Flow Meters: Introduction
Flow meters are used to measure the rate of flow of liquids or gases, just like electric meters measure the amount of electricity consumed. However, unlike electric meters, which are either electro-mechanical or electronic meters, there are many variants in flow-meters, all with different concepts on how the flow of fluid is measured, with some even customized to measure special fluids.

A new generation of electronic flow meters provides better control and accuracy of fluid measurement, however it still leaves several choices on how fluid is measured. Part I of this series covers basic flow meter fundamentals including types of flow meters and the main considerations and challenges in selecting a flow meter.

Fluid Flow Measurement and Reynolds Number
Flow is generally measured inferentially by measuring velocity through a known area. With this indirect method, the flow measured is the volume flow rate, $Q_v$, stated in its simplest terms:

\[ Q_v = A \times V \]  \hspace{1cm} (1)

Where $A$ = Cross-sectional area of the pipe
$V$ = Fluid Velocity

A reliable flow indication is dependent upon the correct measurement of $A$ and $V$. If, for example, air bubbles are present in the fluid, the area term "$A$" of the equation would be artificially high. Likewise, if the velocity is measured as a point velocity at the center of the pipe, and it is used as the velocity term "$V$" of the equation, a greater $Q_v$ than actual would be calculated because "$V$" must reflect the average velocity of the flow as it passes a cross-section of the pipe.

The following are the major factors affecting the flow of fluid through a pipe:

- Velocity - speed at which a fluid moves through a pipe
- Density - weight per unit volume
- Viscosity - ease of flow of a fluid
- Pipe size - diameter of the pipe carrying the fluid
Velocity of the fluid and pipe size: Fluid velocity depends on the head pressure, which is forcing the fluid through the pipe. The greater the head pressure, the faster the fluid flow rate (all other factors remaining constant), and consequently, the greater the volume of flow. Pipe size also affects the flow rate. For example, doubling the diameter of a pipe increases the potential flow rate by a factor of four.

Viscosity of the fluid: Viscosity negatively affects the flow rate of fluids. Viscosity decreases the flow rate of a fluid near the walls of a pipe. Viscosity increases or decreases with changing temperature, but not always as might be expected. In liquids, viscosity typically decreases with increasing temperature. However, in some fluids viscosity can begin to increase above certain temperatures. Generally, the higher a fluid’s viscosity, the lower the fluid flow rate (with other factors remaining constant).

Density of the fluid: Density of a fluid affects flow rates such that a more dense fluid requires more head pressure to maintain a desired flow rate. Also, the fact that gases are compressible, whereas liquids essentially are not, often requires that different methods be used for measuring the flow rates of liquids, gases, or liquids with gases in them.

Reynolds number: The most important flow factors mentioned above can be correlated together into a dimensionless parameter called the Reynolds number, which indicates the relative significance of the viscous effect compared to the inertia effect. The Reynolds number is proportional to inertial force divided by viscous force. The Reynolds number is proportional to fluid flow means velocity and pipe diameter and inversely proportional to fluid viscosity.

\[
\text{Reynolds number (Re) } = \frac{\rho \cdot D \cdot v}{\mu} \tag{2}
\]

Where:
- \( D \) = Internal pipe diameter
- \( v \) = Velocity
- \( \rho \) = Density
- \( \mu \) = Dynamic Viscosity

At very low velocities of high viscosities, Re is low and the fluid flows in smooth layers with the highest velocity at the center of the pipe and lower velocities at the pipe wall where the viscous forces restrain it. This type of flow is called laminar flow and is represented by Reynolds numbers below 2,000.

At higher velocities or low viscosities the flow breaks up into turbulent where the majority of flow through the pipe has the same average velocity. In the “turbulent” flow the fluid viscosity is less significant and the velocity profile takes on a much more uniform shape. Turbulent flow is represented by Reynolds numbers above 4,000. Between Reynolds number values of 2,000 and 4,000, the flow is said to be in transition.

So Reynolds (Re) number is a quantity that engineers use to estimate if a fluid flow is laminar or turbulent. This is important because increased mixing and shearing occur in turbulent flow that results in increased viscous losses, which affects the efficiency of hydraulic machines. A good example of laminar and turbulent flow is the rising smoke from a cigarette. The smoke initially
travels in smooth, straight lines (laminar flow) then starts to "wave" back and forth (transition flow) and finally seems to randomly mix (turbulent flow).

**Types of Flow meters**

A flow meter is an instrument used to measure linear, nonlinear, mass or volumetric flow rate of a liquid or a gas. There are many ways to measure flow of a liquid, gas or steam; and every type of flow meter can be assigned to one of two categories: traditional or mechanical flow meter, and new technology or electronic flow meter.

