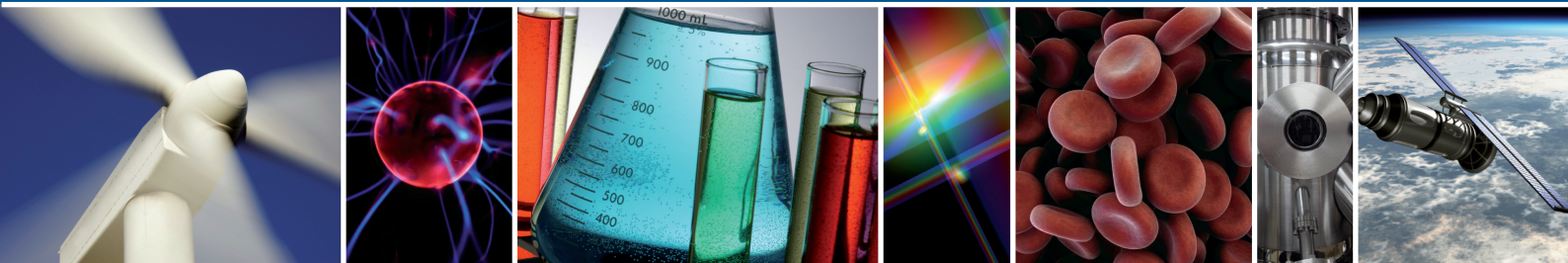


National Measurement System



GOOD PRACTICE GUIDE

AN INTRODUCTION TO FLOW METER INSTALLATION EFFECTS



The aim of this Good Practice Guide is to introduce the subject of installation effects. Every flow meter is subject to some kind of installation effect. A flow meter only stands a chance of living up to the manufacturer's accuracy and uncertainty claims if it is installed correctly. Installation effects can be large or small but can be dramatically reduced if you give them a little consideration.

Contents

Foreword	2
1. What is an installation effect?	3
2. Fluid properties	3
3. How density and viscosity interact with flow	3
4. Flow regimes	4
5. Velocity profiles	4
6. Flow development	5
7. More distortions	6
8. Effects on specific flow meters	7
8.1 Differential pressure meters	7
8.2 Electromagnetic flow meters	8
8.3 Ultrasonic meters	8
8.4 Turbine flow meters	8
8.5 Vortex meters	9
8.6 Variable area meters	9
8.7 Positive displacement meters	9
8.8 Coriolis meters	9
8.9 Thermal mass meters	10
9. What can be done about installation effects?	10
10. Is there an alternative	10
11. Round up	11
12. Further reading	11

Foreword

This is an introductory guide for people who know little or nothing about flow meter installation effects, but who need to learn about them. You, yourself may already be all too aware of the importance of installation effects and armed with this document are going to educate others. It is for anyone involved in flow measurement from engineers, to managers, to sales people, to customers.

A lot of time and money can go into the purchase of a flow meter, yet all too often little consideration is given to its installation. This can lead to the meter over or under reading leading to errors which could easily have been avoided. In some instances, flow meters have been installed so badly that you would have been as well just using a straight bit of pipe and guessing what the flowrate is. To put this into context, imagine you are selling £60 million worth of product a year. A 1% error in your custody transfer meter equates to £600,000, a 5% error will cost you £3 million! That is lost revenue which could have been avoided and is better off in your pocket than someone else's.

This introductory guide is by no means the final word on installation effects. far from it in fact. This is merely a starting point to get the reader to start thinking about the importance of installation effects and how this may impact the type of meter chosen. It does not contain all the answers to installation effects and the problems they can cause but does point you in the right direction to where they can be found.

The opening sections of this introductory guide cover fluid properties and how they interact in flow. This is because in order to understand installation effects you need to know a little bit about flow. Then we move on to velocity profiles, how they develop, and what effects bends and valves have on them. Next, we look at how specific types of meters and how they are affected by installation, finishing off with some possible solutions and some sources of further reading to help you on your way.

1. What is an installation effect?

You may have heard the term installation effects with regards to flow measurement but you aren't sure exactly what this means or why they could be important to you or when you should take them into consideration. This Good Practice Guide (GPG) will remedy that and help you understand what it means and why it is vital that you care.

