Basic knowledge

Flow in pipes and valves and fittings

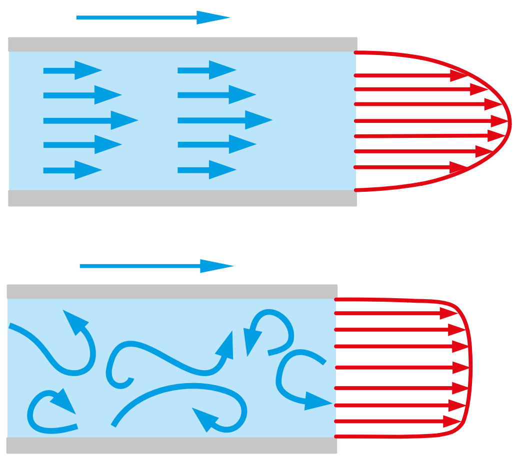
Pipe systems are generally used to transport fluids. When flowing through a pipe the friction causes the pressure energy of the fluid to fall and the internal energy of the fluid to increase. The decrease in internal energy is generally referred to as flow loss, which manifests itself as pressure loss in the fluid.

In case losses occur a distinction is made between the internal friction in the fluid and the friction between the fluid and the wall or resistance.

The following general concepts of fluid mechanics are discussed in connection with the losses:

- laminar and turbulent flow
- pipe friction due to different materials and surfaces
- pressure losses in pipes and pipe fittings
- pressure loss in valves and fittings

Laminar and turbulent flow in pipes



In the case of a laminar flow **A** in pipes, fluid particles move in parallel in layers without mixing with each other. The velocity distribution of the fluid in the pipe is non-uniform. The fluid is decelerated in the boundary zone due to the pipe friction and moves more slowly than in the centre of the pipe. The pressure loss is proportional to the mean fluid velocity. In practice, a fully developed laminar flow is rare.

In the case of turbulent flow **B** the individual fluid layers swirl and exchange energy. The resulting flow field is characterised by three-dimensional, unpredictable and transient movements of the fluid particles. In some cases a laminar boundary layer remains in the boundary zone of the pipe. The velocity distribution is nearly constant over a wide range of the pipe cross-section. In contrast to laminar flow, the pressure loss is proportional to the square of the mean fluid velocity.

In flow through pipes the Reynolds number **Re** can be calculated from the inner diameter of the pipe **d**, the mean fluid velocity **v** and the kinematic viscosity **ν**.

$$Re = \frac{v \cdot d}{\nu}$$

turbulent flow Re ≥ 2300

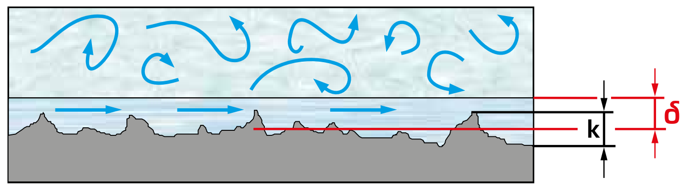
The distinction between laminar and turbulent flow can be determined using the Reynolds number Re. The Reynolds number is a dimensionless figure. A Reynolds number up to approximately 2300 refers to laminar flow. Above a Reynolds number of 2300 the flow is known as turbulent flow. Flows with the same Reynolds number are comparable in their behaviour.

Pipe friction on various materials and surfaces

In practice, the surfaces of pipe walls are always associated with a certain roughness. This surface roughness is created partly as a result of the production process and partly due to deposits or corrosion caused by operation. The pipe's material also has a decisive influence on the roughness.

In laminar flow the roughness of the pipe has a very small influence on the pressure loss, because the fluids in the region of the boundary layer have very low flow velocities or in some cases do not move at all.

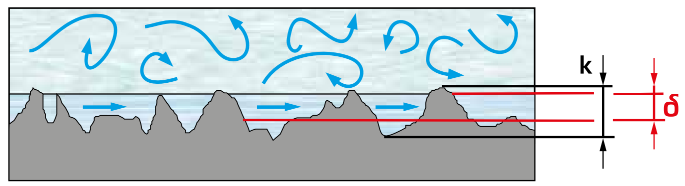
In turbulent flow, however, what is decisive is whether the thickness **δ** of the laminar boundary layer extends over the unevenness of the pipe surface **k** and conceals it. In this case they are referred to as **hydraulically smooth pipes** and the roughness does not affect the pressure loss. If the surface roughness of the pipe extends far beyond the laminar boundary layer, the sliding effect of the boundary layer is lost. In this case they are **hydraulically rough pipes** and the roughness has a considerable effect on the pressure loss.



