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Industrial Flow Measurement Handbook

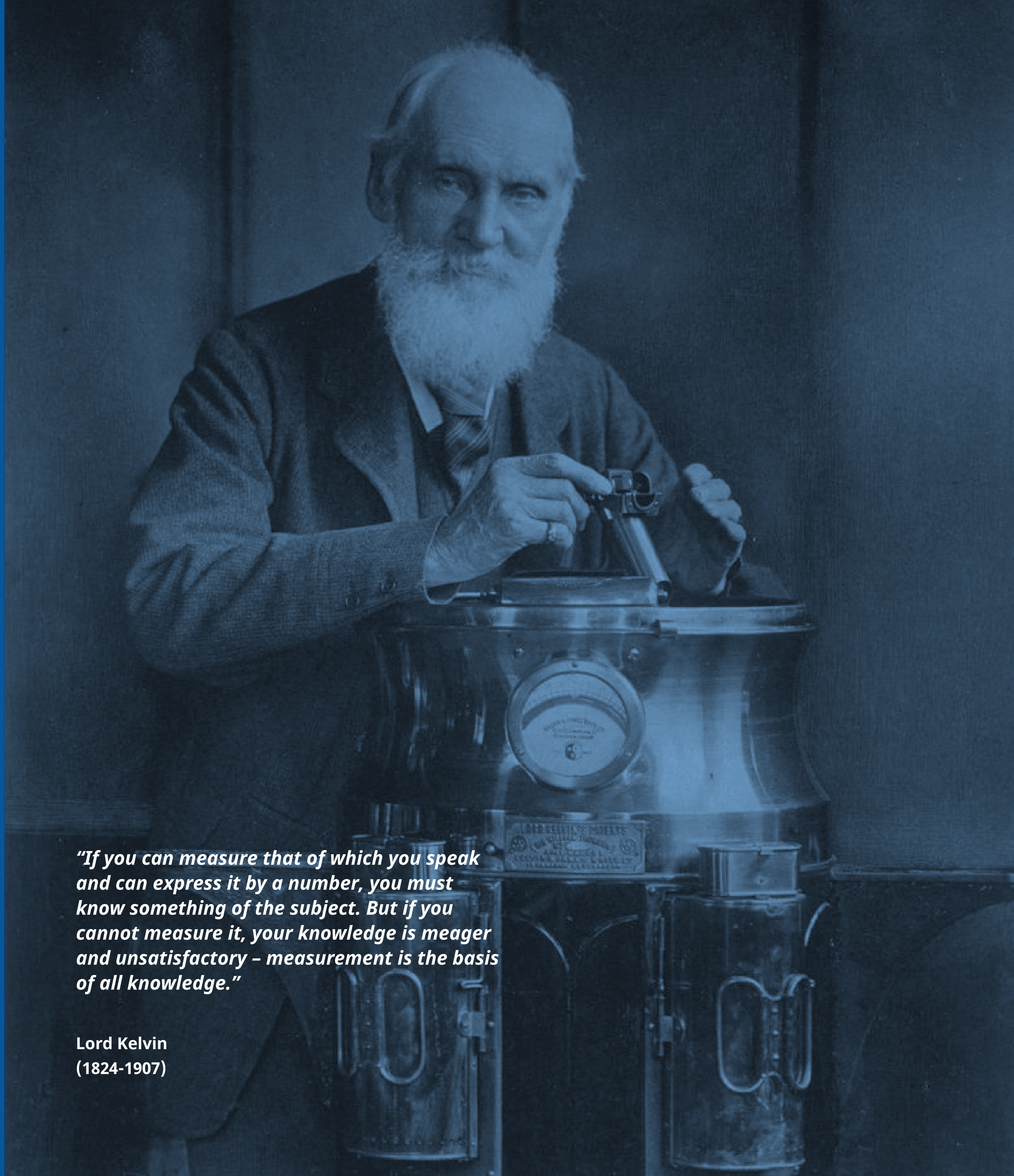
A Basic Guide to Accurate & Reliable Flow Measurement

Foreword

As industries strive to improve control of processes, the quality of the measurement of that process is often overlooked. Good quality measurement is the first requirement of any control scheme, new or old. No matter how good your DCS, PLC, SCADA, or cloud-based data collection is, if you do not have accurate reliable process data, it does not matter.

Process instruments and data collection and control platforms must work together to give users the best performance for the price, ultimately increasing our partner's profits. In the end, that is what we are all here for- to make a profit.

Accurately measuring Flow is a powerful piece of process data. Ultimately, the drive of any good Flow Meter is to get an accurate, reliable flow measurement to the data user quickly, which is what this eBook will discuss.



"If you can measure that of which you speak and can express it by a number, you must know something of the subject. But if you cannot measure it, your knowledge is meager and unsatisfactory – measurement is the basis of all knowledge."

Lord Kelvin
(1824-1907)

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1. Introduction

The aim of a flow meter is to perform a measurement that helps us find the right answer to questions such as: how many liters of flow do we have currently or how many liters have we used so far? Flow meters are used in a great variety of areas. For instance, flow meters are important in terminating the supply of fuel once you have 10 liters of gasoline, or administering only 500cc of medicine to a hospital patient. The main role of flow meters in the Factory Automation field is to manage the flow of “fluid”.

This e-book allows you to get an overview of flow meter technologies which are common in industrial process control. These are flow meters to measure the fluid flow in closed piping. The array is big and until today the task to select a suitable flow meter is not covered by software online or by the use of AI. Most available selection tools focus on the selection of the correct size of a particular flow meter or are comparisons of one manufacturers portfolio based on very limited criteria.

Some engineering knowledge and the understanding of the processes is necessary to choose a good flow meter. This e-book focuses on the basic relations of flow dynamics, flow meter technology and the purpose of the actual application. Installation is a topic which should not be underestimated, because there is a significant influence on the measurement. This handbook guides you through the different topics and explains the different steps and tools available to choose the best flow meter for the application.

2. Fundamentals & Basic Physics of Flow

Objective

To understand what is flow, the various types of flow and the measurement methods; to understand the physics of flow, the properties of fluid, and the phenomena's linked with flow.

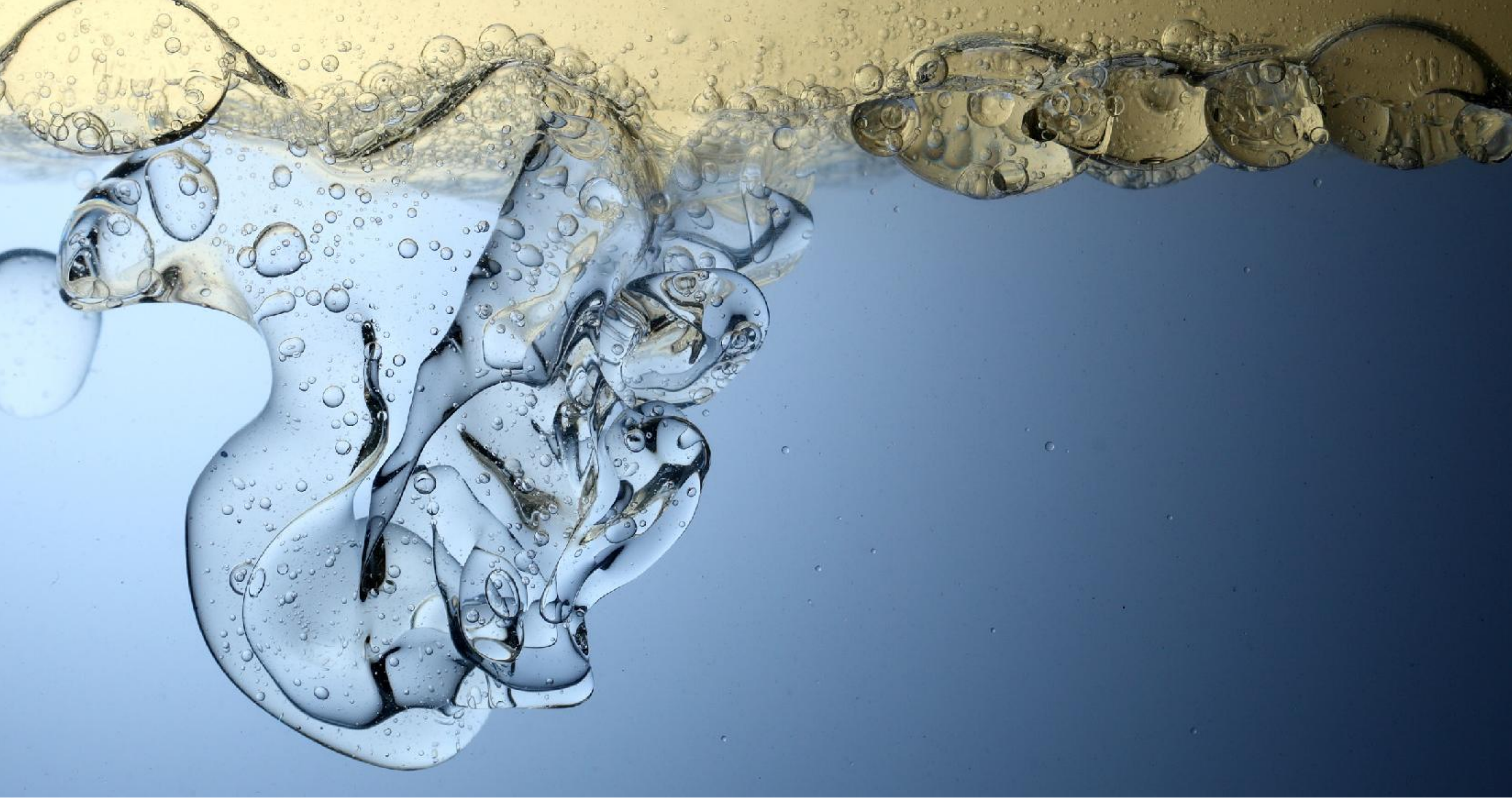
Fluid Flow is a part of fluid mechanics and is associated with fluid dynamics. Fluids such as gases and liquids in motion is called fluid flow.

2.1 Fluid Dynamics

Fluids dynamics is the discipline in physics and engineering that describes the flow of fluids, liquids and gases, in engineering terms.

Fluid dynamics is used widely in engineering. It is used to calculate forces on an aircraft, making weather forecasts, designing hulls of ships, high efficient blades for wind turbines, and determining the flow rate of oil through pipelines, etc.

Flow measurement technology is the practical application of fluid dynamics. It involves the calculation of various properties of the fluid, such as **flow velocity, pressure, density, and temperature**, as functions of space and time. The fluid characteristics are essential for flow measurement and understanding this is relevant for the successful selection application of flow measurement technology.



2.2 Fluids and Fluid Properties

Before starting the study of fluid behavior, its dynamics and statics, we should first have a brief overview of the basic properties of fluids.

What are Fluids?

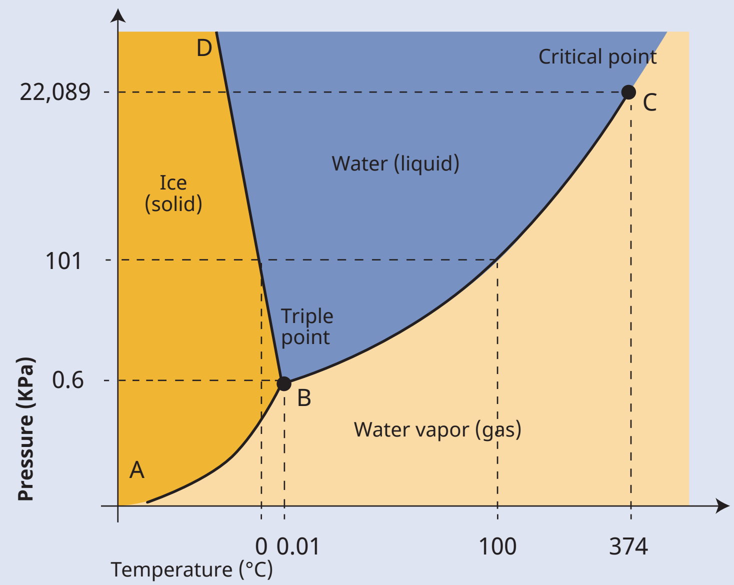
The term “fluid“ is frequently used as a synonym for “liquid”. In Flow measurement, “Fluid” is a general term that describes the flowing matter in the **liquid phase** and **gas phase**.

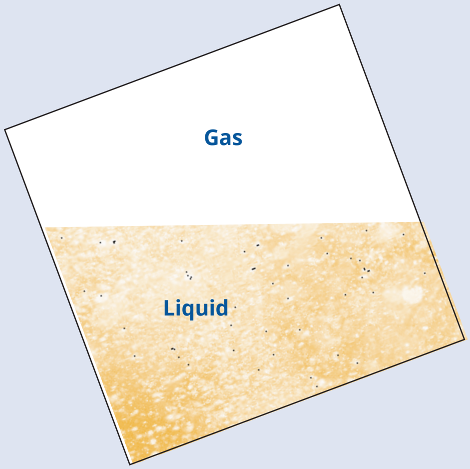
Liquids form a free surface (which is not created by the container) while gases do not. Also, substances with a very high viscosity such as pitch appear to behave like a solid are liquids (eg. pitch drop experiment).

Fluids are a phase of matter and include liquids, gases and plasmas. The phase depends on temperature and pressure. The different phases can be visually shown in **Phase Diagrams**, like the figure below for water.

Such diagrams are useful to understand the status of a fluid in a pipeline or container.

All liquids and gases are fluids including water and air. In space and inside stars another kind of fluid exists called plasma.





Classification of Fluids

- **Simple fluids (1)**: water, glycol, other pure liquids (monophase, 1 component, low viscosity, far away from solidification and boiling points).

- **Simple fluids (2)**: 5% NaOH, diesel fuel and other more component liquids (monophase, 2 components or more, low viscosity, far away from solidification and boiling points).

- **Multi-component fluids**: cheese, grease, cosmetics, mayonnaise (no clear melting point, more states than solid/liquid/gas, strange viscosity behavior).

- **Newtonian liquids**: viscosity depends only on temperature and pressure.

- **Non Newtonian liquids**: viscosity depends on shear forces, such as ketchup.

