Contamination, corrosion and disconnect

– SOME OF THE MEASUREMENT ENGINEERS ENEMIES

Measuring the temperature of flowing liquids in a pipe system is not usually considered a particularly complex problem – rather, the reverse. However, if the liquid is highly contaminated, things can become tricky for the measurement engineer. If corrosion and/or disconnect in the measurement installation is also suspected, things can become really problematic. Temperature measurement in contaminated liquids requires a suitable sensor. This must then be positioned at a suitable location in the pipe system.

Unfortunately, in most cases there is no "best measurement installation" which would apply under all conditions. On the other hand, there will almost always be an optimal installation that satisfies certain requirements.

FOR THE PURPOSES OF DISCUSSING TEMPERATURE MEASUREMENT of contaminated liquids, we will consider a specific measurement problem. The temperature is to be measured near an S-bend in a pipe system as shown in Figure 1 below.

The pipe, which is made of stainless steel, has an outer diameter of 70 mm and a wall thickness of 3 mm. Water is flowing through the pipe, and the water may be clean or heavily contaminated. The water temperature is around 60°C, but it can quickly change to around 75°C before just as quickly returning to 60°C. The pressure in the pipe is 0.8 MPa and the flow rate is around 50 m^3/hour, resulting in a mean velocity of 4.3 m/s. The pipe system is sited in industrial premises having an air temperature of 15°C, and these premises can be very humid.

The contamination in the liquid will affect both the flow and the heat transfer in the pipe. Regardless of whether the sensor intended to measure the liquid's temperature is sited inside or outside the pipe, the contamination inside the pipe will affect the measurement result. We must also allow for the possible effect of corrosion on the measurement installation and that disconnect can occur on some sensor installations.

In industrial applications, the flow in the pipe is almost always turbulent and this can be determined using the dimensionless Reynolds number, Re.

$$Re = (w\,D)/\nu$$

where w is the fluid's mean velocity in m/s, D the pipe's inner diameter in m and ν the kinematic viscosity of the fluid in m^2/s. The kinematic viscosity of a given fluid depends inter alia on its temperature, T, in °C. For clean water, the following applies: $\nu = \nu(T) = \nu(60°C) = 0.477\ 10^{-6}\ m^2/s$. The Reynolds number will be Re = 580 000.

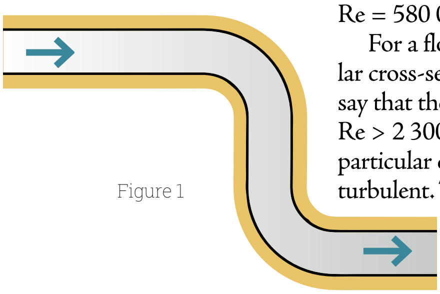


Figure 1

For a flow in a pipe of circular cross-section, generally we say that the flow is turbulent if Re > 2 300. The flow in this particular case is without doubt turbulent. The flow in the pipe is assumed to be fully developed. For a fully developed turbulent flow, the velocity profile is comparatively smooth, as can be seen in *Figure 2*. The mean velocity is then 82% of the maximum velocity.

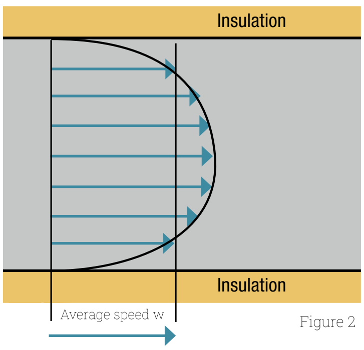


Figure 2

The straight entrance length required before the flow becomes fully developed is comparatively long. For a turbulent flow, the entrance length can in certain cases be as much as 50 pipe diameters. In many industrial applications, such long straight lengths are rare.

The straight lengths which, according to the literature, are required to obtain a fully developed turbulent flow are based on experiments. In most experiments, it is assumed that the straight pipe is connected to a large vessel containing a stationary fluid. In many industrial contexts, the entrance length may be estimated at 25 to 40 pipe diameters. Such a large variation is due to the fact that there are many parameters that will affect the extent of entrance length. If we assume that the entrance length is 40 pipe diameters, the entrance length in this case will be 2.6 m.

