in order to divide the required pressure loss into two elements. This is done to reduce the noise in liquids and to avoid cavitation. It is advisable to avoid cavitation in order to protect the process elements before the restriction orifice plate in blowdown systems, and as flow limiter.

Restriction Orifice Plates and their calculation, construction and application is going to described in this guideline. KLM Technology Group would be happy to assist in your needs for restriction orifices as well as other process equipment. We can engineer, supply or troubleshoot your application. Please contact us at info@klmtechgroup.com.

General Design Consideration

The Restriction Orifice (RO) is utilized to achieve controlled or restricted process fluid flow. It can be designed as a single or multiple orifice configuration to provide a defined restriction to the process flow and create a calculated pressure drop from the upstream to the downstream side of the device. The permanent pressure loss generated by the RO is intentionally sized to control the flow rate and achieve the desired final pressure at the outlet side of the unit.

These are different from the orifice plates used for measuring flow rates as they are sized to achieve main purpose of inducing a permanent pressure drop in the process line where these are installed. Therefore, bore or internal diameter sizing along with the thickness for given process fluid at specified pressure and temperature is of utmost importance.

When a fluid, either liquid or gaseous, passes through an orifice, its pressure increases upstream of the orifice. As the fluid is forced to converge and pass through the orifice, the velocity increases, and the fluid pressure decreases. This occurrence is based on the principle of conservation of energy and is used to derive Bernoulli's equation.

Higher pressure drop implies higher velocities and can lead to orifice outlet pressure dropping below vapor pressure of the liquid in the line. This leads to Cavitation i.e formation and collapsing (implosion) of vapor cavities or bubbles or voids. These not only cause noise and vibration problems but collapsing voids which implode near metal surface also cause cyclic stress resulting surface fatigue and hence Pitting or cavity formation. This ultimately can result in damage to Piping material itself. Therefore, Cavitation check is performed immediately after determining bore diameter of Restriction orifice.

A calibrated orifice is the most basic flow restrictor. Orifice diameter, length, and geometry all impact the restriction of the orifice. As the diameter is increased, the amount of restriction decreases. As the length of an orifice increases, the amount of restriction increases.

Various types of Restriction orifice assemblies are Single stage, Single stage multi-hole and Multi-stage. Single stage contains single orifice plate. Single stage multi-hole contains multiple holes to reduce noise into acceptable limits. While single restriction orifices are often sufficient to meet the requirements, Multi-stage i.e. use of multiple restrictions in series with gaps in between are used where desired pressure drop cannot be obtained from single restriction orifice due to very high pressure reduction ratio leading to cavitation

The most basic flow restrictor is a single orifice plate; it is highly adaptable, low cost, and widely used in controlling liquid and gas flow rates. The orifice plate can be attached to a housing in a variety of ways for retention. The orifice designer varies the diameter, length, and geometry of the orifice to create the desired restriction. The orifice plate is the simplest and most widely used differential pressure flow measuring element and generally comprises a metal plate with a concentric round hole (orifice). Restriction Orifice plates and designs follow Bernoulli's principle

Restriction orifices are normally designed as a simple plate with an attached tag handle. This plate is mounted between pipe flanges and can be offered for all existing types of flange faces. Restriction orifices may also be designed as a weld-in component. If the plant dictates limits to the noise level or if the -pressure loss could lead to cavitation it may be recommendable to use a multi-hole or multistage restriction orifice. A combination of multi-hole and multistage design is also possible. For most materials we also offer stellation or other hard facing of the orifice bore hole in order to achieve a higher durability and therefore a longer service life time.

Two orifices with identical lengths and diameters may have a wide variation in flow based on the geometry of an orifice. For instance, an orifice with a sharp-edged entrance results in a lower flow rate than one with a chamfered edge or a radiused edge. In addition to flow rate, the geometry of an orifice can be used to create specific fluid behavior: for example, spin the fluid to help generate an atomized, conical spray pattern or focus the fluid to hit a specific target point.