HOMOGENEOUS are equal distributed mixtures.

- **Two phases - liquid/liquid:** milk, blood, glues
  well mixed emulsion, flow velocity restricted

- **Two phases - liquid/solid**: paints
  well mixed suspension, flow velocity restricted

- **Two phases - liquid/gas**: *foams*

HETEROGENEOUS separates out to two phases.
liquid/gas: bubble flow
liquid/liquid: slug flow
liquid/solid: slurry (pipe clogging)

Measuring the ratio of multiphase mixtures is possible with advanced flow meters like Coriolis mass flow meter and by combination of several sensors. The use of additional (flow) computer and the understanding of the process lead to a useful measurement results.

Simple fluid (1): Water

Simple fluid (2): Diesel Fuel

Multi-component fluid: Mayonnaise

Density

Density is the weight per volume of a fluid. Liquids are mostly incompressible, which means the density is independent form the applied pressure. Gases on the other hand are compressible and therefore the conditions play an important role.

Relation between Mass, Volume and Density

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}} \qquad \rho = \frac{m}{V}$$

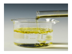
$$\text{Volume} = \frac{\text{Mass}}{\text{Density}} \qquad V = \frac{m}{\rho}$$

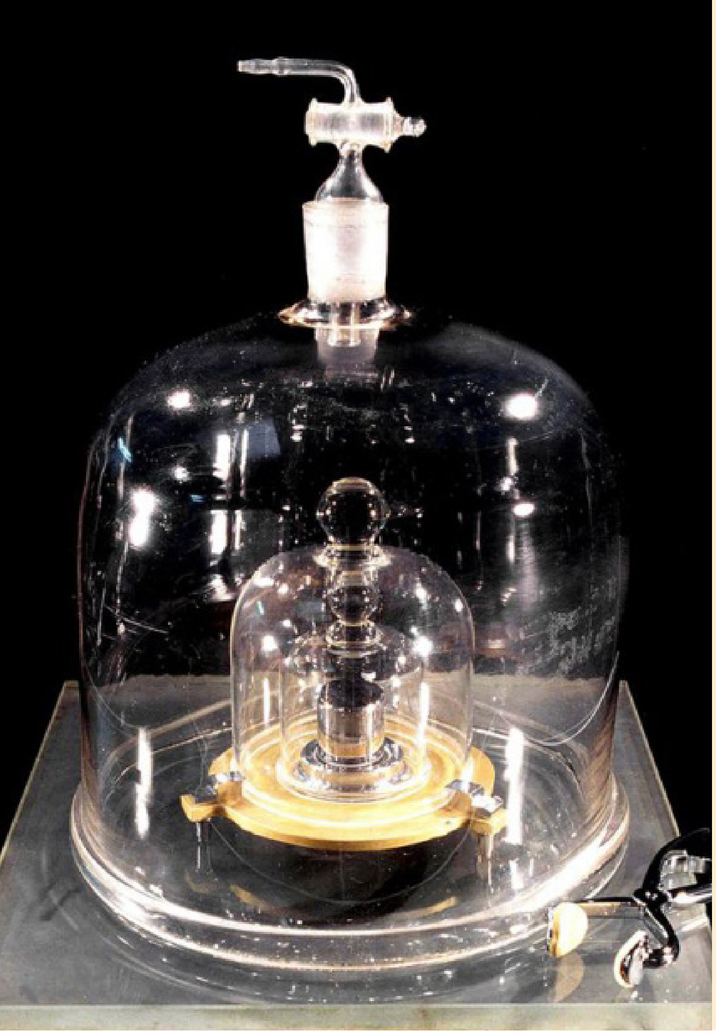
$$\text{Mass} = \text{Volume x Density} \qquad m = V \, x \, \rho$$

The mass or amount of fluid is constant. It is not influenced by temperature, pressure or other environmental factors.

The volume and therefore also density of an amount of fluid are **not constant** as both are influenced by:

- Temperature (thermal expansion)
- Pressure (compressibility)

 **Click here to watch the video "Density".**



The international prototype of the kilogram in its housing at the Pavillon de Breteuil in Saint-Cloud, near Paris.

A balloon has a low density even though it occupies a large area.

A bar of lead has a high density yet occupies a very small area.

Viscosity

Every fluid has a viscosity. The viscosity describes the inner shear forces of a fluid and how easy it is flowing through a pipe, and how much resistance is generated.

Gases have a low viscosity, but still have a viscosity. Water has a low viscosity for a liquid; honey or bitumen have a high viscosity.

Viscosity is very dependent on temperature. Overall, the viscosity of liquids decreases when temperature increases. Gases demonstrate the opposite behaviour i.e. the higher the temperature, the higher the viscosity.

 **Click here to watch the video "What is Viscosity?"**

One way to measure a fluid's resistance to flow when an external force is applied is referred to as Dynamic Viscosity. **Dynamic Viscosity** is commonly reported in Centipoise (cP) and Brookfield rotary method is useful for its measurement.

Kinematic Viscosity is measured by looking at the time taken for a fluid sample to flow through an orifice in a capillary under the force of gravity. The time taken is recorded and converted into Kinematic Viscosity, reported in Centistoke units (cSt).

All above fluid parameters are **temperature dependent**. Kinematic Viscosity is usually only applied to **liquids**.

Kinematic Viscosity (cSt) = Dynamic Viscosity (cP) / Density

Newtonian and Non-newtonian Liquids

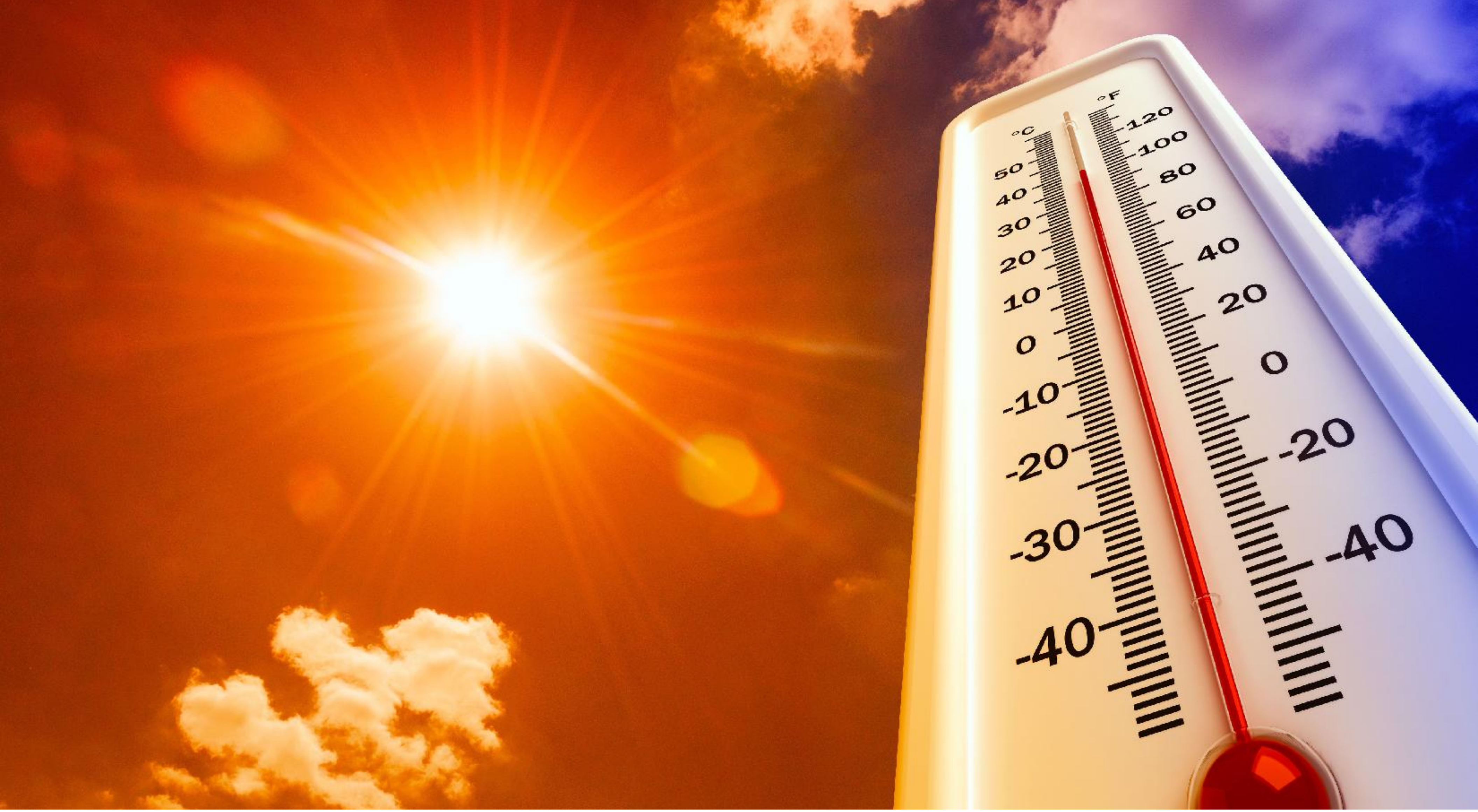
Most liquids have the same viscosity independent if they are flowing or not. These are Newtonian Fluids. Typical examples are Water, air, alcohol, glycerol, and thin motor oil.

Non-Newtonian fluids like Ketchup and Yoghurt have a **high shear stress resistance** when the flow is starting, but when the relative motion is increasing the shear stress drops and the flow is more easy.

$$\nu = \frac{\mu}{\rho}$$

ν: Kinematic Viscosity $[\nu] = m^2/s$
μ: Dynamic Viscosity $[\mu]$ = Pa*s=N*s/m^2
ρ: Density (kg/l) $[\rho] = kg/m^3$

A non-Newtonian fluid is a liquid or fluid whose viscosity can change when stress or pressure is applied to it.



2.3 Thermodynamic State Variables: Pressure & Temperature

As the thermodynamic state of a system depends on numerous variables – such as **temperature, pressure, and volume –** it is crucial first to decide how many of these are independent and then to specify what variables can change while others are held constant.

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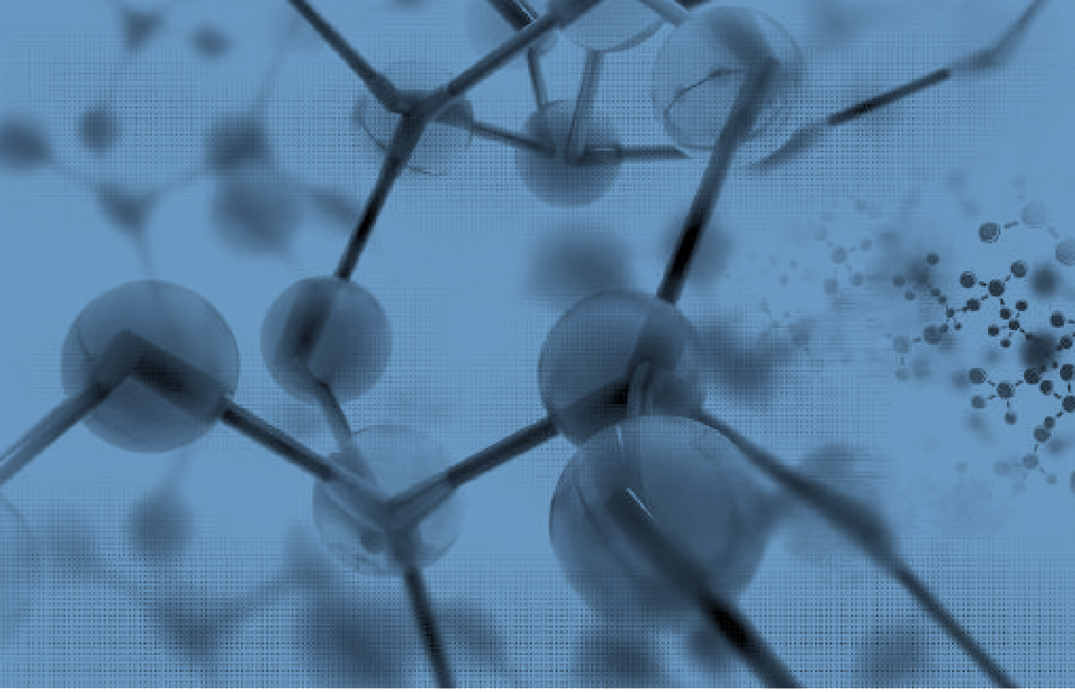
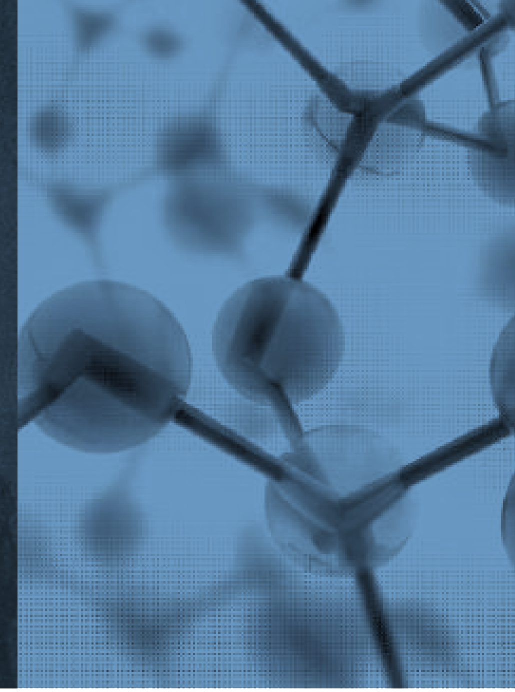




Molecules in a constant random motion within a closed container

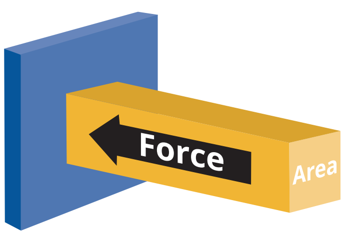
Blaise Pascal (1623-1662)

Pressure

When a gas or a liquid is contained within a closed container, their molecules are in a constant, but random motion, constantly colliding with each other as well as with the container walls.