δ thickness of the laminar boundary layer
k height of the unevenness

Hydraulically smooth pipes

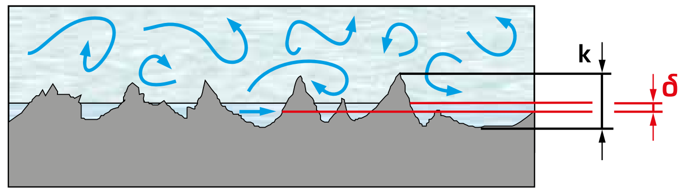
The laminar boundary layer is sufficiently pronounced to cover the unevenness in the pipe surface. The turbulent pipe flow can flow freely.



δ thickness of the laminar boundary layer
k height of the unevenness

Pipes in the transition region

In practice, hybrid forms occur depending on the flow condition and the nature of the pipe. If the laminar boundary layer is considerably pronounced but does not entirely cover the unevenness, this is referred to as pipes in the transition region.



δ thickness of the laminar boundary layer
k height of the unevenness

Hydraulically rough pipes

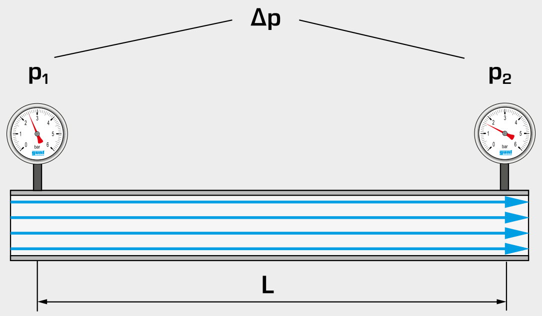
The laminar boundary layer is not sufficiently pronounced to cover the unevenness in the pipe surface.

Basic knowledge

Flow in pipes and valves and fittings

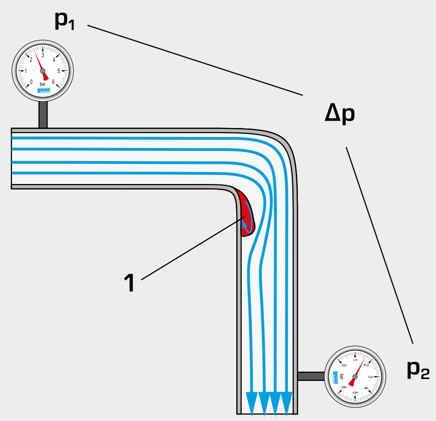
Pressure loss in pipes, pipe fittings and valves

Pressure loss in the straight pipe element



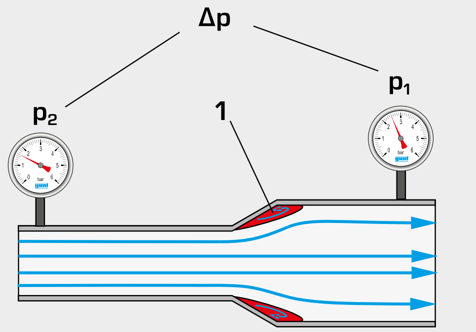
p pressure, **Δp** pressure difference, **L** pipe length

Pressure loss in the pipe bend



p pressure, **Δp** pressure difference, **1** secondary flow

Pressure loss in an enlargement



p pressure, **Δp** pressure difference, **1** flow separation

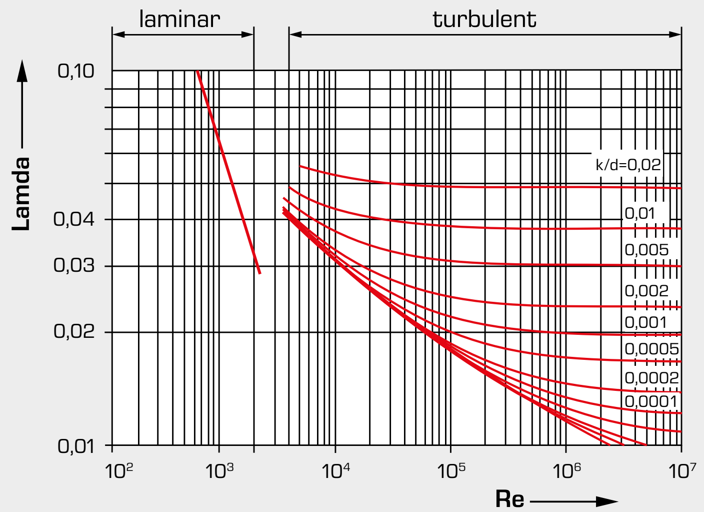
Pipe systems are composed of various pipe elements, each with specific properties. When determining pressure losses a distinction is made between pure friction losses in straight pipe elements and the additional losses in pipe fittings and other components such as valves. Unlike in straight pipe elements, further losses occur in pipe fittings due to flow separation or secondary flow, in addition to the friction losses caused by the surface roughness.