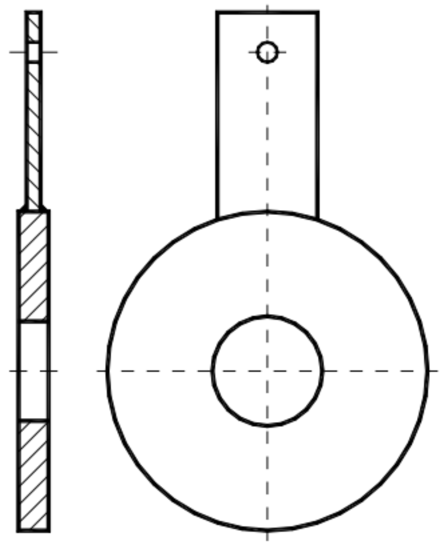

Figure 1. The orifice plate

The orifice features a sharp square upstream edge and, unless a thin plate is used, a beveled downstream edge. A major advantage of the orifice plate is that it is easily fitted between adjacent flanges that allow it to be easily changed or inspected as the configuration is shown in Fig. 2.

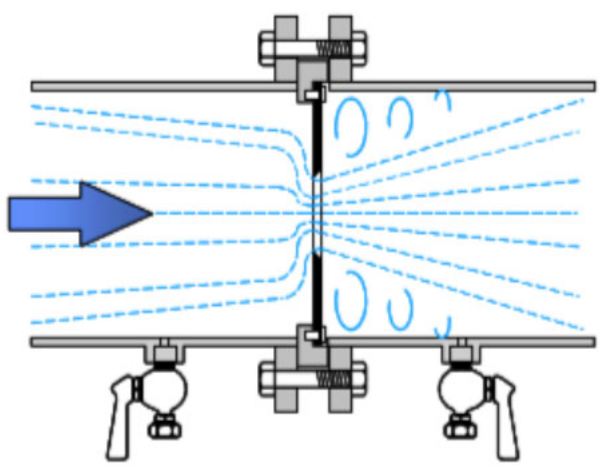

Figure 2. Orifice plate fitted between adjacent flanges.

Types of restriction orifice

The orifice plate configurations are classified according to the bore location and it is shape geometric. Indeed, these configuration allows the designers to use it in different flow meter applications. Various types of Restriction orifice assemblies are Single stage, Single stage multi-hole & Multi-stage. Single stage contains single orifice plate. Single stage multi-hole contains multiple holes to reduce noise into acceptable limits.

While single restriction orifices are often sufficient to meet the requirements, Multi-stage i.e. use of multiple restrictions in series with gaps in between are used where desired pressure drop cannot be obtained from single restriction orifice due to very high pressure reduction ratio leading to cavitation.

The selected configurations are determined by the performance characteristics required of the system, ranging from simple to complex. A simple configuration may be a single orifice restrictor used in a system to reduce the acceleration of a cylinder. A more complicated configuration may be a multi-orifice design used to help reduce cavitation in a pump or to protect sensitive components from system pressure spikes. Each configuration has some limitations that restrict or preclude its use in a particular system.

1. Single Stage Restriction Orifice

The first type of Restriction Orifice is the single-stage restriction orifice which provides the simplest pressure drop. It is usually a plate with a single orifice bore of the required size/beta ratio for an intended pressure loss. It is usually machined with a square-edged plate edge to resist the maximum DP with sufficient headroom. Installation of Single stage Restriction is shown below

A single-stage restriction orifice usually looks much similar to the square-edge orifice plates. Normally, the 45-degree bevel proving on the measuring orifice plate should not be on the restriction orifice plates. But generally, many manufacturers are sizing the restriction orifice plate based on the standard industry guidelines.

Since the discharge coefficient values and permanent pressure loss are considered from the standard, the bevel and surface finish should be followed to maintain the uncertainty of downstream pressure. Otherwise, the flow pattern gets disturbed by the downstream edge of the orifice. And this may deviate the actual downstream pressure from the predicted one.