All of these collisions occur over a given area combined to result in a force. This force over a defined area is referred to as pressure.

$$\text{Pressure} = \frac{\text{Force}}{\text{Area}}$$



Pascal's Law (Gas and Liquids)

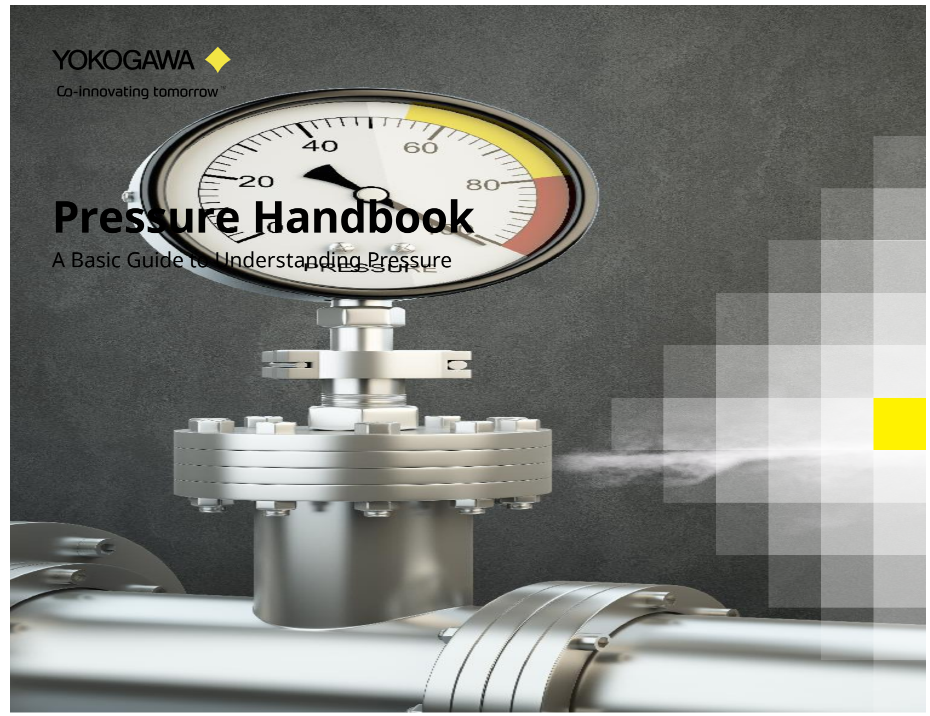
In the 1600s, Blaise Pascal developed his principle of transmission of fluid-pressure or more commonly known as Pascal's Law. This law states that a change in the pressure within the closed container will be conveyed equally in every direction within the container. Therefore, the pressure within the container can be measured from any point within the container.

Pressure acts equally in all directions.

Free Pressure Handbook

A basic guide to understanding pressure

Accurately measuring pressure is a powerful pice of process data. Download this eBook and learn how to accurately, quickly and reliably measure pressure.



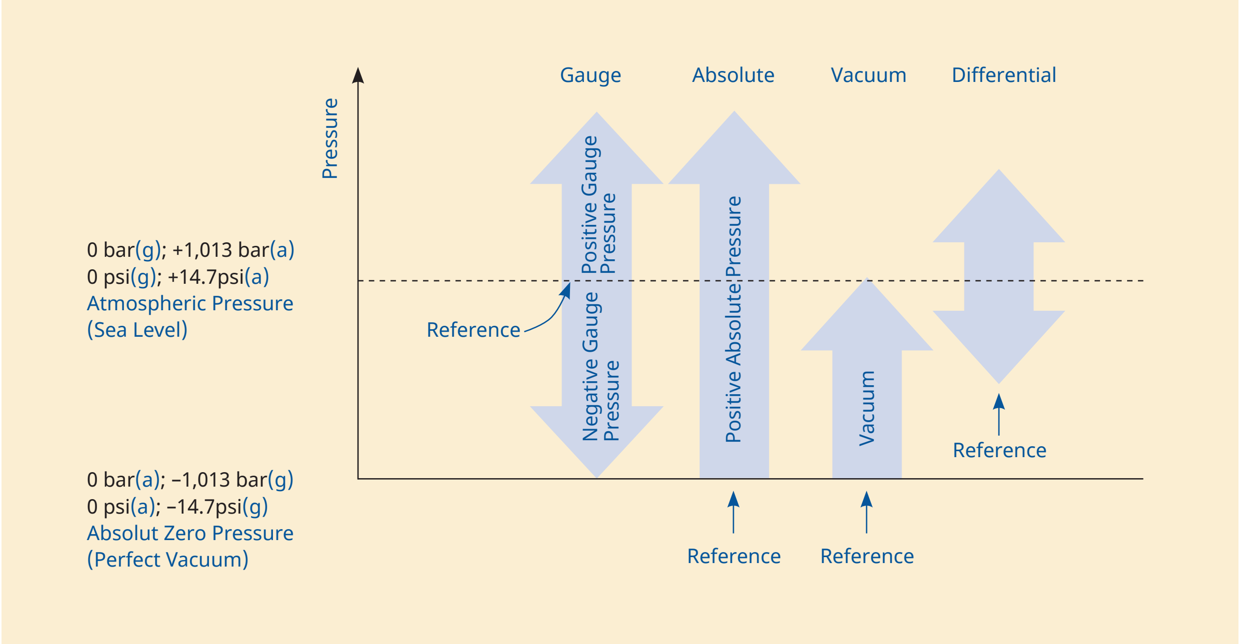
For more information, click here to download the Yokogawa Pressure Handbook.

Absolute vs. Gauge Pressure (relative pressure)

- **Absolute pressure** is zero-referenced against a perfect vacuum, meaning it is equal to gauge pressure plus atmospheric pressure.

- **Gauge pressure** is zero-referenced against ambient air pressure (atmospheric pressure), so it is equal to absolute pressure minus atmospheric pressure. Negative signs are usually omitted.

▶ **Click here to watch the video "Absolute Pressure vs Gauge Pressure – Fluid Mechanics – Physics Problems".**



Temperature

The density and viscosity of fluids is always temperature dependent. Temperature is a measure of a material's internal molecular activity. As the level of molecular activity rises, the temperature of a substance increases. Using the words hot and cold is very subjective, so temperature scales were defined to establish numerical values.

The most common ones are:

- °C Celsius
- °F Fahrenheit
- °R Rankine
- °K Kelvin

Click here to download the Yokogawa Temperature eBook.

Units Conversion Overview

From		To		Equation
Fahrenheit	°F	Celsius	°C	[°C] = ([°F] – 32) x 5/9
		Rankine	°R	[°R] = [°F] + 459.67
		Kelvin	°K	[°K] = ([°F] + 459,67) x 5/9
Celsius	°C	Fahrenheit	°F	[°F] = ([°C] + 273.15) x 9/5
		Rankine	°R	[°R] = ([°C] +273.15) x 9/5
		Kelvin	°K	[°F] = [°C] + 273.15
Rankine	°R	Fahrenheit	°F	[°F] = [°R] – 459.67
		Celsius	°C	[°C] = ([°R] – 491.67) x 5/9
		Kelvin	°K	[°K] = [°R] x 5/9
Kelvin	°K	Fahrenheit	°F	[°F] = [°K] x 9/5 – 459.67
		Celsius	°C	[°C] = [°K] – 273.15
		Rankine	°R	[°R] = [°K] x 9/5

Liquid Metal: Every rock and metal can be fluid if they are hot enough, that is what happens deep inside the Earth.

Ideal Gas Law

Gas is compressible which leads to a challenge when describing volume of gas. It is important to state the condition of the gas in terms of temperature and pressure. The Ideal Gas Law can be derived from basic principles, but was initially deduced from experimental measurements of Charles' law (that volume occupied by a gas is proportional to temperature at a fixed pressure) and from Boyle's law (that for a fixed temperature, the product is a constant).

Charles and Boyles Laws describe together the ideal gas Law which is:

$$P \times V = \eta \times R \times T$$

The Ideal Gas Law can also be written in the following form, which is more practicable:

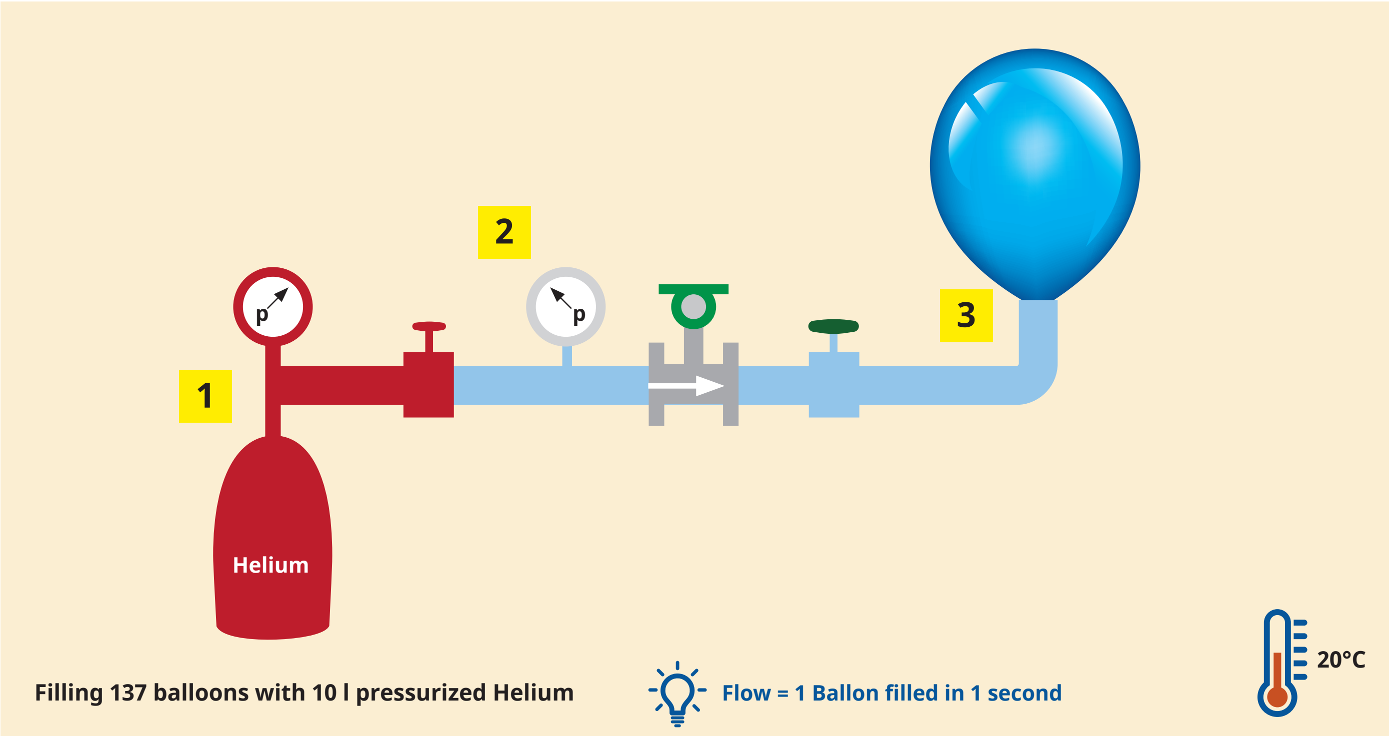
$$\frac{V}{V_0} = \frac{P_0 \times T}{P \times T_0}$$

P Pressure
V Volume
η Number of moles
R Gas constant
T Temperature

Gas is compressible which leads to a problem when discussing volume of gas. Therefore, it is important to state the condition of the gas in terms of temperature and pressure. Gas flow is often described as **Volumetric Flow** under defined conditions instead under actual conditions.

The actual (measured) volumetric flow rate is converted to standard temperature and pressure conditions.

An ideal gas can be characterized by three state variables: absolute pressure (P), volume (V), and absolute temperature (T).



1

Helium is stored for easy transport at high pressure in a bottle. Fairly large amount of gas can be stored in small space.

200 bar
33 kg/m³
10 l = 0,01 m³
= 330 g

2

In the balloon filling process, the helium is released from the high pressure bottle at lower pressure by a control valve. In our example the helium runs through a flow meter. These would be the **operating conditions** for the flow meter.

20 bar
3,3 kg/m³
330 g
= 100 l = 0,1 m³

3

The helium is inside the balloon. The pressure is slightly above atmosperic pressure and the balloon is fully inflated. Pressurized Helium in a 10 liter bottle fill 137 balloons with a diameter of 30 cm.

1,01 bar
0,16 kg/m³
330 g
= 2060 l = 2,06 m³

The balloon is outside and it is cold **0°C**. The atmospheric pressure is **1.0135 bar a**. This condition is commonly referred to a **"Normal"** condition and the volume unit is marked by an "N" to clearly mark it as a reference condition is contrast to operating condition.

The 330 g of helium fill a space of **1,94 m³** at **0°C and 1.0135 bar a** which is **1,94 Nm³**.

10 l He = 137 balloons

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2.4 Flow

In order to fully understand the physics of flow, it is primarily essential to understand the physical properties of fluids as well as a basic understanding of phenomena's associated with flow in pipes. The most interesting item is **how much** of a fluid is flowing through the pipeline at any given moment. The desired result of any measurement system to measure flow is either **mass flow** or **volume flow**.

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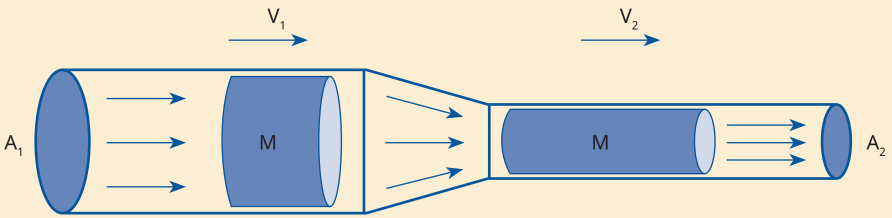
Continuity Equation

Mass Flow is described through the equation of continuity. The **Mass** per second which is flowing at any given time through a pipeline must be the same, even if the diameter of the pipe is changing.

The flow inside a pipe can be described as **Mass Flow** and as **Volume Flow**. The dimensions and geometry of a pipe are known and when the **Density** of a fluid is also known, the **Flow Rate** can be derived by measuring the **Flow** velocity.

If Fluid is stable Constant Density (incompressible fluid)



M = const.