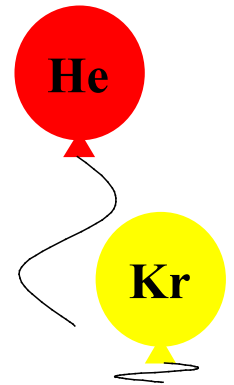
However, before trying to understand what an installation effect actually is, it is important to understand a little about fluid properties and flow.

2. Fluid properties

The concepts of mass and volume are fairly familiar and encountered in every day life when buying a pint of beer, filling a car with petrol, or buying a kilogram of apples. Some less well known fluid properties are density and viscosity which are important in the understanding of installation effects.

Density is the mass of a substance divided by a unit of volume such as litres, gallons, cubic meters, and so on. Helium gas is less dense than air hence why when you buy a balloon filled with helium you need to hold on tight or it will float away. Conversely, krypton is denser than air so if your balloon is filled with krypton it would sink to the ground.

Viscosity is a measure of a fluid's ability to resist external forces which are trying to change its form. A simple way to think of viscosity is as "thickness". Comparing treacle with water, we would say that treacle is more viscous than water as it is much thicker than water. Temperature affects viscosity; heating up treacle will make it thinner or in other words, decrease the viscosity. However, the same does not apply when it comes to gasses. Increasing the temperature of a gas will actually increase its viscosity.



$$\rho = \frac{m}{v}$$

LIQUID	GAS
Temperature ↑	Temperature ↑
Viscosity ↓	Viscosity ↑

3. How density and viscosity interact in flow



Density relates to the mass of a fluid which in turn relates to momentum¹ and is what keeps the fluid travelling along the pipe. Viscosity on the other hand relates to internal friction which will slow and possibly even stop the fluid from travelling.

The interaction between density and viscosity of fluids was studied in the 19th Century by Osborne Reynolds, a prominent scientist in the understanding of fluid mechanics. He also studied the heat transfer between solids and fluids but that is not relevant to this particular topic.

Reynolds described the relationship between the momentum and retarding forces within a fluid and this led to the Reynolds number which is the momentum of the fluid divided by the viscosity of the fluid. The Reynolds number, Re, has no units and is therefore known as a dimensionless number.

¹ Momentum is the mass of an object multiplied by the velocity at which the object is travelling.

3. How density and viscosity interact in flow (cont.)

WARNING! Although Re is dimensionless you need to use consistent units when calculating it. Using SI² units throughout helps to keep things simple.

Now that we know about the Reynolds number how does it help our understanding of fluid flows?

$$Re = \frac{UD\rho}{\mu} \quad \text{or} \quad Re = \frac{UD}{\nu}$$

U = velocity D = pipe diameter
 μ = absolute viscosity = kinematic
 viscosity
 ρ = density

4. Flow regimes

Flow will propagate itself in one of two ways and these types of propagation are referred to as flow regimes. The Reynolds number can be used to classify the flow regime.

If the Reynolds number is less than 2000 then the viscous forces are dominant and this means the flow is laminar. Laminar flow can be thought of as the fluid moving along in thin layers with no mixing between the layers. It is sometimes referred to as Poiseuille flow in text books.



If the Reynolds number is greater than 5000 then the inertial forces dominate and this means flow is turbulent. With turbulent flow the bulk motion is parallel to the pipe's axis but with mixing between the layers. This is why turbulent flow is good for heat transfer.

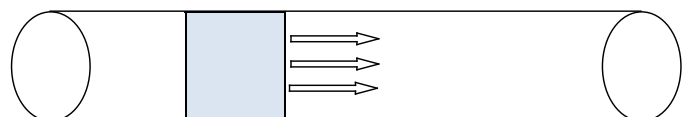


You may be wondering what happens if your Reynolds number lies between 2,000 and 5,000. This region is known as transitional flow where your flow switches back and forth between the laminar and turbulent flow regimes. Transitional flow is less predictable and because of this it is more difficult to meter.