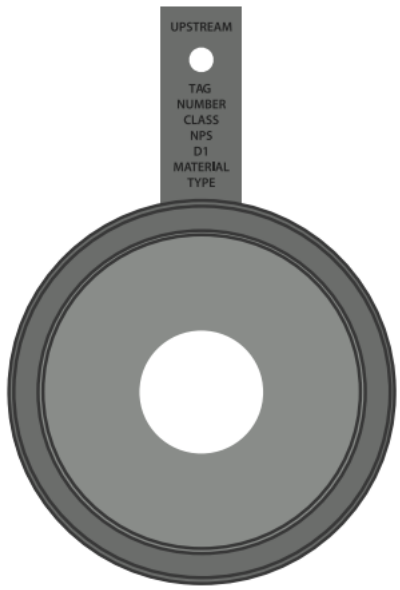

Figure 3. single-stage restriction orifice

2. Multi-hole Single Stage Restriction Orifice

The second type of Restriction Orifice is a multiple-hole single-stage restriction device. The extra holes help to reduce fluidic noise and resonance generated due to a high velocity across the reduction. This type of restriction orifice can have the same area ratio as a single-hole unit and offer the same pressure reduction parameters. However, the multiple holes help to distribute the flow streams to reduce the overall noise.

Usually, when a high-velocity flow at the RO inlet is distributed through multiple-hole designs, the overall noise value is reduced. This type of Restriction orifice is commonly used to help minimize cavitation problems since the flow distribution across several holes is known to improve cavitation factors, which can reduce overall noise levels

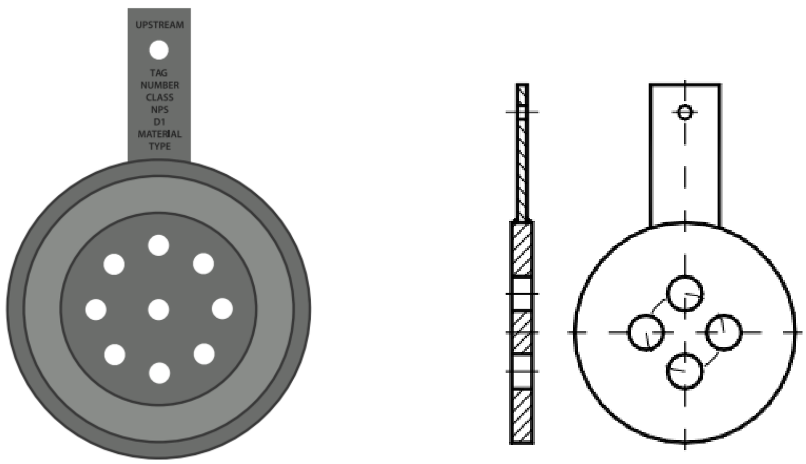

Figure 4. Multi-hole Single Stage Restriction Orifice

3. Restriction Orifice Typical Separator Installation (multi stage)

The third type, known as a Multi-Stage restriction Orifice, is a multi-element pressure reduction/flow control device. This restriction unit is designed with either single-hole multiple orifice plates or multi-hole designs with different hole sizes. It allows for effective control of pressure and flow rates, preventing cavitation in a pressure reduction system or reducing the flow to manageable values. The below figure shows one typical pressure reduction application as applied to a separator outlet in the oil and gas industry as currently being used by Oil and Gas midstream operators.

Multistage RO (MSRO) are used when the required pressure reduction ratio is very high and cannot be achieved by a single-stage orifice plate. Thus, a multistage device essentially consists of a number of single-stage devices built in a single spool. Like a single-stage device, it can be a single-hole multistage design or multi-hole multistage design or a combination of both. In single-hole MSRO, eccentric-type orifice plates are generally used and are installed diametrically opposite each other. The minimum distance between each stage is equal to the internal diameter of the pipe.