In most industrial applications, therefore, we cannot assume that the flow is fully developed. We have to accept this uncertainty about the exact appearance of the velocity profile. When calculating heat transfer and flow resistance for a sensor, we must be aware of this uncertainty about the velocity profile in the pipe. I will now discuss the use of insert probes and surface-mounted sensors upstream and downstream, respectively, of the pipe bend. I will also discuss an insert probe which is installed in the pipe bend itself.

Installation of an insert probe upstream of the pipe bend

We will begin by considering a sheathed thermocouple positioned in a protective tube upstream of the pipe bend, as shown in *Figure 3*. Let us assume initially that the liquid is clean water.

In the pipe there is a radial heat flow emanating from the liquid at a temperature of 60°C, passing through the pipe wall and insulation to the pipe's environment at a temperature of 15°C. This means there is a difference between the temperature of the liquid

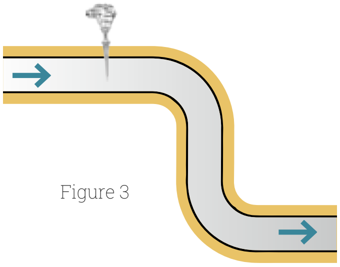


Figure 3

and that of the pipe wall. This in turn means that we have a heat flow along the protective tube and the sheathed thermocouple to the pipe wall. The measurement location in the thermocouple therefore measures a temperature which is somewhat lower than the temperature of the liquid.

If the pipe is well insulated, the heat flow from the liquid to the environment will be very small, and the temperature difference between the liquid and the pipe wall will also be very small. This means that the heat flow along the thermocouple to the mounting in the pipe wall is very small. The temperature that the sensor measures is therefore slightly below the temperature of the liquid.

In some types of installation, the pipe is allowed to be uninsulated. This may be due to, for example, an authority requirement. In such cases, the heat flow from the fluid to the environment increases, as does the heat flow along the protective tube and thermocouple to the wall. The measurement error increases. The exact degree of measurement error will depend inter alia on the protective tube's or the sheathed thermocouple's diameter and insert length, the thermal conductivity in the protective tube and thermocouple, the heat transfer coefficient between the liquid and the protective tube, and the temperature difference between the liquid and the pipe wall. The latter temperature difference is determined inter alia by the heat transfer coefficient between the liquid and pipe wall and the dimensions and thermal characteristics of the pipe and insulation.

We can estimate the measurement error as a consequence of the axial heat flow in the protective tube and sheathed thermocouple to the pipe wall. See:

www.pentronic.se/en/ > Menu > Archive Technical Publications > Properties and sources of error by thermocouples > Measurement error due to thermal conduction in a sheathed thermocouple

We will now consider the case where the fluid is highly contaminated and where both the sensor and the inside of the pipe have built up a thick coating, whose thermal conductivity is lower than that of the pipe wall, protective tube and thermocouple. See *Figure 4*.

If the thermocouple and pipe wall have built up a coating of contamination, this will affect both the heat transfer and the flow. In this context, the contamination can be seen as a form of insulation. This means that the temperature of the pipe wall drops and the heat flow along the protective tube and sheathed thermocouple is affected. The temperature difference between the liquid and the measurement location in the thermocouple increases, and so the measurement error increases as well. The thicker the coating, the greater the measurement error. The coating of contamination also means that the flow resistance in the pipe system increases.

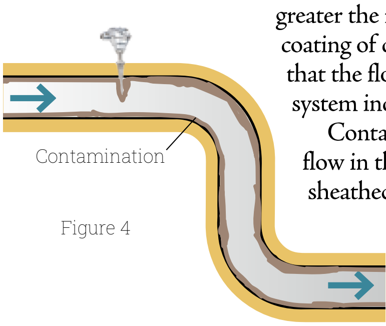


Figure 4

Contamination affects the heat flow in the protective tube and sheathed thermocouple to the pipe wall. For calculation of the measurement error:

www.pentronic.se/en/ > Menu > Archive Technical Publications > Properties and sources of error by thermocouples > Measurement error due to coating build-up

The heat transfer coefficient between the liquid and the protective tube is slightly reduced when the protective tube is contaminated. The coating of contamination can be seen here as insulation, which causes the heat flow from the fluid to the measurement location to be reduced compared to a situation where there is no such coating of contamination. In the event of a change in fluid temperature, the response time will therefore increase if the protective tube is contaminated. The thicker the coating, the longer the response time.