$Q = A_1 \times v_1 = A_2 \times v_2$

A = Section of pipe m^2

Q = Mass Flow

v = velocity

Maximum Flow Velocity in Piping Systems

The fluid flow velocities in piping systems should not exceed certain limits to avoid noise and damaging wear and tear of pipes and fittings. The table below is a guide to maximum velocities which are used to select pipe sizes:

	m/s
Liquids	1 – 3
City Water	1 – 2,5
Tap Water (low noise)	0,5 – 0,7
Benzine, Light Fuel	1,8 – 2
Lubricating Oil, Heavy Fuel	1,5
Saturated Steam	20 – 30
Superheated Steam for Turbines	30 – 80
Gas	10 – 30
Compressed Air	20
Natural Gas	30
Oxygen	9 – 20

***Table is a reference only, other conditions apply to severe conditions and should be considered carefully.**

Bernoulli's Principle

Bernoulli's principle states in fluid dynamics that an increase in the flow velocity occurs simultaneously with a decrease in pressure or a decrease in the fluid's potential energy. The principle is named after Daniel Bernoulli who published it in his *Hydrodynamica* in 1738.

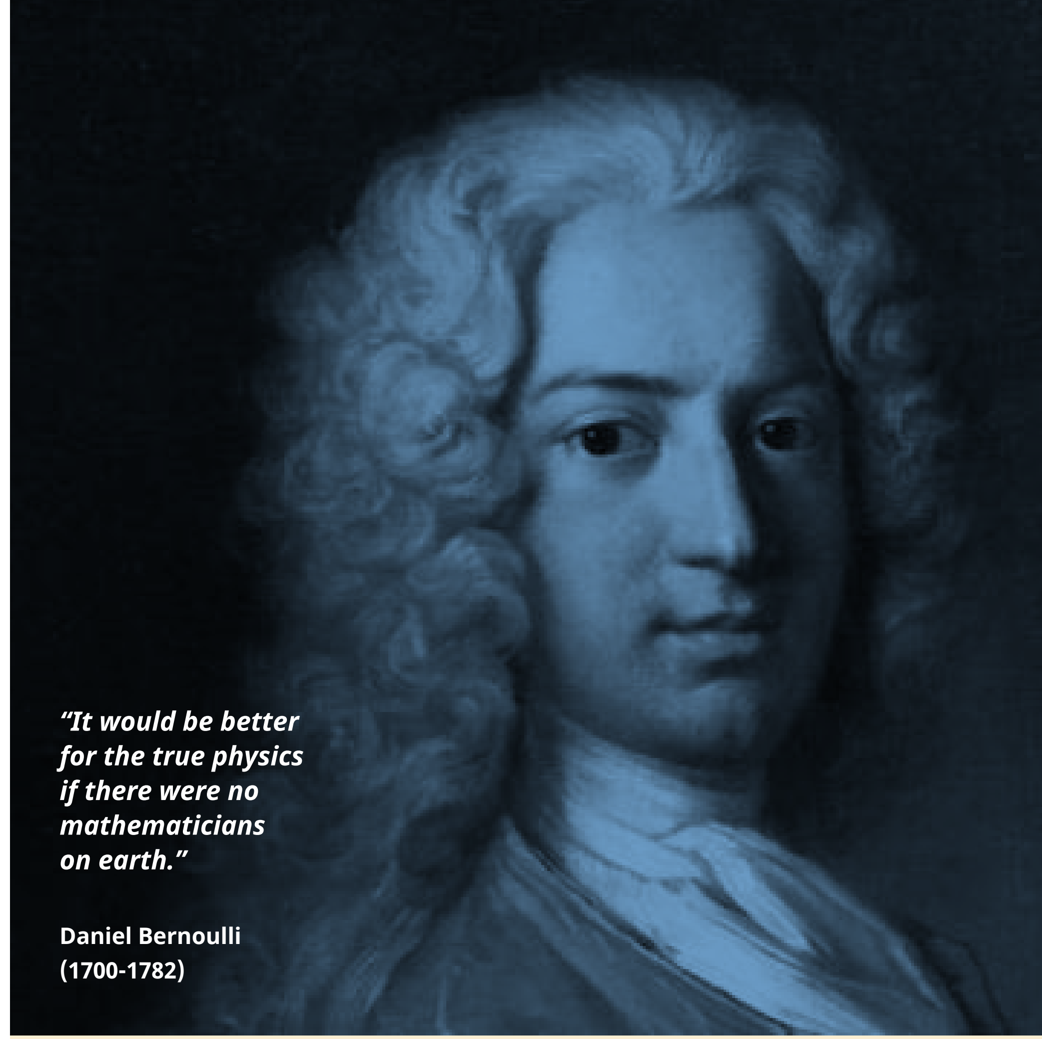
$$\tfrac{1}{2}\,\rho\upsilon^2 + \rho g h + p = \text{constant}$$

The principle above describes that the combination of pressure, density, flow velocity and vertical height is **always constant**. This opens possibilities to measure the **flow velocity** by a change in pipe diameter by measuring the pressure at two different points in a pipeline.

Flow Measurement

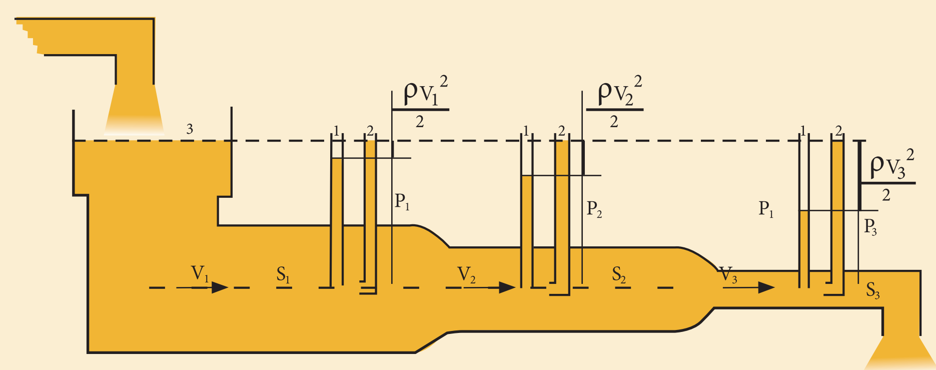
The application of Bernoulli‘s principle is the Differential Flow Measurement using a primary element and a Differential Pressure Transmitter. Primary Elements are defined pipe reduction elements e.g. Orifice Plates, Wedge or Venturi Nozzels.

Click here to read more about Yokogawa’s Differential Pressure.



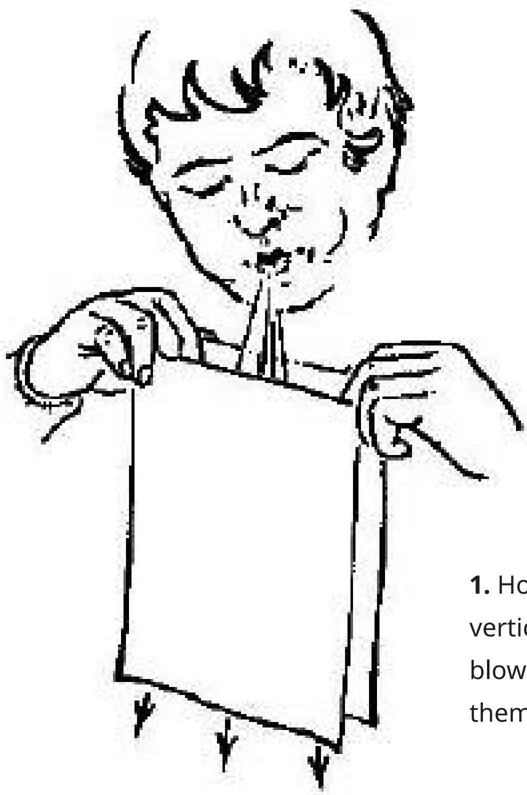
“It would be better for the true physics if there were no mathematicians on earth.”

Daniel Bernoulli (1700-1782)

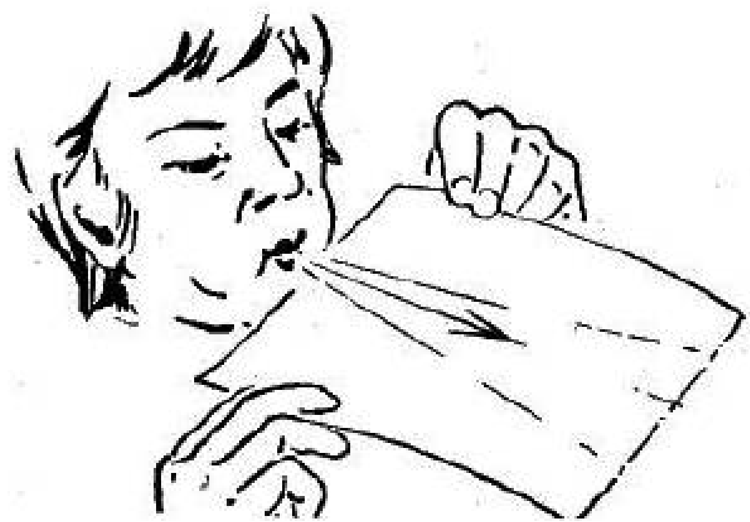


The Bernoulli Comparison at three points in a tube.

Do It Yourself



1. Hold two pieces of thin paper vertically a short distance apart and blow down into the space between them.



2. Hold one end of a small sheet of paper in both hands. Keep the held edge horizontal while the other end sags under its own weight. Blow steadily over the top of this horizontal edge.

It seems amazing that the two sheets of paper move closer together. In both cases, pressure is reduced where air is moving quickly. This is called the Bernoulli principle.

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Reynolds Number (Re)

The Reynolds Number describes the pattern of a of a fluid flow. It is used to determine whether a flow is turbulent or laminar. It is dimensionless and allows comparisons and simulations of flow behavior with different fluids. Reyonlds number (Re) and Flow Profile have significance in the design of flow sensors.

Laminar flow

For practical purposes, if the Reynolds Number is less than 2000, the flow is laminar.

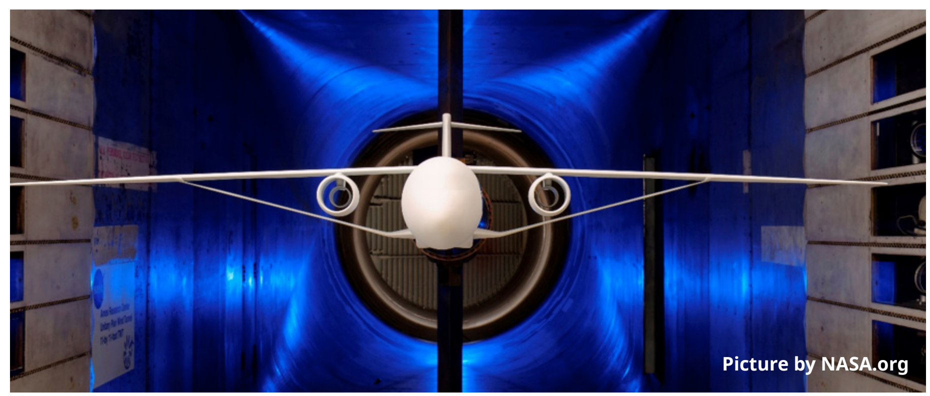
Turbulent flow

If the Reynolds Number is over 3500, the flow is turbulent. Most fluid systems operate with turbulent flow.

$$Re = \frac{\text{Inertia forces}}{\text{viscous forces}} = \frac{\rho \cdot V \cdot D}{\mu}$$

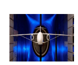
"But we have reason to think that the annihilation of work is no less a physical impossibility than its creation, that is, than perpetual motion."

Sir George Stokes (1819 – 1903) introduced Reynolds numbers.



Picture by NASA.org

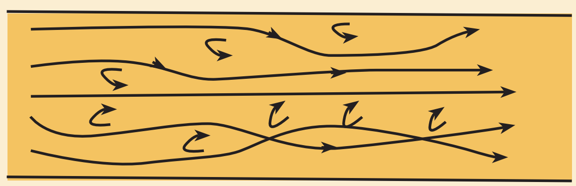
The Reynolds Number enables simulating airplane design with scale models in wind tunnels.

 **Click here to watch the video "Reynolds Numbers and Turbulence".**

Flow Profile

The flow profile explains how the flow of a fluid behaves or is likely to behave in a pipeline based on its velocity and viscosity. Once this is known, it is possible to decide which of the various different types of flow meter available is best suited to the demands of the application. Flow can be described as **laminar or turbulent flow**.

Laminar flow



Turbulent flow

Laminar flow occurs at stable, low flow rates and is the most predictable type of flow. In laminar flow, the fluids can be imagined as several layers of fluid moving smoothly. Laminar flow is apparent at low flow velocities.

Turbulent flow occurs at faster flow rates. At a Reynolds number around 2000, a flow is transitioning from a laminar flow to a turbulent flow. If the flow velocity increases the previously seemingly ordered layers, the fluid molecules become less organized and begin to swirl chaotically. The flow profile in a pipe is also changing. The flow is turbulent.

Now the flow is less ordered and the swirls cause internal friction, which is increasing the drag or the resistance of the flow.

The condition for a flow to be laminar or turbulent depends on the fluids density and viscosity but also on dimensions of the fluid containing body, e.g. the diameter of the pipe. A dimensionless description is the **Reynolds Number (Re)**.

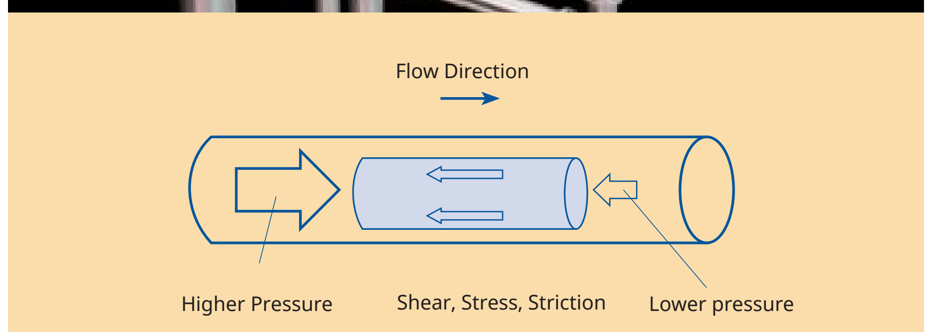
Friction in Pipes, Pressure Loss

A fluid flows from a high pressure to a low pressure. When fluids are moving through a pipe, the flow generates a resistance, which is a loss in pressure. When the pressure up stream is lower than the necessary pressure to overcome the resistance, flow is not possible.