Re < 2,000 Laminar
Re > 5,000 Turbulent

5. Velocity profiles

A velocity profile describes how fast a fluid is flowing at different points across the pipe. If there was no friction at all the fluid would all move at the same velocity like a solid plug. However, the pipe wall creates friction and a thin layer of fluid next to the pipe wall does not move.



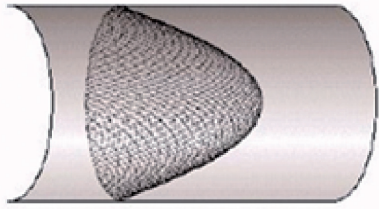
The further away from the pipe wall the fluid is, the less friction there is and so the fluid moves at increasingly higher velocities. This means that the highest velocity occurs at the centre of the pipe i.e. at the furthest point from the pipe walls.

How the velocity profile changes across the pipe depends on the nature of the flow regime; laminar or turbulent.



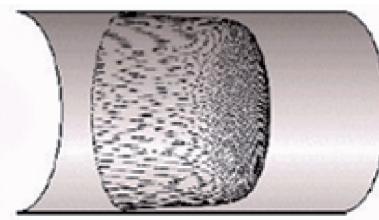
5. Velocity profiles (cont.)

As previously discussed, laminar flow occurs when the viscous forces (or “internal friction”) dominate so the velocity of the fluid changes gradually from the pipe wall to the centre line. If you were to plot the velocity profile of a fully developed laminar flow you would see that it is parabolic in shape.



The maximum velocity in the centre of the pipe is twice the average.

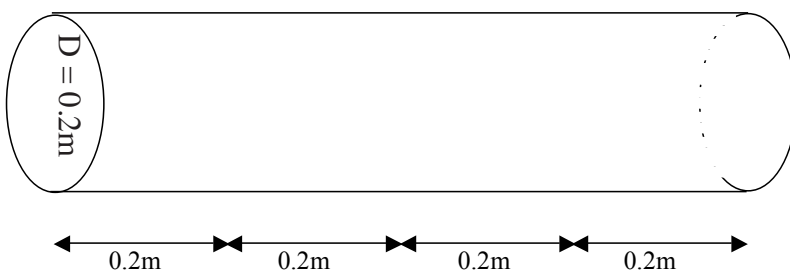
However, with turbulent flow the inertial forces are dominant so the velocity profile is flatter in the middle and varies steeply near the pipe wall.



The maximum velocity in the centre of the pipe is between 1.1 and 1.3 times the average velocity.

6. Flow development

A velocity profile takes time to develop but when it does stabilise it is considered to be fully developed which is also commonly referred to as an “ideal” profile. An ideal profile develops within a length of pipe which, theoretically, is of infinite length. In reality though, an engineer or designer is looking for the length of pipe which will allow the flow to develop a profile that is very close to ideal. As this length is related to the diameter it is usually expressed as pipe diameter equivalents rather than distance.

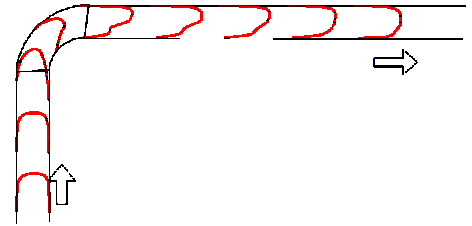


For example, we would say this pipe is 4 diameters long i.e. $4 \times 0.2\text{m} = 0.8\text{m}$

Pipeline components such as partially closed valves, reducers and bends, distort the velocity profile. Let’s take an example of a fluid travelling around a bend. The fluid on the outside of the bend has to move more quickly and this gives a skewed or asymmetric profile.

6. Flow development (cont.)

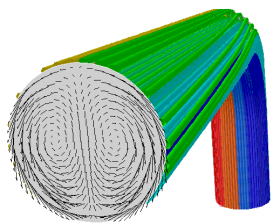
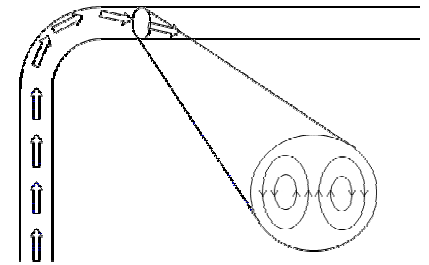
Most flow meters have been developed to work best under “ideal” conditions. International Standards Organisation (ISO) or the meter manufacturer will advise on the best installation and usually specify a length of straight pipe upstream of the meter and another length of straight pipe downstream. The specific ISO standards relating to installation can be found in the reference section at the end of this guide.