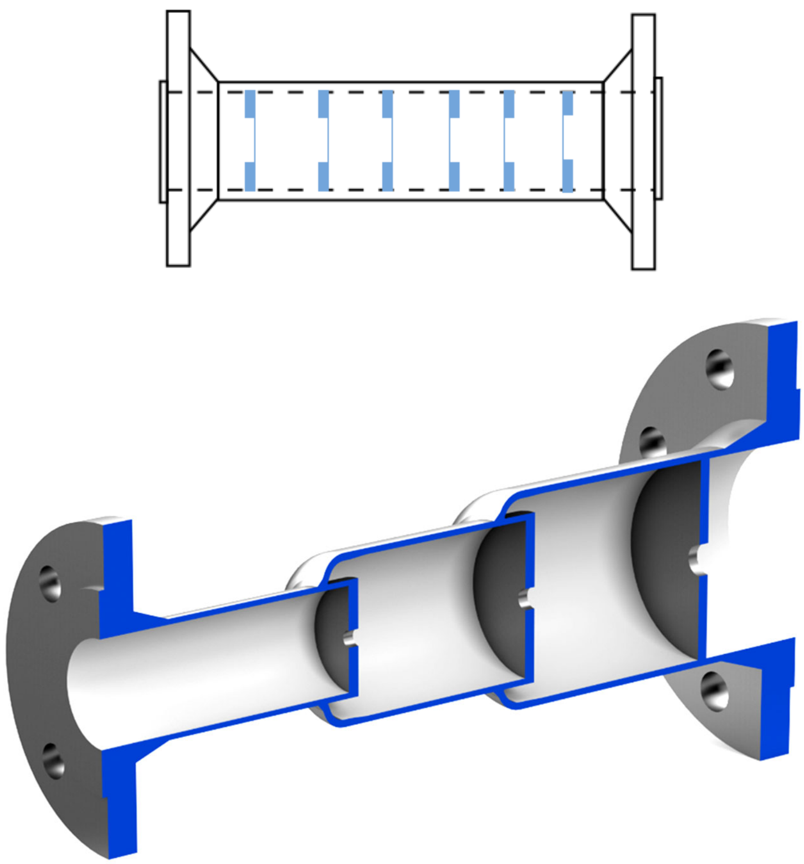

Figure 5. Multistage RO (MSRO)

4. Multi-hole multistage RO

Multi-hole multistage restriction orifices are used for higher pressure drop and where noise needs to be controlled.

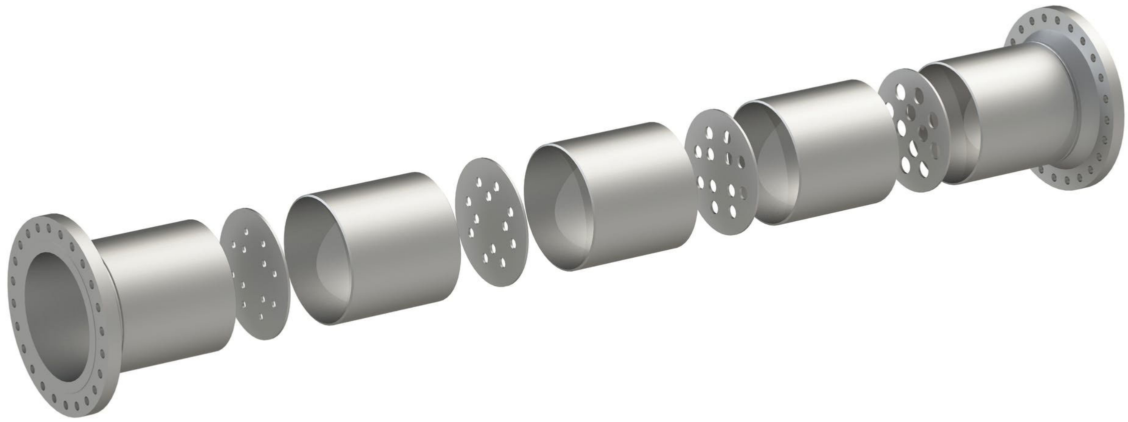

Figure 6. Multi-hole multistage restriction orifices assembly

Applications of Restriction Orifice Plates

Restriction orifice has many uses:

- Pump recirculation line to avoid cavitation in pump.
- Draining of condensate of high pressure lines into atmospheric pressure.
- Re-routing of pump discharge to an alternate sump. This prevents any damage which may occur to the pump as a result of sudden stoppage of flow due to failure of downstream equipment.
- Startup drain of high pressure equipment discharge line to clean out the entrapped air, cold water accumulated in the drain line to avoid water hammering during unit startup

Followings are a few examples of common applications where these restriction orifice devices are used to achieve controlled flow from the upstream to the downstream. Restriction orifices are often exposed to severe flow conditions associated with large pressure reductions and the related fluid conditions caused by liquids flashing to a gas, cavitation, and sonic (choked) flow. Hence such conditions also are taken into consideration.