Most flow meters mean a restriction or a modification from a straight pipeline. The resistance or pressure drop is important information which can be calculated using **tables and databases of flow elements**.

The pressure drop is also information provided by flow meter manufacturers.

Click here for more product information about Yokogawa's ADMAG AXG Magnetic Flow Meter.



Free body diagram of a volume of fluid within a pipe. The pressure difference between two locations balances the viscous shear stresses between the fluid and the pipe's inner surface. The fluid is in equilibrium, and it moves with a constant speed.

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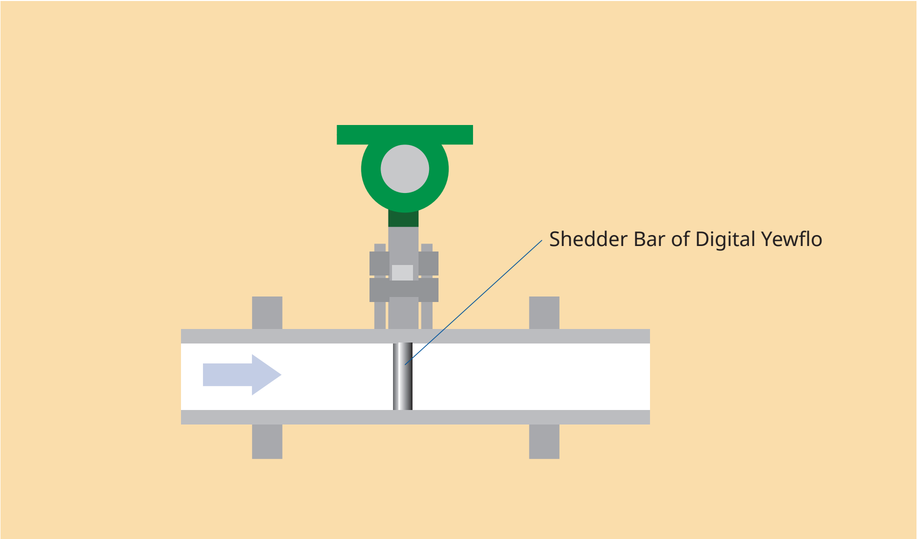
Pressure Loss at Flow Elements

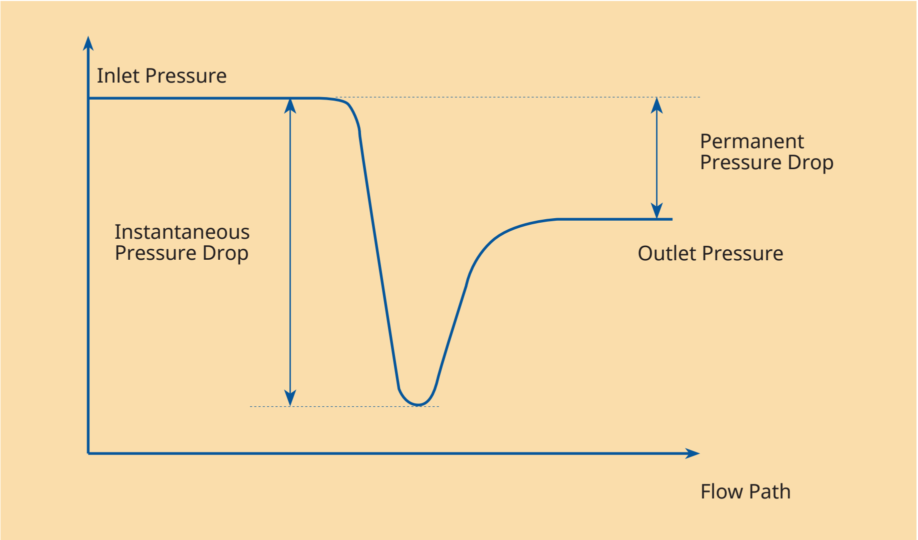
Many flow meter measurement principles are based on a restriction in the flow tube and the resulting pressure difference. Other principles force a change of the flow path in order to take advantage of a flow pattern effect, e.g. Vortex. Liquid restriction results in a reduction of pressure, which can be distinguished between an instantaneous and permanent pressure loss.

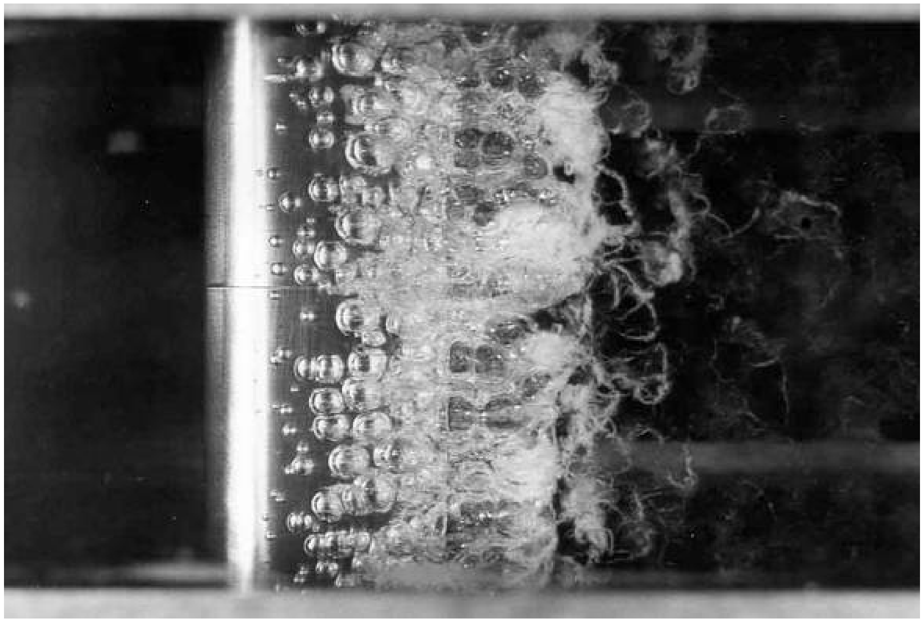
Permanent **Pressure Drop** is important to know which pressure is available after the flow meter. This is important for pipe layout and dimensioning of pumps.
Instantaneous pressure is the lowest absolute pressure at the narrowest point where the flow velocity is the highest. The absolute pressure is relevant for the phase of the fluid.

This could be critical, if the absolute pressure drops below the vapor pressure of the fluid. In this case gas bubbles appear in the liquid and the measurement accuracy is reduced.

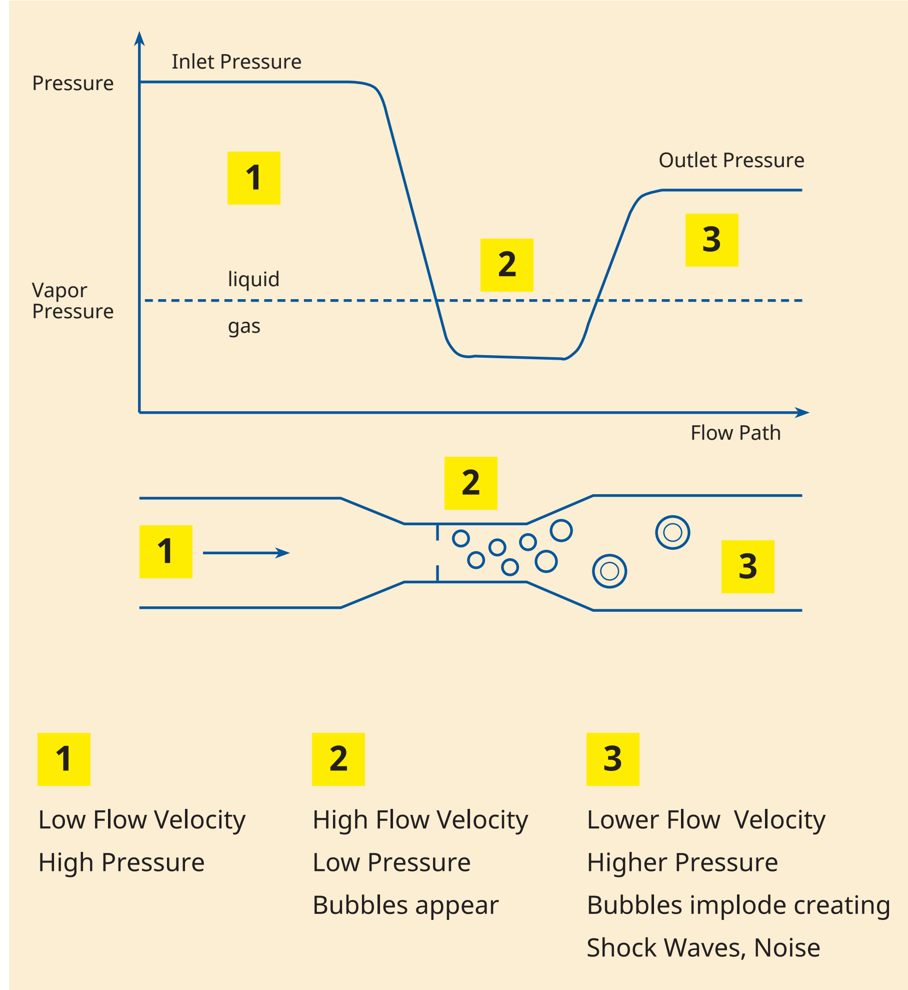
Don’t worry – Yokogawa provides you the tools to calculate!







Cavitation



Flow noise

Vapor Pressure (Cryogenic Fluids)

The effect of flashing is evident when handling cryogenic fluids. Cryogenic fluids are fluids which are in a gas state in ambient temperature. The gases are turned into liquid for various reasons.

Typical examples are liquid nitrogen or LNG. These Liquids are stored in vessels always slightly below the boiling point. Any drop in pressure or increase of temperature will lead to vaporization. Therefore, extra care needs to be taken when it comes to flow measurement of cryogenic fluids.

Miscellaneous Hydraulic Phenomena: Cavitation

Cavitation is the process where a liquid rapidly vaporizes at a region of low pressure and then returns into its liquid condition when pressure recovers. Cavitation occurs when pressure drops below the liquid's vapour pressure.

Due to cavitation, vapour bubbles form and collapse again in the pressure recovery area The sudden formation and collapse of vapour bubbles is a violent process and can severely damage to the components.
A countermeasure to prevent cavitation is to take any local pressure drop into consideration and keep the pressure always above the vapour pressure.

3. Flow Meter Installation

Objective

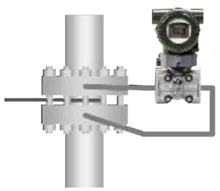
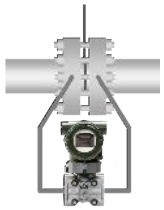
To understand the significance of the installation of a flow meter for its performance.

When selecting a flow meter, it is crucial to consider exactly where and how the device will be installed, as this can significantly affect both **accuracy** and **efficiency**. The installation of a flow meter is important for the performance of the flow meter. The best flow meter will deliver poor results, when installation has flaws. Each flow meter has of course its own specific requirements, which are shown in installation instructions which come with the flow meter. Here you see several general installation guidelines, which give an idea what to take into consideration when planning and installing a flow meter.

Every flow meter works best when the fluid to be measured is **a single phase fluid**, either gas of liquid. If it is known that fluid is two phase, e.g. a slurry or entrained gas cannot be avoided, the expectation to the measurement under such condition must be taken into account in the flow meter selection.

3.1 Orientation

In this part, we would like to show flow meter installation orientation can affect meter performance and accuracy. The flow meters can be mounted in any orientation, with the **exception of the Rotameter, which can only be mounted in a vertical direction with flow from bottom to top**.

	Coriolis	Rotameter	Magnetic	Vortex	DP
Flow Upward					
Flow Horizontal					
Inlet and Outlet Length	No	No	Yes	Yes	Yes
Reversible Flow Direction	Yes	No	Yes	No	No

Overview of the inherent installation requirements and possibilities of the different flow meters.

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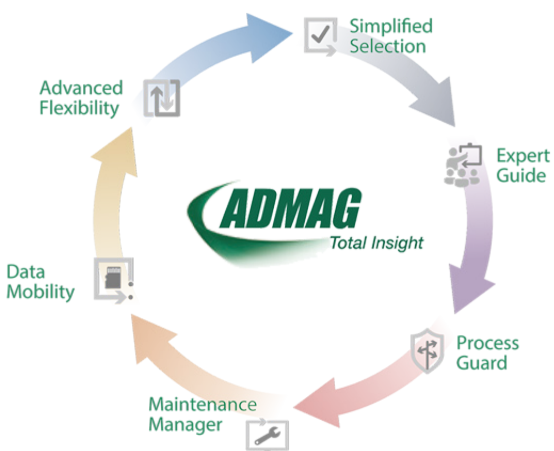
3.2 Inlet & Outlet Straight Pipe Requirements

Flow meter installation guidelines are mostly based on flow meter piping requirements, which play an essential role in determining the metering technology.

Magnetic Flow Meters & Vortex Flow Meters are based on **flow velocity**. The **Volume flow** is derived from the diameter and the even flow profile. To achieve this condition, a straight unobstructed inlet and outlet length is required. These lengths are shown in the installation manual of each flow meter.

The **straight length** is the distance how far from the flow meter a change in the piping can be placed. This can be an expander or reducer, a bent to change the piping direction, a valve or any other element in the pipeline.



Click here for more info about Yokogawa's Magnetic Flow Meters.

Click here for more info about Yokogawa's Vortex Flow Meters.

Click here to watch the video "Magnetic Flow meter (ADMAG Series) – AXF Detector".