Installation of a surface-mounted sensor upstream of the pipe bend

We will now consider a surface-mounted sensor installed upstream of the pipe bend. See *Figure 5*. It is assumed that the pipe is insulated and that the sensor measures the external temperature of the pipe. An advantage of a surface-mounted sensor compared to an insert probe is that the former does not affect the flow in the pipe system. Let us now assume that the liquid is contaminated.

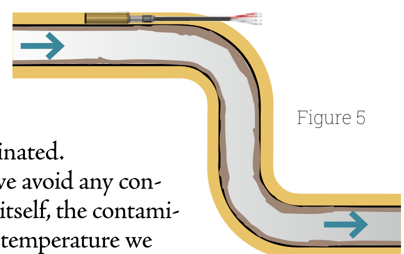


Figure 5

In this case, although we avoid any contamination of the sensor itself, the contamination will still affect the temperature we measure. The thicker the coating of contamination inside the pipe, the lower the heat flow to the environment. The coating of contamination may be seen as a form of insulation inside the pipe.

The temperature difference between the liquid and the pipe wall increases. The surface-mounted sensor measures the pipe's external temperature, which means that the measurement error increases. Even in this case, the temperature difference between the inside and outside of the pipe is very small.

If the pipe were uninsulated it would have a lower temperature than an insulated one, with the result that the measurement error would be greater. When a surface-mounted sensor is used, it is very important that the sensor makes good contact with the pipe. Contact paste should be used to ensure good contact.

Unfortunately, corrosion can sometimes occur between the sensor and the pipe, resulting in a temperature difference between the pipe and sensor. There will be an increase in measurement error. Often, corrosion builds up slowly, making it difficult to detect. A regular check is therefore needed on the measurement installation to make sure the surface-mounted sensor is making good contact with the pipe. If the pipe is insulated, the inspection will be more complicated, but it must still be carried out. After the inspection, the insulation must be reinstated, though it is unfortunately easy to overlook this when working under stress. This will lead to an unnecessary increase in the measurement error.

Normally there should be no disconnect between the sensor and the pipe. If disconnect were to occur, this would dramatically increase the measurement error. On the other hand, if the measurement error becomes very significant, it does tend to make discovering a fault in the measurement installation easy. The response time is affected by the heat flow to the pipe and the pipe's thermal characteristics. The coating of contamination acts as a form of insulation, which reduces the heat flow to the pipe and lengthens the response time. The thicker the coating of contamination, the longer the response time.

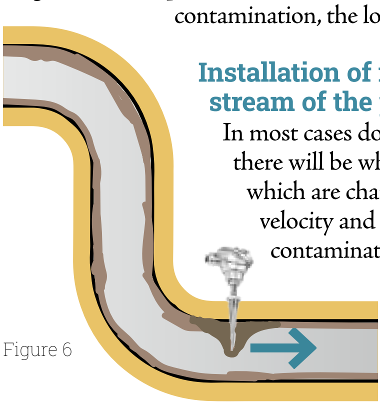


Figure 6

Installation of insert probe downstream of the pipe bend

In most cases downstream of the pipe bend, there will be what are termed "wakes", which are characterised by low flow velocity and backflow. In the case of contaminated fluids, there will also be a build-up of contamination in the wakes. If a sensor is installed in the wakes, problems can occur. See *Figure 6*.

The low velocity restricts the heat flow to the wall in the wake area, and the temperature difference between the fluid and the wall increases. In this case, when determining the pipe's temperature in order to calculate the degree of measurement error, we need to consider the axial heat flow along the pipe as well as the radial heat flow within the pipe. Low velocity around the protective tube will also reduce the convective heat flow to the protective tube and sheathed thermocouple. The contamination will therefore result in an increase in the measurement error.