One of the biggest problems with industrial metering systems is a failure at design stage to appreciate the importance of providing the meter with as near to an ideal flow as possible.

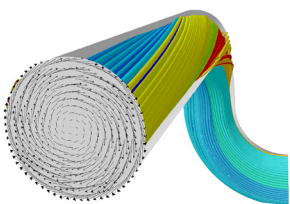
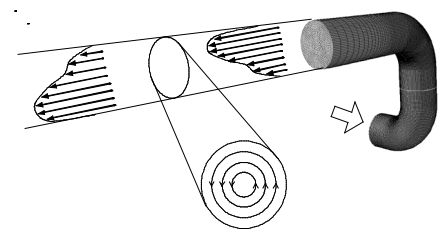
7. More distortions

As well as creating an asymmetric velocity profile, flow around a bend can create a secondary flow. The flow coming round the bend is forced against the pipe wall on the outside of the bend and rebounds towards the opposite side of the pipe forming vortices. These departures from an ideal profile can interact with the flow meter giving significant measurement errors.



One bend is bad, two bends are worse!

Two bends in different planes cause a distorted profile and a single vortex also known as swirl. Swirl can take well over 100 pipe diameters to decay; in fact there have been cases where swirl has persisted for over 500 hundred pipe diameters before the profile returns to acceptably close to ideal. Swirl tends to affect meters more than asymmetry causing your meter to potentially over or under read significantly. Viscosity of the fluid often has a bearing on the rate of decay of swirl. Thin fluids, or very low viscosity, tend to propagate swirl for very long distances.



Distorted profiles and swirl can lead to meters under or over reading. The effects can be large or small and vary from meter type to meter type. They are known as installation effects as they are dependant on the layout of the pipe system into which the meter is installed.

Flow meters are designed for use in “ideal” conditions but in reality they need to cope with valves and bends distorting the flow, electromagnetic noise, acoustic noise, particles and bubbles, to name but a few and all of them are potential sources of error.



8. Effects on specific flow meters

There are many different types of flow meter and installation effects will influence them in different ways. For example some can have large errors caused by swirl whereas some will be relatively unaffected by it.

Standards and manufacturers quote the minimum length of straight pipe required.

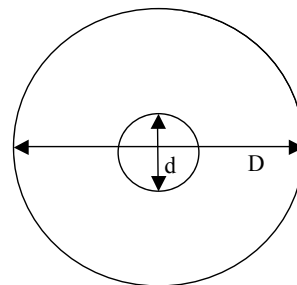
8.1 Differential pressure meters

By differential pressure meters we are talking about Venturi tubes, orifice plates, critical flow nozzles and cone meters which all work on the same principle in that the flowrate is measured using the pressure drop caused by a constriction in the flowing fluid in a pipeline, a concept first introduced by Bernoulli in the 18th century.

A distorted velocity profile can lead to Venturis, orifice plates, nozzles and cones to over read. With orifice plates, generally speaking, the lower the β the lower the error will be.

Swirl on the other hand will cause Venturis, nozzles, cones³ and orifice plates with high β to over read and low β orifice plates to under read.

Corrosion, erosion and dirt can also lead to errors in differential pressure meters as they can cause the orifice or throat diameter to increase or decrease. Droplets, such as the ones found in wet gas can cause errors but years of research and experimentation has been carried out on this topic and so correction factors are available. In fact, many multiphase and wet gas meters actually incorporate a differential pressure meter, usually a Venturi tube, into their design although cone meters are becoming more common.