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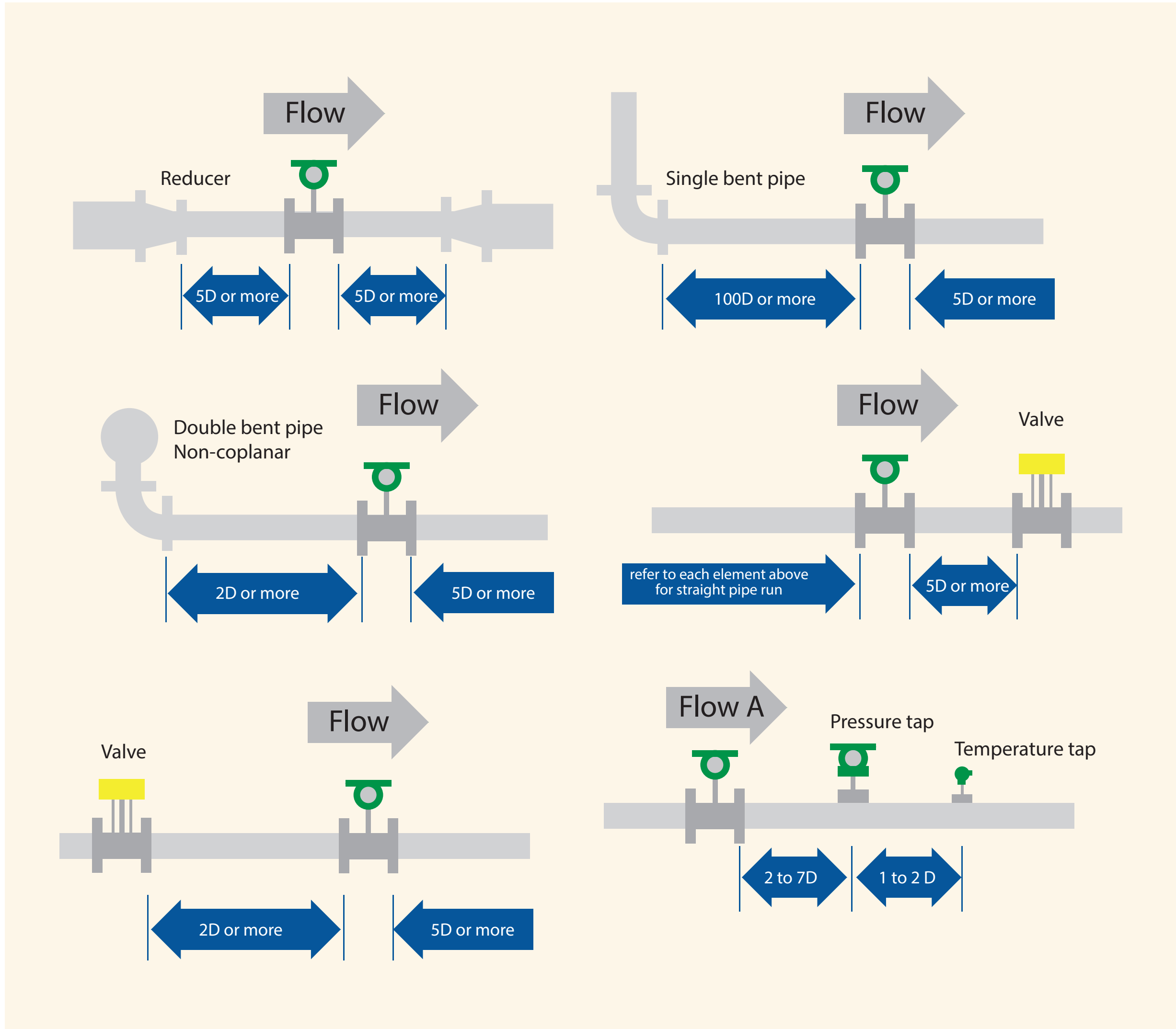
3.3 Installation for Gas or Liquid

The flow meter should always be placed in a position where it is **always filled with the fluid**, even it there is no flow. Also, there should be an **escape path** for a second undesired phase, gas in liquid or liquids in gas services.

Click here to watch the video "Vortex Flow meter (digitalYEWFLO Series) Working Principle".



Examples of straight length requirements of Yokogawa Vortex Flow Meter DY.

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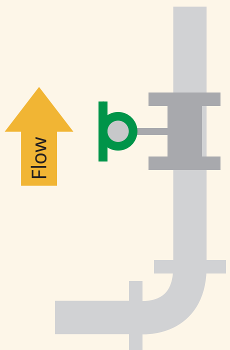
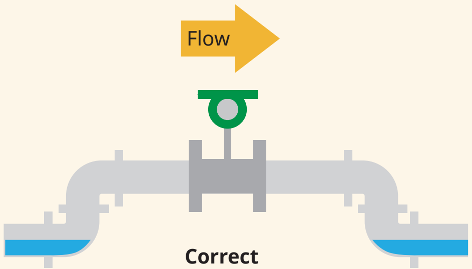
3.4 Installation for Gas or Steam Applications

Liquid is formed when the pressure and temperature conditions turn the gas to liquid. When this happens, any condensate will be trapped in the lower part of the pipe.

In horizontal piping, the flow meter should be placed in a high point, to enable liquid to drain away from the flow meter.



Correct



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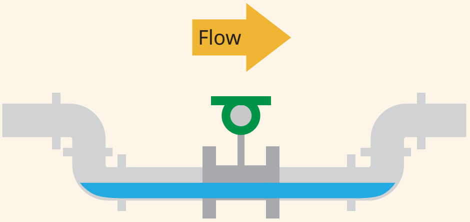

Incorrect

Please note that the flow meter should not be installed in the location where liquid can be trapped.

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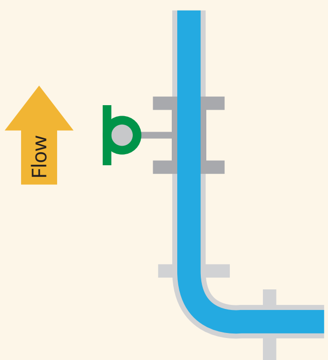
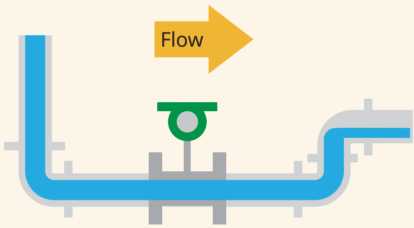
3.5 Installation for Liquid Applications

As for gas, it must be ensured, that the pipe and the flow meter is **always filled with the liquid** and to enable bubbles to escape.
The preferred installation is vertical with flow **from bottom to top**.



Correct

A flow from top to bottom is not recommended, unless it is secured, that the flow meter is always filled with the liquid.



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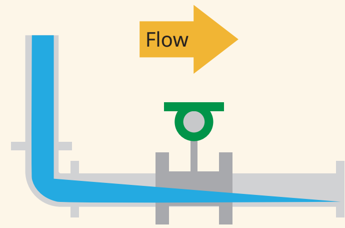
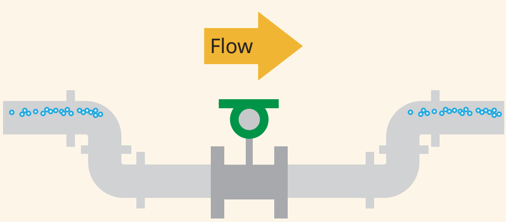
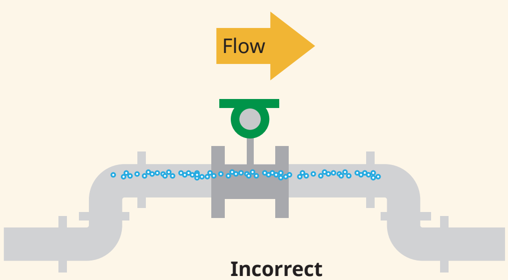


Incorrect

In this picture you can see that in this situation the flow meter is only partially filled with liquid. It is best to control the flow by allowing the fluid to flow against the gravity. If the flow is moving with the gravity, lift the downstream pipe above the flow meter to ensure a full pipeline.

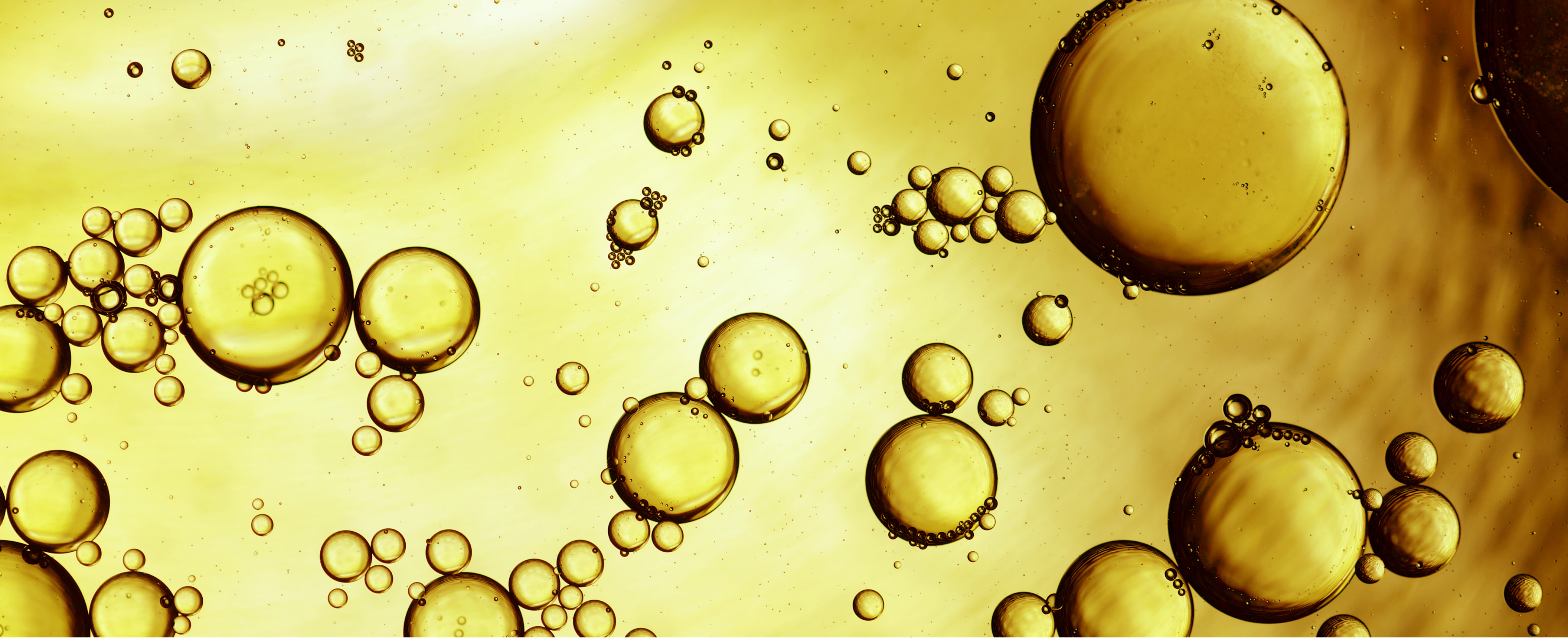


Correct



Incorrect

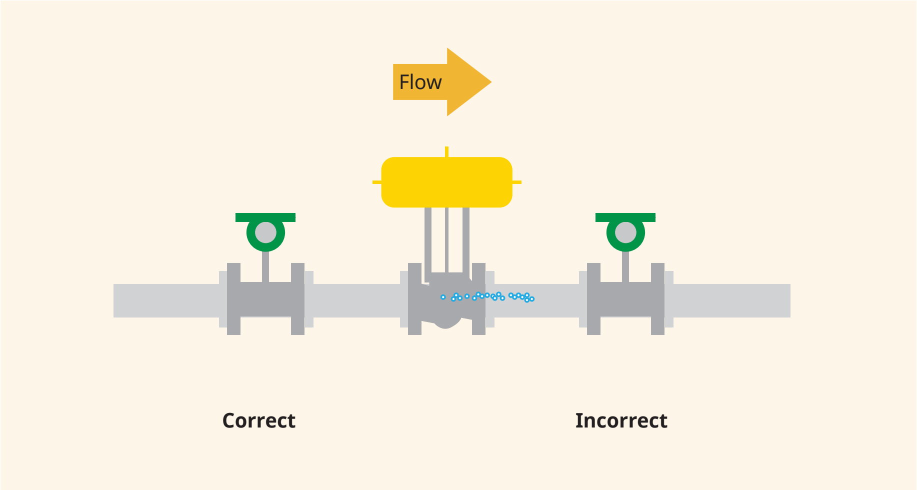
For liquid applications place the flow meter at a low point in the pipeline. This will help to avoid that any bubbles are going through the flow meter.



Avoid Bubbles

Install the piping in a way to avoid generating bubbles. Sudden pressure drop in the flow line causes gas to come out of the liquid solution. This effect is called cavitation. Items prone to gasification are valves and sharp changes in diameter.

These simple guidelines are helping to find the best spot for the flow meter in the applications. In some cases some restrictions may be there, then it must be compromised that the flow meter accuracy is slightly impacted. If a very critical measurement has restrictions of optimal installation, it might be considered to simulate this situation in a flow calibration facility to find out the performance before it goes into operation.



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Gasket

Flow meters are delivered without gaskets and bolts. These are provided by the installer. Gaskets must be selected to be suitable to the fluids. Gasket vendors provide tools and selection guides.

Most flow meter connections are installed with flat gaskets. During the installation, you should pay attention that the gasket is not protruding into the inner diameter of the pipeline, because this influences the flow pattern and cause inaccurate readings. Therefore, you must **check proper size and inner diameter**. These are not always standard.
Use gasket with bolt holes when possible. When using a spiral gasket (without bolt holes), conform the size with the gasket manufacturer, as standard items may not be used for certain flange ratings.

Also, make sure that the surfaces of sealing area is clean and the gasket is not damaged prior or during the installation.

It is recommended to use gaskets with bolt holes for best alignment.

Installation Checklist

- Make sure that the hazardous area specified on the approval tag is suitable for the environment in which the meter will be installed.
- Verify that the local ambient and process temperatures are within the limits of the meter.
- Check whether the correct Power Supply is available.
- Confirm the communication protocol, to enable seamless signal transfer to the control system.