1. Restriction Orifice (RO) at the downstream of blowdown valves

These are used to ensure a controlled flow rate in a blowdown piping or blowdown header. When the blowdown valve (which is usually an FB or RB ball valve) opens to release the high pressure on its upstream, the restriction orifice plate at its downstream ensures that the flow is not excessive to overload the flare header. Usually, the pressure drop in the blowdown circuit across the restriction orifice could be very high say, typically 80-100 bar.

If the high-pressure drop is achieved through a single-stage device or by a device with not too many stages, there will be a fall in temperature during the blowdown event due to the Joule-Thompson effect. Thus the design of the RO needs to take care of the low temperature.

2. Restriction Orifice (RO) in pump re-circulation line

ROs are also used in centrifugal pump's re-circulation line where a constant re-circulation flow is required and control of re-circulation and forward flow rate is not important. The re-circulation ensures that cavitations/starvation cannot happen in the pump.

3. Restriction Orifice (RO) to restrict gas blow-by

A typical case is the flow of hydrocarbon condensate from the high-pressure separator to the low-pressure separator. Usually, a level control valve (LCV) controls the level of the high-pressure separator. In case of valve failure, the valve needs to open fully to stop the separator from overflowing.

Full open of LCV is accompanied by the high rate of flow of condensate followed by the flow of gas. To stop the downstream relieving system from overloading the gas flow is controlled by a restriction orifice at downstream of the LCV. A similar application is seen in the heating medium flow into the re-boiler to mitigate the effect of the heating medium valve fail open position.

4. Restriction Orifice (RO) to check excess flow

ROs are used to restrict the excessive flow in case of a rupture. Thus in Well head applications if the down holes valves are to be closed due to fire, the hydraulic power oil to the valve actuator is depressurized by the use of a fusible plug which fuses and allows the hydraulic oil to leak through an RO at a restricted flow rate.

5. Restriction Orifice (RO) for controlled pressurization

During the start-up of a process plant, many plant sections are required to be pressurized with the incoming process fluid in a controlled manner.
This is because the upstream section will be usually at a much higher pressure than the downstream. Thus if there is no restriction on the flow rate, the initial flow rate may be very high and may damage the pipeline and equipment.

ROs are used for gradual pressurization. To restrict the flow the ideal condition is to design for the choked flow for gas. During the choked flow, the rate of flow will be less as it will be proportional to the square root of inlet pressure rather than to the differential pressure.

Advantages and Disadvantages of Orifice Plates

Orifice meter maintenance consists of periodic inspection, cleaning primary elements, and scheduled testing and calibration against standards (if necessary) of the secondary elements. Maintenance frequency, if not set by agreement or contract, should simply be based on experience and performed as often as necessary to correct any calibration drift or error that may occur. Proper records for each station will determine this schedule.

Advantages of orifice plates include:

1. High differential pressure generated
2. Exhaustive data available
3. Low purchase price and installation cost
4. Easy replacement
5. Well documented in standards;
6. Enjoys wide acceptance; personnel knowledgeable across the industry about requirements for use and maintenance;
7. Relatively low cost to purchase and install;
8. No moving parts in the flow stream; and
9. When built to standards requirements, does not require calibration beyond confirming mechanical tolerances at the time of purchase and periodically in use.

Disadvantages include:

1 High permanent pressure loss implies higher pumping cost.

2 Cannot be used on dirty fluids, slurries or wet steam as erosion will alter the differential pressure generated by the orifice plate.

3 Low rangeability with a single device;

4 Relatively high pressure loss for a given flow rate, particularly at lower beta ratios;

5 More sensitive to flow disturbances at higher beta ratios than some meters; and

6 Flow pattern in the meter does not make meter self-cleaning.

DEFINITIONS

Beta ratio - Ratio of the calculated orifice diameter to the pipe internal diameter. The ratio of the measuring device diameter to the meter run diameter (i.e., orifice bore divided by inlet pipe bore).

Bernoulli equation - the relationship between fluid velocity (v), fluid pressure (p), and height (h) above some fixed point for a fluid flowing through a pipe of varying cross-section, and is the starting point for understanding the principle of the differential pressure flowmeter

Coefficient of Discharge - Empirically determined ratio from experimental data comparing measured and theoretical flow rates.