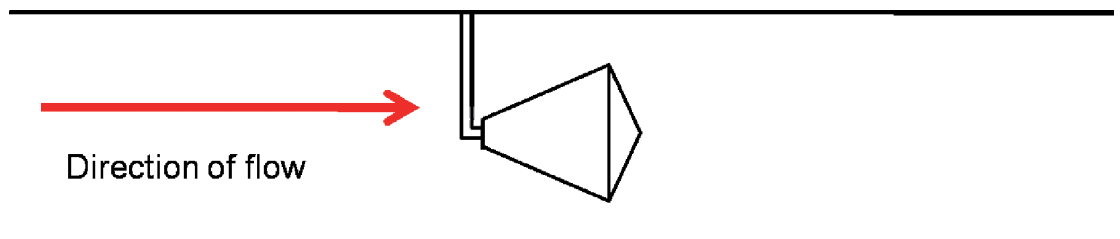


Orifice Plate

β is the ratio between the diameter of the restriction (or hole) and the pipe diameter.

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

Cone Meter

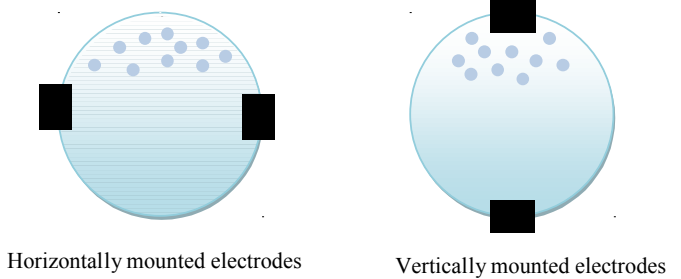


Putting an orifice plate in backwards, which is a more common occurrence than you may think, can cause over reading of up to 20%. Illustrating just how vital correct installation is.

8.2 Electromagnetic flow meters

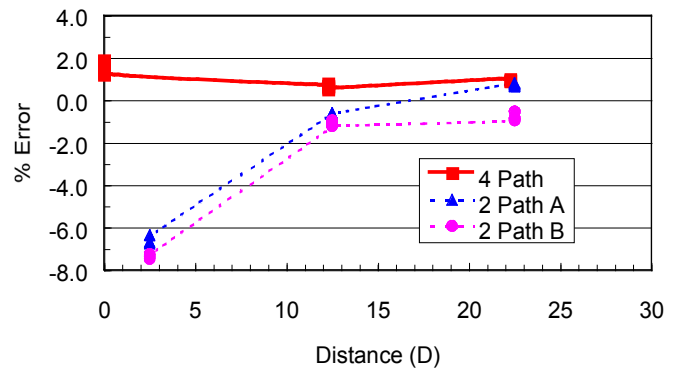
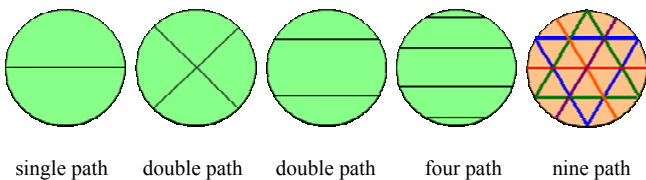
This type of meter generally requires over 10 diameters of straight pipe upstream for its installation and there can be problems with large bore meters. On the plus side, electromagnetic meters are not as affected by swirl as much as other types of meters are.

However, that is not to say that they aren't affected by swirl at all. Particles or bubbles present in a fluid can affect an electromagnetic flow meter as they tend to either rise to the top of the pipe or fall to the bottom. One way to reduce the effect would be to install the electrodes horizontally on the pipe wall.

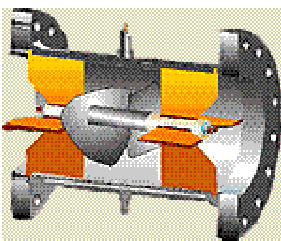


8.3 Ultrasonic meters

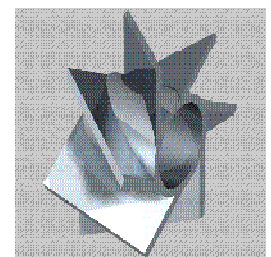
The effect a flow disturbance, such as swirl, has on an ultrasonic flow meter is dependent on the path design. As a general rule, the more paths the less of error there will be as you get a better average of the velocity profile. However, the more paths you have the more you will need to pay for your meter. A 4-path meter will be less affected than a meter with 2-paths and an 8-path meter will be less affected than a 4-path meter. When you get up to a 16 path ultrasonic meter you would then need to jump up to say 32-paths to get further useful information and so on. The graph below shows the errors in 3 different ultrasonic meters installed downstream of a bend.