4. Flow Meter Selection

Objective

To understand the possibilities to measure flow, Flow Meter Technology, and which tools are available.

The massive array of flow technology options on offer can make selecting the right flow meter for an application a challenging task. The ideal flow meter is inexpensive, universal flow meter that could handle any fluid (liquid, gas or vapor) and that would have a wide range of operating conditions- from cryogenic to superheated steam. It would have high accuracy (better than 0.25%) and a wide range (zero to infinity).

Since this does not exist, a selection needs to take place based on understanding of the actual flow, the measuring technology and most important, the purpose of the measurement.

4.1 Types of flow meters
4.2 Physical & Environmental Conditions
4.3 Flow Selection Charts
4.4 Flow Configurator

4.1 Types of Flow Meters

Vortex Flow Meters

Magnetic Flow Meters

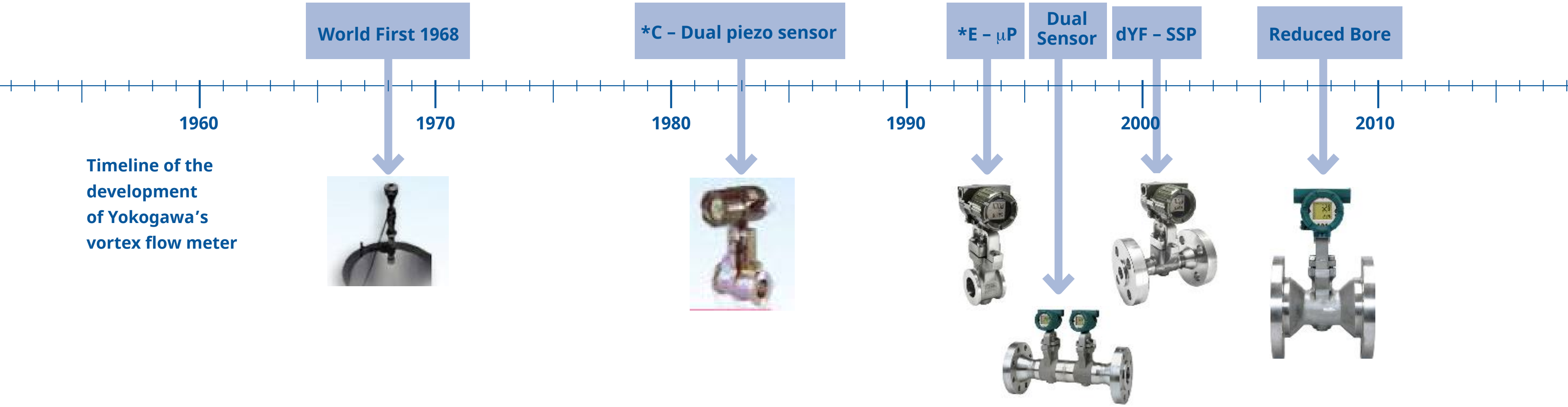
Coriolis Flow Meters

Yokogawa has more than 100 years experience in the development, design, and manufacture of various flow meter technologies. With many industry firsts, Yokogawa continues to lead innovation in flow measurement.

Rotameter Flow Meters

Differential Pressure (DP) Flow

Vortex Flow Meter



1968 Marked the first milestone in the development of Yokogawa's vortex flow meter – the development and subsequent success in bringing the product to market. At the core of this product concept was Yokogawa's reliable metering technology for a wide application range. These design fundamentals are still valid today.

Click here for more information

Vortex Flow Meters use the **Von Karman Effect** to measure the rate of flow of a **fluid** or **gas**.

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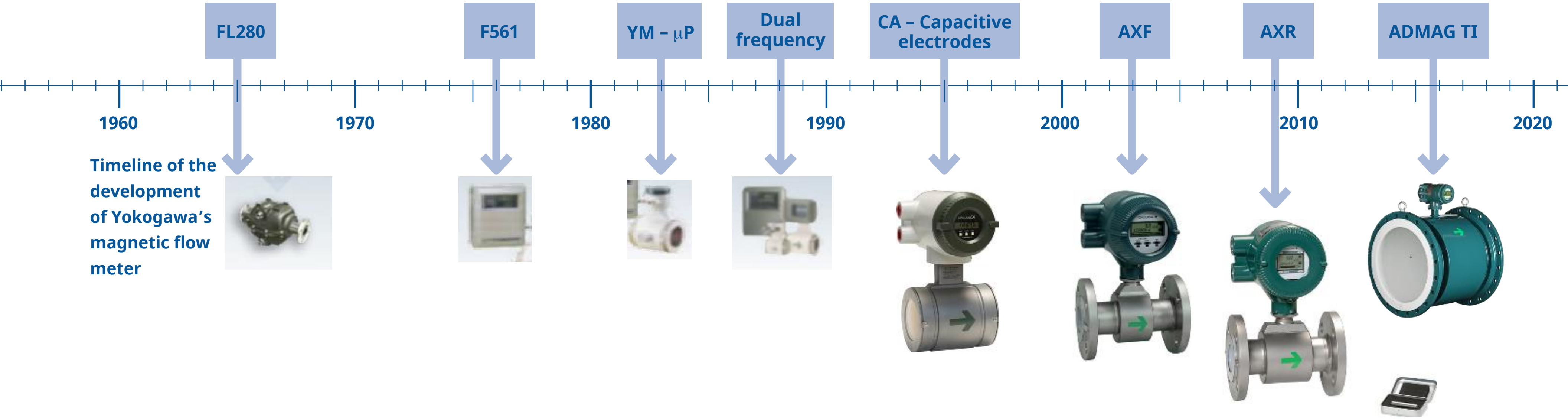
Magnetic Flow Meter



Timeline of the development of Yokogawa's magnetic flow meter

Yokogawa's Magnetic Flow Meter is supported by a long history of more than half a century. We added innovative specifications in each era, and have always lead the industry. The consistent policy of YOKOGAWA's Magnetic Flow Meter is to have high performance and high quality.

During the 1970s, Yokogawa responded to huge process industry demand for reliable flow meters of various types. In 1983, Yokogawa concluded a strategic merger with Japan's Hokushin Electric Works, a flow meter manufacturer. Combining their respective strengths in vortex and magnetic flow meter technology, the two companies formed **Yokogawa Hokushin Electric** and went on to focus on flow meter development, with an uncompromising commitment to quality and reliability. 2017 was the birthyear of ADMAG TI series to adopt the "Total Insight" concept and totally support the product life cycle.

ADMAG Total Insight

Click here for more information

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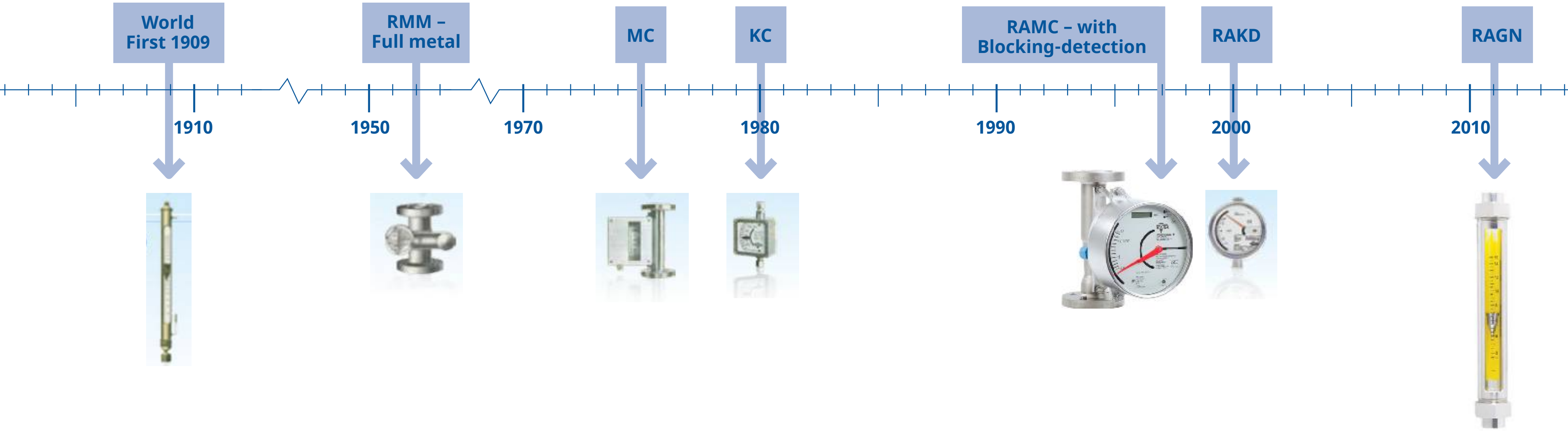
Rotameter Flow Meters

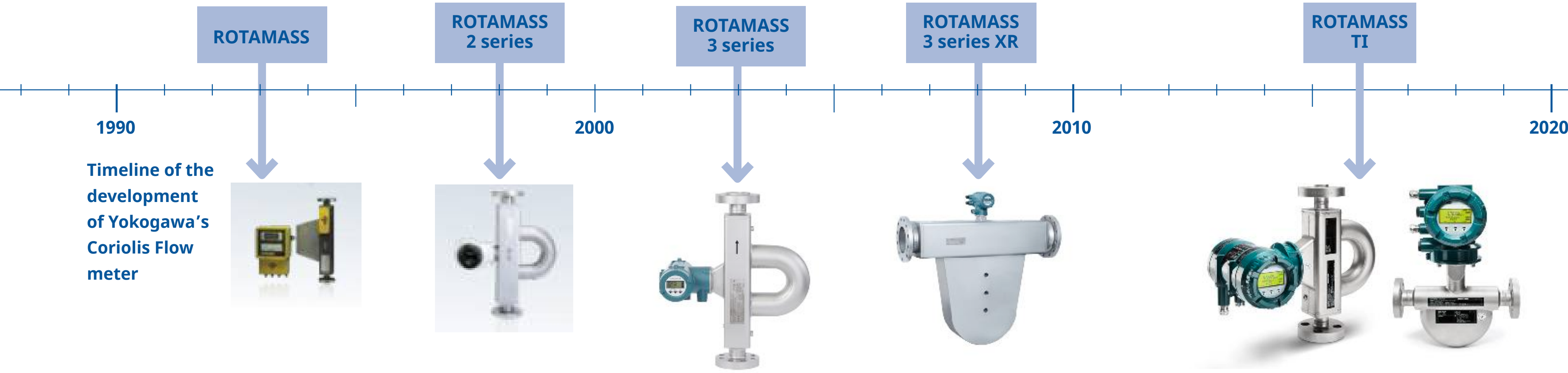


The Variable Area Flow Meter is one of the oldest and mature principles in flow measurement with its simple design: a float rises inside a conically shaped glass tube as the flow increases and its position on a scale can be read off as the flow rate.

In the 1990s, Yokogawa strengthened its focus on flow meters through cooperation with and eventual acquisition of the German flow meter manufacturer ROTA. In so doing, Yokogawa gained access to 100 years of flow meter expertise and completed its flow meter portfolio by adding the Rotameter (variable area) and Rotamass (Coriolis) product lines.

Click here for more information

Coriolis Flow Meter



Timeline of the development of Yokogawa's Coriolis Flow meter

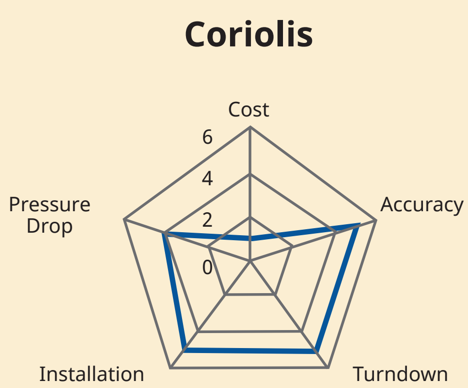
In 2016, the next generation Coriolis Flow Meter was designed using "Total Insight" technology. In the last decade, the use of Coriolis Flow Meters has been changing from general purpose to supporting your needs in specific applications. While the technological complexity increased, the demand for simple operation and handling is also a rising requirement.

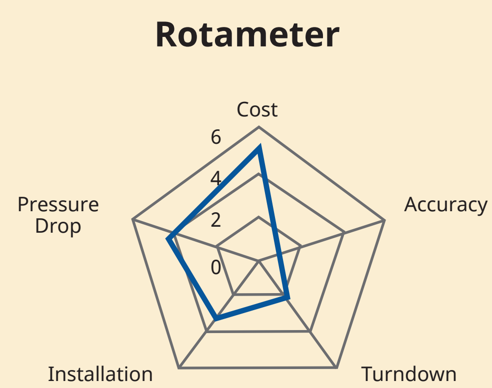
Yokogawa answers these needs by offering six dedicated product lines with two specialized transmitters allowing the highest flexibility **– the ROTAMASS Total Insight**. The ROTAMASS philosophy gives Total Insight throughout the whole lifecycle. To facilitate optimal processes and increase the efficiency of personnel, Yokogawa has placed a strong focus on simplifying fundamental operating concepts with Total Insight. The Total Insight concept is built in to the latest generation of Rotamass transmitters and provide enhanced settings for customized setups, pre-defined trend views, or multiple configuration sets for fast changeover in batch production are supported.