Cavitation - The level of cavitation is checked for each plate. In the presence of cavitation, a multistage alternative can be proposed depending on the operating conditions of the restriction

Critical flow or Choked flow - If the fluid reaches its maximum speed when passing through the restriction, its flow rate can no longer increase. A multi-stage solution can be proposed depending on the operating conditions of the restriction

Compressible Fluid - Molecules in a fluid to be compacted and the density is varies. Energy is exchanged not only among the kinetic energy and the potential energies due to gravity and pressure, but also with the internal energy

Density - The density of a quantity of homogenous fluid is the ratio of its mass to its volume. The density varies with temperature and pressure changes, and is therefore generally expressed as mass per unit volume at a specified temperature and pressure.

Discharge Coefficients - The ratio of the true flow to the theoretical flow. It corrects the theoretical equation for the influence of velocity profile, tap location, and the assumption of no energy loss with a flow area between 0.023 to .56 percent of the geometric area of the inlet pipe.

Flange Taps - A pair of tap holes positioned. The upstream tap center is located 1 inch (25.4 mm) upstream of the nearest plate face. The downstream tap center is located 1 inch (25.4 mm) downstream of the nearest plate face

Flow Profile - A relationship of velocities in planes upstream of a meter that defines the condition of the flow into the meter.

Flow Regime - The characteristic flow behavior of a flow process.

Fluid Flow Measurement - The measurement of smoothly moving particles that fill and conform to the piping in an uninterrupted stream to determine the amount flowing.

Fluid Dynamics - Mechanics of the flow forces and their relation to the fluid motion and equilibrium

Head—type flow measurement derives from Bernoulli's theorem which states that in a flowing stream, the sum of the pressure head, the velocity head and the elevation head at one point is equal to their sum at another point in the direction of flow plus the loss due to friction between the two points. Velocity head is defined as the vertical distance through which a liquid would fall to attain a given velocity. Pressure head is the vertical distance which a column of the flowing liquid would rise in an open-ended tube as a result of the static pressure

Fluid flow measurement - the measurement of smoothly moving particles that fill and conform to the piping in an uninterrupted stream to determine the amount flowing.

- **Fluid:** 1. having particles that easily move and change their relative position without separation of the mass and that easily yield to pressure; 2. a substance (as a liquid or a gas) tending to flow or conform to the outline of its container.
- **Flow:** 1. to issue or move in a stream; 2. to move with a continual change of place among the consistent particles; 3. to proceed smoothly and readily; 4. to have a smooth, uninterrupted continuity.
- **Measurement:** 1. the act or process of measuring; 2. a figure, extent, or amount obtained by measuring.

Laminar Flow - Laminar flow occurs when adjacent layers of fluid move relative to each other in smooth streamlines, without macroscopic mixing. In laminar flow, viscous shear, which is caused by molecular momentum exchange between fluid layers, is the predominant influence in establishing the fluid flow. This flow type occurs in pipes when $Re < 2,100$

Net expansion factor - Net expansion factor for compressible flow of gas or vapour through an orifice

Noise - Noise level control estimated at 1 m. In the event of a high noise level, refer to the multihole plate

Nozzle - A flow device with an elliptical inlet profile along its centerline and made to a specified standard; usually used for high-velocity flows. Resistant to erosion because of its shape.

Orifice diameter - Sized according to the fluid, to the desired pressure drop and flow rate when passing through the restriction.

Orifice Plate Holder: A pressure-containing piping element, such as a set of orifice flanges or orifice fitting, used to contain and position the orifice plate in the piping system

Orifice Plate: A thin plate in which a circular concentric aperture (bore) has been machined. The orifice plate is described as a “thin plate” and “with sharp edge,” because the thickness of the plate material is small compared with the internal diameter of the measuring aperture (bore) and because the upstream edge of the measuring aperture is sharp and square.

Orifice velocity head loss coefficient - Permanent pressure loss across orifice expressed in terms of velocity head loss

Phase - A state of matter such as solid, liquid, gas, or vapor.

Phase Change - A change from one phase to another (such as a liquid to gas). Most flow meters cannot measure at this condition.

Pipeline - a line of pipe or A conduit of pipe with pumps, valves, and control devices for conveying liquids, gases, or finely divided solids.