8.4 Turbine flow meters



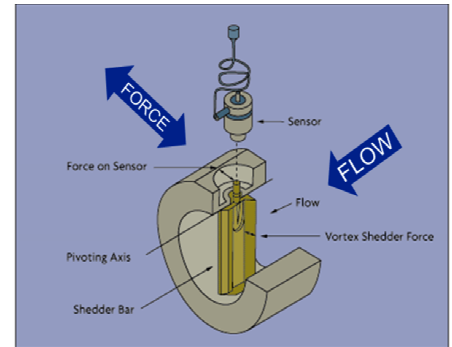
The degree to which a turbine meter is affected by asymmetry and swirl is very much dependent on the design of the turbine blades. If you have swirl turning in the same direction as the turbine blade then it will propel the turbine round faster giving the impression of a faster fluid flowrate. On the other hand if the swirl is rotating in the opposite direction from the turbine it can slow the blades down or in an extreme scenario cause the blades to go in the other direction giving a reduced or negative flowrate. In some cases swirl generated downstream of the meter can actually have an effect on the turbine. So once again watch out for those double bends.





8.5 Vortex meters

Vortex meters work by deliberately introducing a disturbance into the flow. This means that other disturbances in the flow can lead to errors in the region of $\pm 3\%$. Due to this, in some cases, up to 70 diameters of straight pipe could be required which is a significant amount of straight pipe. Vortex meters can also lock on to vibrations and pulsation frequencies such as those generated when a valve is being opened or closed so that is another factor to take into consideration.



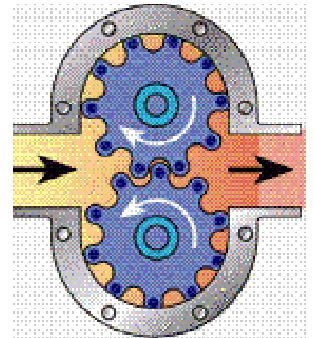
8.6 Variable area meters

Variable Area Meters (VAMs) work on the same principle as differential pressure meters but instead of having a fixed area and recording the change in pressure, VAMs have a constant pressure and the area changes which is related to the flowrate. Like differential pressure meters they too are affected by flow disturbances and other things such as particles which can erode the float. They are relatively low accuracy devices even when installed correctly, ± 2 or $\pm 3\%$ at best.

8.7 Positive displacement meters

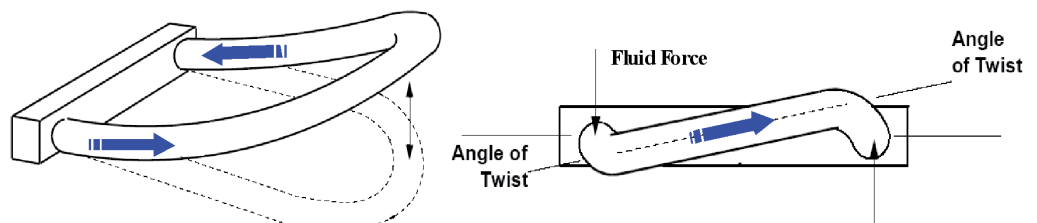
Positive displacement meters are one of the few types of meter that are not particularly affected by asymmetry and swirl.

However, they can be affected by a change in viscosity. If your fluid decreases in viscosity and becomes "thinner" then it is possible that some of the fluid may slip between the gears rather than propelling them round leading to your meter under reading. Also, as positive displacement meters have moving parts in contact with the fluid any particles or droplets present can wear away the gears. Even if there are no particles in the fluid general wear and tear can occur over a period of time so regular maintenance and inspection is recommended.



8.8 Coriolis meters

With a Coriolis meter the fluid is directed through a vibrating flow tube, Coriolis forces exerted by the moving fluid cause the tube to twist. The amplitude of the twist is related directly to the mass flow rate.