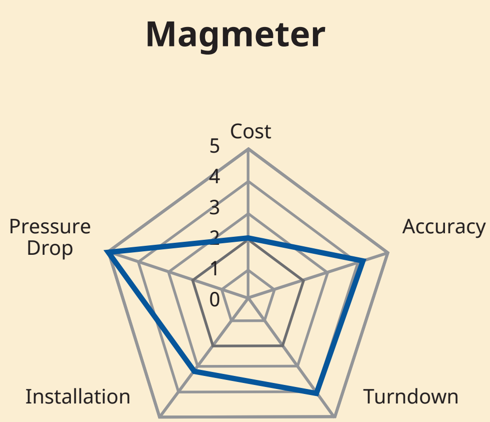
ROTAMASS Total Insight

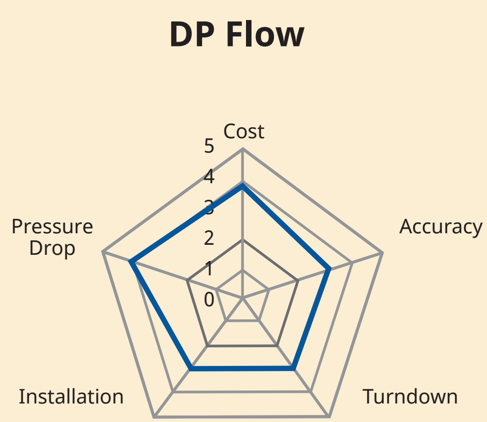
Click here for more information

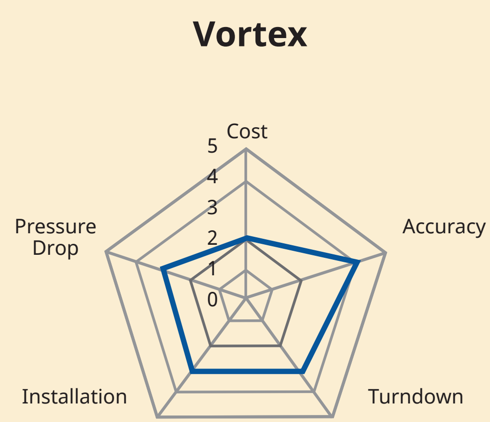
Flow Meter Characteristics











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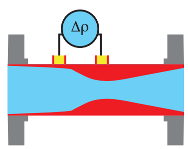
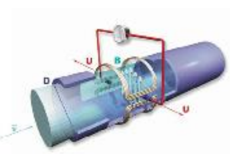
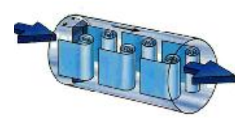
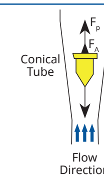
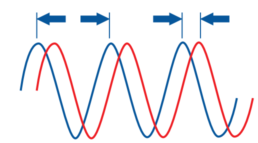
	Volumetric				Mass
Flow Meter Type	Differential Pressure	Electromagnetic	Vortex	Variable Area	Coriolis
	 EJA + Orifice/Ventury/ Pitotube/Annubar	 ADMAG	 digital YEWFLO	 Rotameter	 RotaMass
Liquids	Excellent	Excellent	Excellent	Excellent	Excellent
Gas/Steam	Excellent	N/A	Excellent	Excellent	Excellent
Principle of Measurement					
Technology	Operates according to Bernoulli's streamline energy equation. A restriction in a pipeline cased by a primary element (office, ventury, etc.) creates a differential pressure, between upstream and downstream pressure, witch is proportional to the square root of the flow rate.	Based on Faraday's law of induction whereby a conductive liquid flowing through a magnetic field induces a voltage proportional to the flow velocity.	Operates according to von Karman's vortex street principle. Vortices are created alternate behind the shedder bar. The number of vortices shed per time unit, the vortex frequency, is directly proportional to the flow rate.	Rotameters operate on the principle of generating a condition of dynamic balance within the flow meter in which a float is positioned in accordance with the flow through the flow meter.	Mass flow dependent Coriolis force occurs when a moving mass is subjected to an oscillation perpendicular to the flow direction. The phase shift is proportional to mass flow and the frequency is proportional to the density.
Purpose					
Just an Indication	√	√	√	√	√
Process Control	√	√	√	√	√
Custody Transfer	√	X	X	X	√

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4.2 Physical and Environmental Conditions

Space requirements

Weight and Height of flow meter

Installation constraints and pipework

Ambient Temperature and changes

Humidity

Wind, Sunlight

Hazardous Areas

Electromagnetic Interference

Additional equipment, like flow computer, pressure and temperature measurement for correction

Besides looking at the measurement characteristics, practical items must not be forgotten. Real life conditions may contribute to equipment downtime. Are there local environment or government regulations that might affect your operations? What about vendor selection?
On this page are a host of environmental conditions and factors beyond your control that might affect everything from flow meter selection to operations. Also, factors tied to the installation of the flow meter and the general lifespan of the equipment might also weigh in on flow meter decision making process.

4.3 Flow Selection Charts

Flow selection charts are a good tool to make a first choice and get an overview of the available flow meters. Follow these steps and the final choice will lead to the best suitable flow meter technology. The following step is to choose the right size and configuration of the particular flow meter.

Fluid Properties → **Application/ Performance** → **Installation** → **Economic Factors** → **Meter Selected**

Topics

Fluid Properties

- Liquid, Gas, Steam
  Conductivity
- Multi-phase/Slurries
- Viscosity
- Pressure
- Temperature

Can the fluid be measured by the flow meter technology?

Are there best practices known for the measurement application?

Application/ Performance

- Control / Monitor
- Indicating
- Batching
- Safe Guarding
- Custody Transfer

Which output information is requested, Volume flow-rate only or multiple simultaneously like additional density or temperature?

Does the application require approvals?

Which minimum accuracy is necessary?

Installation

- Line Size
- Vibration
- Pulsation
- Straight Pipe Runs
- Submergence
- Ambient Temperature
- Corrosion/abrasion

Is standard flow meter design sufficient or are special materials required?

Is enough space available for correct installation?

Are additional sensors necessary for compensation?

Economic Factors

- Cost
- Installation
- Reliability
- Maintenance

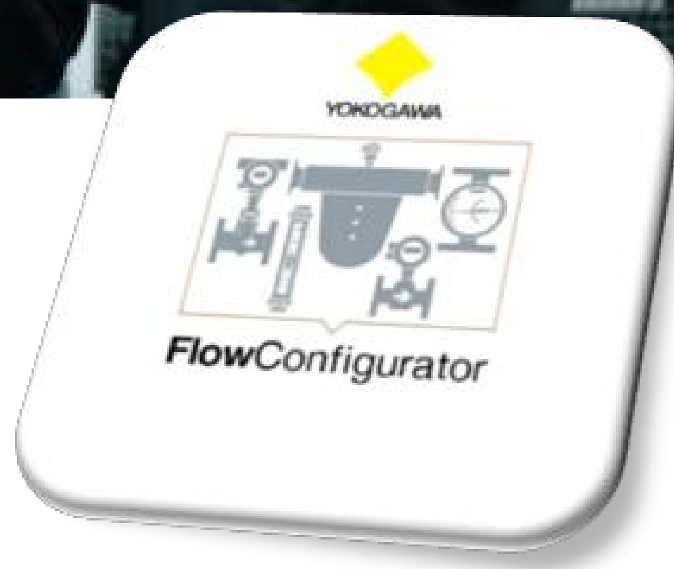
Is pipe work necessary?

Is power supply and communication available?

Are maintenance and re-calibration costs considered?

Meter Selected

- Coriolis
- DP
- Magnetic
- Vortex
- Rotameter



4.4 Flow Configurator

Our flow configurator guides you to the suitable flow measurement system in several simple steps. Such a sizing Software is available by Yokogawa to enable the correct selection and setup of a flow meter. The Yokogawa software is the FlowConfigurator.

Before making a final decision...

It is just as important to know what a flow meter cannot do as well as what it can do before a final selection is made.

Each instrument has advantages and disadvantages, and the degree of performance satisfaction is directly related to how well an instruments capabilities and shortcomings are matched to the applications requirements.

Once the detection method has been determined, further detailed selection can be completed for this model.

Lastly, compare costs. Removing a flow meter also requires time, therefore, you must make a decision that not only considers the unit price of the product, but also considers maintenance time after installation as well as the cost of set-up or troubleshooting. Generally when the product unit price is low, frequent maintenance or failure replacement may be required.

Accuracy

Flow Meters which offer a very high accuracy are more sophisticated and therefore more expensive than flow meters which measure with a low accuracy.

Repeatability

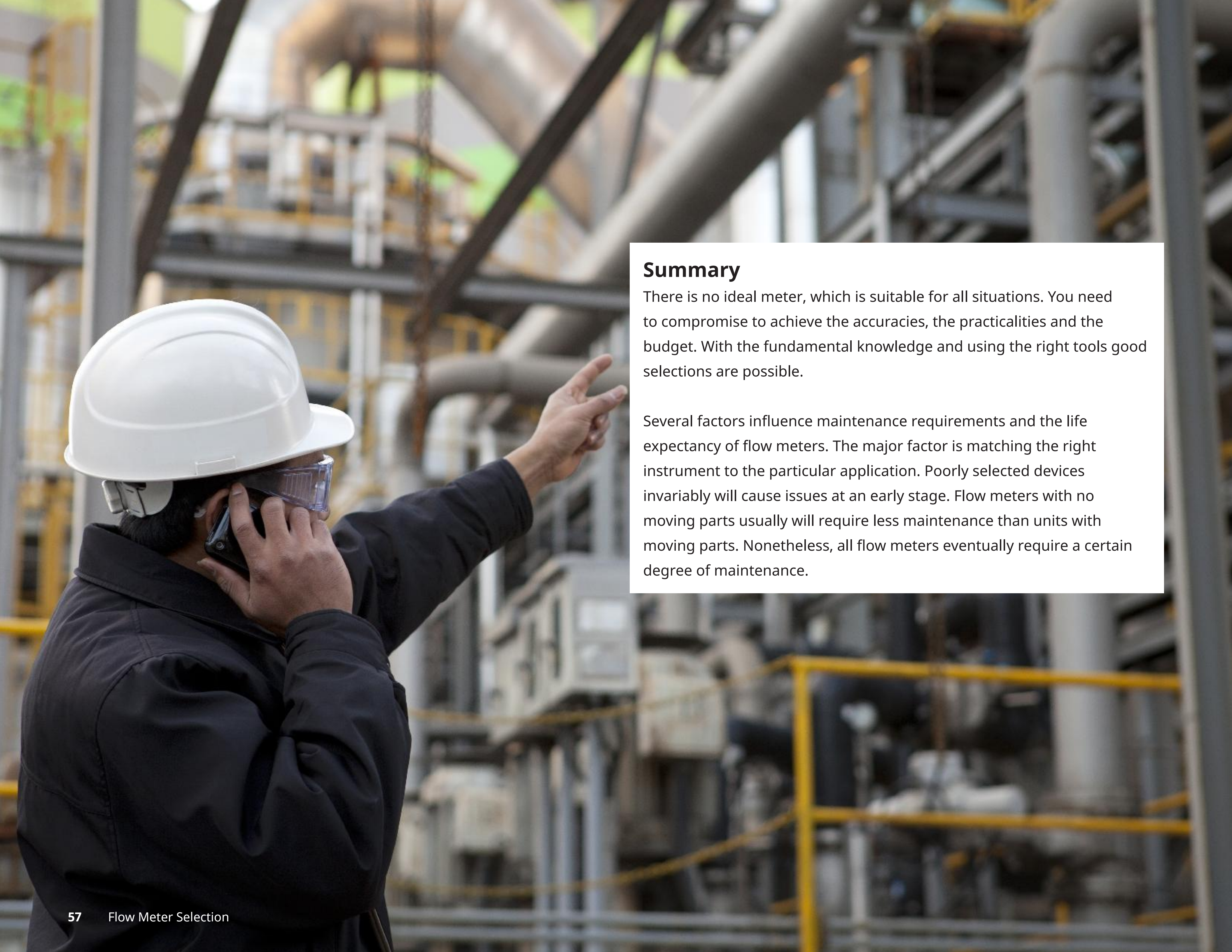
Same is true for repeatability, however a good repeatability is also possible with a low accuracy.

Pressure Loss

Most Flow meters, with the exception of magnetic inductive and Clamp-On Ultrasonic flow meters are based on a reduction in pipe geometry, which results in a pressure loss. Often a high accuracy comes with a relatively high pressure loss. This pressure loss must be taken into account.

Range & Turndown

Pick the flow meter with the widest turndown for the application. It is virtually impossible to know in advance the exact flow rate to be measured. Selecting a technology that allows for a wide turndown can cover anticipated flow variations.



Summary

There is no ideal meter, which is suitable for all situations. You need to compromise to achieve the accuracies, the practicalities and the budget. With the fundamental knowledge and using the right tools good selections are possible.

Several factors influence maintenance requirements and the life expectancy of flow meters. The major factor is matching the right instrument to the particular application. Poorly selected devices invariably will cause issues at an early stage. Flow meters with no moving parts usually will require less maintenance than units with moving parts. Nonetheless, all flow meters eventually require a certain degree of maintenance.

5. Support

Last but not least, remember...

Use the same supplier for all your flow metering equipment

A flow meter works often only as good as the equipment that sits alongside it. For instance, a flow computer or other form of display is needed to process data from the meter and show flow rates.

The best way to ensure a completely matched system where all components are compatible is to specify everything from a single reputable supplier. This will guarantee that all equipment has been manufactured to the same standards, and will also ensure that back-up is available from the same supplier for your whole flow metering system.

Recommended Reading

Further Information on Temperature

Click here for more information about the YTA710 Temperature Transmitter.

Click here to download the Temperature Handbook for free.

Further Information on Pressure

Click here for more information about the EJA530E In-Line Mount Gauge Pressure Transmitter.

Click here to download the Pressure Handbook: A Basic Guide to Understanding Pressure for free.

Meaningful definitions to know about measurementation

Accuracy

The ability of a flow measuring system to indicate values closely, approximating the true value of the quantity measured. The same term is uncertainty.

Repeatability

Value below which the absolute difference between two single successive test results obtained with the same flow meter on the same fluid under the same conditions, can be expected to lie with a probability of 95%.

Turndown

Flow range over which a flow measuring system operates while meeting a stated accuracy tolerance.

Calibration

An operation that, under specified conditions, in the first step establishes a relation between the quantity values with measurement uncertainties provided by measurement standards and corresponding indications with associated measurement uncertainties and, in the second step, uses this information to establish a relation for obtaining a measurement resulted from an indication.

Adjustment

A set of operations carried out on a measuring system so that it provides prescribed indications corresponding to given values of a quantity to be measured.

Thank you for reading this eBook!

For more information on Yokogawa's flow meters, please contact us for further advice.

Flow Handbook
Industrial Flow Measurement Handbook

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About Yokogawa

Yokogawa's global network of 92 companies spans 59 countries. Founded in 1915, the US $3.7 billion company engages in cutting-edge research and innovation. Yokogawa is active in the industrial automation and control (IA), test and measurement, aviation, and other business segments.

For more information about Yokogawa, please visit our website **www.yokogawa.com/nl**.

YOKOGAWA

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