If the temperature of the main flow changes, the low velocity in the wakes means that the temperature of the liquid in that area will adjust comparatively slowly to that of the main flow. The heat transfer coefficient between the liquid in the wakes and the protective tube will also drop as a result of the low flow velocity. So, there will be a reduction in the heat flow to the measurement location. Overall, this means that the response time will increase.

An installation involving an insert probe in the wakes both increases the measurement error and extends the response time compared to an installation outside this area. Furthermore, the contamination has a negative effect both on the measured value and on the response time, compared to the situation involving a clean liquid. Where possible, a measurement installation in the wakes should be avoided.

Installation of surface-mounted sensor downstream of the pipe bend

If we install a surface-mounted sensor in the wakes downstream of the pipe bend, we generally encounter the same disadvantages as with an insert probe positioned in the wakes. The measurement error increases and the response time is lengthened. In this case too, the contamination has a negative effect both on the measured value and on the response time. Where possible, an installation of this kind should be avoided.

Installation of an insert probe in the pipe bend

In *Figure 7*, the sensor has been positioned in the pipe bend itself and the narrow tip of the sensor is parallel with the flow upstream of the bend. In this case, there will be rather less contamination coating on the measuring tip itself, resulting in a smaller degree of measurement error.

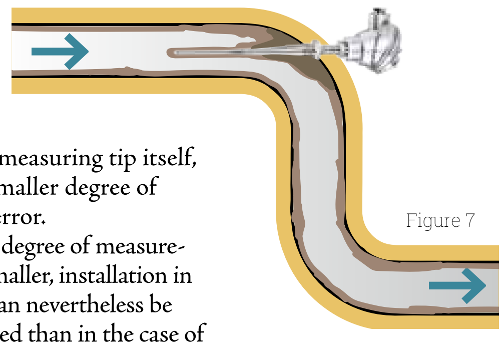


Figure 7

Though the degree of measurement error is smaller, installation in the pipe bend can nevertheless be more complicated than in the case of the previous installations. Significant coatings may also occur at the sensor's mounting, and this will also affect the flow in the pipe and increase the flow resistance.

A long insert and a narrow sensor reduce the heat flow to the pipe wall, which also reduces the loss in the protective tube. The sensor must be designed to withstand the anticipated forces from the flow, which imposes requirements on inter alia the sensor's diameter and length. From a measurement technology perspective, this solution is often the preferred one. However, in many cases an installation in the bend is difficult to execute and, like all insert probes, it will result in a greater drop in pressure. The increased drop in pressure will in turn require additional pumping power.

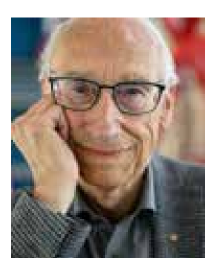
Sensor positioning – a summary

Where possible, avoid installing the sensors in the wakes downstream of the pipe bend. This applies in equal measure to insert probes and surface-mounted sensors. However, there may be cases where there is no other option but to install a sensor in this area. You would then have to be aware of the measurement errors and increased response times such an installation will entail.

Unfortunately, there is no overall answer to the question of whether you should opt for an insert probe or a surface-mounted sensor. Both types of sensor have their advantages and disadvantages. You should opt for the type of sensor that is most advantageous for the requirements in question.

Installation of a sensor in the pipe bend where the sensor is parallel with the pipe upstream of the bend has many advantages, but also quite a few disadvantages. A long insert and a narrow sensor tip reduce the effect of contamination and result in a small degree of measurement error and short response time. One disadvantage is that the installation is comparatively complex. Other disadvantages are that the flow resistance is increased and contamination may accumulate at the mounting in the wall.

As stated above, all measurement installations have advantages and disadvantages. Unfortunately, there is no such thing as a "best measurement installation" that applies universally to all types of requirement. On the other hand, we can almost always identify an optimal installation for the requirements in question. Examples of such requirements are minimum measurement error, shortest response time and minimum flow resistance.



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