Pressure drop - decrease in pressure from one point in a pipe or tube to another point downstream. Pressure drop occurs with frictional forces on a fluid as it flows through the tube.

Pressure difference across orifice - Unrecovered pressure loss across orifice equivalent to the pressure difference between 1 pipe diameter upstream and 0.5 pipe diameters downstream of the orifice plate

Pressure, Vapor - The term applied to the true pressure of a substance to distinguish it from partial pressure, gauge pressure, etc. The pressure measured relative to zero absolute pressure (vacuum).

Pressure ratio - Ratio of downstream to upstream pressures

Plate thickness - Calculation based on the pressure drop created by the plate and the piping inside diameter to prevent plate deformation during operation

Reynolds number - A dimensionless number defined as (ρ d v) / μ where ρ is density, d is the diameter of the pipe or device, v is the velocity of the fluids and μ is the viscosity—all in consistent units. Its value is in correlating meter performance from one fluid to another

Sonic Velocity (Choked Flow) - The maximum velocity that a gas or gas-liquid mixture can attain in a conduit at a given upstream pressure (except in certain converging-diverging nozzles), no matter how low the discharge pressure is. For gases this maximum velocity is equal to the speed of sound at the local conditions.

Steam Hammer - Steam hammer is excessive pipe vibrations that occur due to the collapse of large vapor bubbles in a cool liquid stream

Tap Hole - A hole drilled radially in the wall of the meter tube or orifice plate holder, the inside edge of which is flush and without any burrs.

Transition Flow - Flow regime lying between laminar and turbulent flow. In this regime velocity fluctuations may or may not be present and flow may be intermittently laminar and turbulent. This flow type occurs in pipes when 2,100 < Re < 4,000.

Turbulent Flow - Turbulence is characterized by velocity fluctuations that transport momentum across streamlines; there is no simple relationship between shear stress and strain rate in turbulent flow. Instantaneous properties cannot be predicted in a turbulent flow field; only average values can be calculated. For engineering analyses, turbulent flow is handled empirically using curve-fits to velocity profiles and experimentally determinate loss coefficients. This flow type occurs in pipes in industrial situations when Re > 4,000. Under very controlled laboratory situations, laminar flow may persist at Re > 4,000.

Vapor Phase - The term, used interchangeably with “gas,” has various shades of meaning. A vapor is normally a liquid at normal temperature and pressure, but becomes a gas at elevated temperatures. There is also some use of “vapor” to indicate that liquid droplets may be present. In a strict technical sense, however, the terms are interchangeable.

Velocity - Time rate of linear motion in a given direction.

Viscosity - A fluid’s property that measures the shearing stress that depends on flow velocity, density, area, and temperature—which in turn affects the flow pattern to a meter and hence measurement results.

Water Hammer - Water hammer is the dynamic pressure surge that results from the sudden transformation of the kinetic energy in a flowing fluid into pressure when the flow is suddenly stopped. The sudden closing of a valve can cause a water hammer.

NOMENCLATURE

$A_{orifice}$	Orifice flow area (m)
B	Beta ratio
C	Flow coefficient
$d_{orifice}$	Orifice diameter (m)
d_{pipe}	Pipe internal diameter (m)
Ho	Pressure head at orifice (m)
Hv	Vapor pressure head of liquid (m)
k	Ratio of specific heat capacities
K	Orifice velocity head loss coefficient
Kd	Cavitation index
P_1	Upstream pressure [1pipe diameter upstream of orifice] (Pa)
P_2	Downstream pressure [0.5 pipe diameter downstream of orifice] (Pa)
P_3	Fully recovered downstream pressure [4-8 pipe diameters downstream of orifice] (Pa)
Q	Flow rate through orifice (m^3/s)
r	Pressure ratio
Re	Reynolds number
Y	Net expansion factor
Vo	Volumetric flow rate at orifice (m^3/s)

Greek Letters

ρ	Density of fluid(kg/m^3)
μ	Viscosity of fluid(Pa.s)
$\Delta P_{orifice}$	Pressure difference across orifice (Pa) = $P_1 – P_2$
$\Delta P_{permanent}$	Permanent pressure loss across orifice (Pa) = $P_1 – P_3$

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