The following list shows some of the popular flow meter types:

**Mechanical flowmeters:**

- Positive Displacement
- Paddle Wheel
- Variable area
- Differential Pressure
- Turbine
- Open channel

**New Technology Flowmeters:**

- Coriolis
- Magnetic
- Pulse based
- Vortex
- Ultrasonic

*Traditional flow meters* were introduced many years ago, and their performance characteristics, such as accuracy, are lower than their newer counterparts and require greater maintenance. For instance, the orifice plates in differential pressure meters are subject to wear and can be knocked out of position by impurities in the flow stream. The various technologies represented in this group have been slow to incorporate recent advances in communication protocols such as HART, Foundation Fieldbus, and Profibus.

*New Technology or electronic flow meters* have the advantage of microprocessor based technology. Their construction and operating principles avoid some of the problems inherent in the traditional meter types and they generally out perform their precursors, particularly in their accuracy levels of ±1.0% or better.

In this part of the series we are going to cover some of the popular mechanical flow meters to make readers aware of the ongoing challenges with mechanical meters and later we will cover the details of the more popular microprocessor, pulse based as well as ultrasonic flow meters in Parts 2 and 3 of this series.

**Mechanical Flow Meters a.) Positive Displacement Flow meter**

Positive-displacement (PD) meters mechanically make direct measurements of the fluid by separating the fluid into segments of known values (Figure 1). Fluid goes through a chamber with a unit that repeatedly fills and discharges a fixed volume.
The total volumetric flow rate can then be calculated from the rate of filling and discharging the discrete volumes. The speed of flow therefore is not of consequence to these meters. They excel at measuring low flows and those with high viscosity like honey, oil and syrup. Highly accurate PD meters are commonly used in commercially to measure industrial water, natural gas, and hydrocarbon liquids such as petroleum and diesel as they are transferred to and from delivery trucks.

b.) **Differential Pressure Flowmeter**
Differential-pressure (DP) flowmeters incorporate an obstruction in the flow stream that reduces flow velocity. This reduction has the effect of lowering the fluid pressure. The DP flow meter measures the difference between upstream and downstream pressure, and computes flow rate based on that difference.

There are several types of DP meters used in the industry, for example Orifice Plate, Venturi tube, nozzle, and Pitot tube to name few.

Figure 2 shows a Pitot tube DP flow meter where a probe with an open tip (Pitot tube) is inserted into the flow field. The tip is the stationary (zero velocity) point of the flow. Its pressure, compared to the static pressure, is used to calculate the flow velocity. Pitot tubes can measure flow velocity at the point of measurement.

Figure 2: Pitot Tube Differential Pressure Flowmeter

DP meters are preferred for measuring clean liquids, steams, and gases in applications that are not adversely affected by pressure drop and that require low-to-medium accuracy. One of the other
advantages is that they are considerably less expensive than new technology flow meters like Coriolis and ultra-sound meters.

c.) **Variable Area Flowmeter**
Most variable-area (VA) flow meters (Figure 3) consist of a tapered tube containing a float. Fluid passing through the meter exerts an upward force on the float that is counter-balanced by the force of gravity. The point at which the float stays constant indicates the volumetric flow rate, which is often read on a scale on the meter tube.

![Rotameter Variable Area Flowmeter](image)

**Figure 3: Rotameter Variable Area Flowmeter**

The tubes are made of metal, glass, or plastic. Metal, the most expensive, is used for high-pressure applications.

While most VA meters are read manually, some incorporate transmitters that generate an output signal, which can be sent to a controller or recorder. These meters are not a good choice for high-accuracy applications, but they do very well when a visual indication of flow is sufficient. They are quite effective at measuring low flow rates and can also serve as flow/no-flow indicators. Because they do not require electric power, they can safely be used in flammable environments.

d.) **Open Channel Flowmeter**
Open-channel flow meters are those in which a liquid flows in a stream or conduit that is not closed, or in a partially filled pipe that is not pressurized. The open-channel meters come in different flavors. Some require hydraulic structures such as weirs or flumes, similar to the primary elements of DP meters. The liquid of interest passes through the structure, and flow rate is calculated based on the level or depth of the passing fluid. Another popular method is velocity area, in which the velocity of the stream is computed by one method (e.g., electromagnetic), and the level or depth by another (e.g., radar). These values are then used to determine flow rate, although the area of the flow must also be known.

In **Part 2**, we will discuss new technology flow measurement covering some of the popular sensors.
like optical, magnetic, etc used in pulse based counting.