Coriolis meters are not very sensitive to swirl and asymmetry but are affected by incorrect installation. When putting a Coriolis meter into your piping system you need to ensure that the vibrating tubes are aligned and not under stress so that they twist and contort otherwise you will get errors.

8.9 Thermal mass meters

There are a number of different kinds of thermal mass meters but they all work on the principle in that the rate of heat absorbed by a flowing fluid is directly proportional to its mass flowrate.

Since there is such a large variation in the designs no hard and fast rules about this type of meter can be given in this good practice guide. However, good places to find information are the ISO standard or the manufacturer's manual specific for your particular meter.

9. What can be done about installation effects?

All is not lost as there are ways to reduce installation effects.

Ideally the meter would be moved to a more suitable location with the required amount of straight pipe upstream and downstream. Alternatively, the type of flow meter currently being used could be changed or a different design of the same kind of meter could be used i.e. still using an ultrasonic meter but choosing one with more paths. Perhaps even a combination of both would be most suitable.

10. Is there an alternative?

There is another solution and that is to use either a flow conditioner or a flow straightener. Flow conditioners are, generally speaking plates with holes in them and come in various designs.

They can remove swirl and asymmetry from the flow. Flow straighteners on the other hand are usually tube bundles and are capable of removing swirl but not asymmetry.

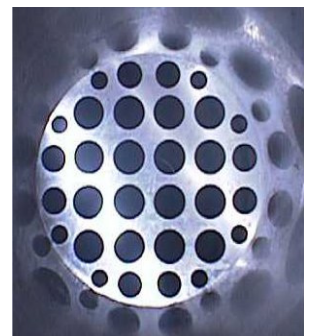
Whilst flow conditioners and straighteners will reduce the amount of straight pipe needed they won't eliminate the use of straight pipe altogether.

It may seem like flow conditioners and straighteners are the answer to reducing the effect of flow disturbances but it's not that simple. Yes a straightener will reduce the amount of straight pipe needed by removing swirl but in turn it will increase the pressure losses. A flow conditioner will give even greater pressure losses but will remove both swirl and asymmetry.

Pressure losses are something you want to avoid where possible. This is because it takes a certain amount of energy to move your fluid from A to B and pressure losses remove some of that energy meaning you need to compensate by adding more energy which ultimately costs you money.

These are things that must be considered to see if the trade-off is worth it.

Incorrect installation of a conditioner may actually make things worse so take care!



11. Round up

So what can you take away from this introductory guide to installation effects? Well, hopefully by reading this, you will now be aware that flow meter error can be increased by valves and bends disturbing the flow as well as by electromagnetic noise, acoustic noise and pulsations, and particles, droplets and bubbles.

Different meters respond in different ways so the type and design of meter you choose is important. Next time you have to buy a meter think outside the flanges and consider where it's going to go and what kind of things it will need to cope with.

Take a look at where it's installed. Is it after a bend, or worse still a double bend? Can it be moved? Should it be replaced with a different design or different type of meter completely? Is a combination of both the best solution?

Even with all the experimentation and research carried out in connection with installation effects they are still not well understood. This means that standards get updated and manufacturers can change installation recommendations. Never design to the minimum, if 20 meters of straight pipe are required ask for 50 and hopefully you will be met in the middle.

Remember, installation effects: Your meter, Your production, Your profits

12. Further reading

The ISO standards for meter installations are a good starting point:

- Coriolis – ISO 10790
- Critical nozzles – ISO 9300
- Differential pressure⁴ – ISO 5167
- Electromagnetic – ISO 6817
- Positive displacement – ISO 2714
- Thermal mass – ISO 14511
- Turbine – ISO 2715
- Ultrasonic – ISO 6416
- Variable area – ISO 11605
- Vortex – ISO/TR 12764

Alternatively you could attend one of our training courses to learn more about installation effects and other flow-related topics.

⁴ Cone meters are not covered by ISO 5167 or any standard for that matter at this time.

For further information, contact:

TUV NEL, East Kilbride, GLASGOW, G75 0QF, UK

Tel: + 44 (0) 1355 220222 Email: info@tuvnel.com www.tuvnel.com



National Measurement System



The National Measurement System delivers world-class measurement for science and technology through these organisations