The pressure loss in a pipe fitting depends on the type of deflection and is referred to as resistance coefficient ζ. Resistance coefficients are determined by experiment via a pressure measurement of inlet p_1 to outlet p_2 of the pipe fitting and are given as guide values in tables. The resistance coefficient indicates that pressure difference there has to be between the inlet and outlet in order to maintain a certain flow rate through a pipe element.

Pressure difference in straight pipe elements

The pressure difference **Δp** from inlet to outlet of a straight pipe element results from the friction factor **λ**, the pipe length **L**, the density of the fluid **ϱ** and the square of the mean fluid velocity **v** divided by the pipe inner diameter d_i.

$$\Delta p = \frac{\lambda \cdot L \cdot \varrho \cdot v^2}{d_i \cdot 2}$$

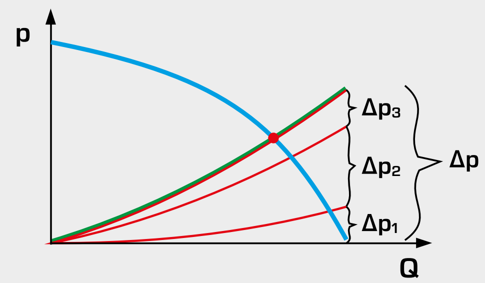


The pipe friction chart shows the dependence of the friction factor **λ** on the Reynolds number **Re** and the roughness **k**

Pressure differential in pipe fittings

The pressure differential **Δp** between inlet and outlet of a pipe fitting is determined by the resistance coefficient ζ, the density of the fluid **ϱ** and the square of the mean fluid velocity **v**.

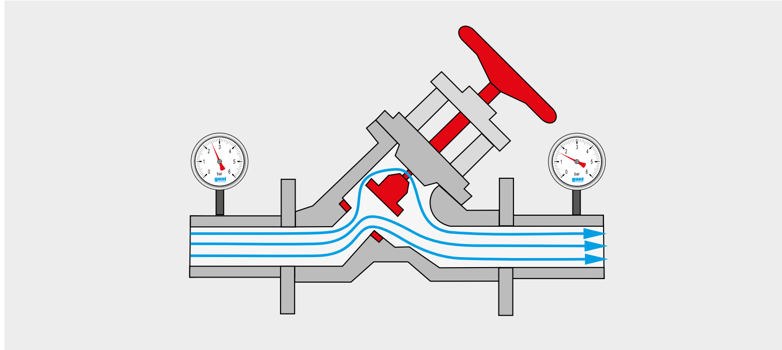
$$\Delta p = \zeta \cdot \frac{1}{2} \cdot \varrho \cdot v^2$$



individual resistances $\Delta p_{1\text{-}3}$ of a system,
total resistance **Δp** of the system,
pump characteristic;
Δp pressure differential, **p** pressure, **Q** flow

Adding all the pressure losses in the various pipe elements gives the system characteristic of the pipe system. The necessary pump head as a function of the flow rate results from the system characteristic.

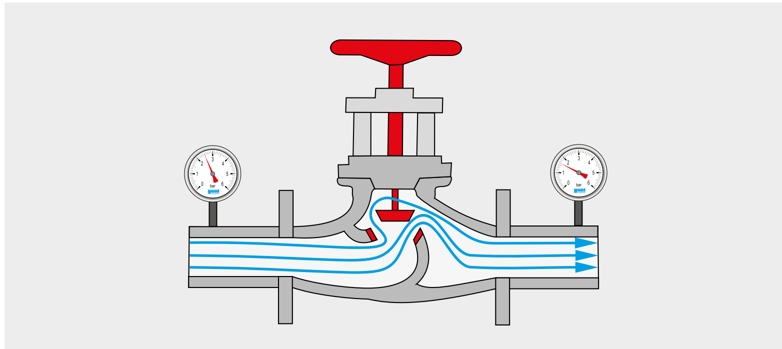
Pressure losses in shut-off valves and fittings



Shut-off valves and fittings are used as components for shutting off the flow in pipe systems. The main types of shut-off valves and fittings include valves, taps and gate valves. The closing mechanism is implemented in different ways depending on the design of the valve. When flow passes through the various valves, different pressure losses occur depending on the geometry and open condition of the valve.

Pressure losses occur even in the fully open state, as a result of the often sharp deflection of the flow within the valve. The pressure difference in this case can be expressed by the resistance coefficient ζ for the open state.

Pressure losses in control valves and fittings



The flow through a flow control valve can be adjusted thanks to the design of the valve. The flow rate at the respective open state is characterised by the valve characteristic.

When selecting valves, the flow coefficient K_{vs} at 100% open provided by the valve manufacturer is given. This flow coefficient is a measure of the maximum possible throughput of a fluid through a valve. For valve openings smaller than 100% the flow coefficient is called K_v. The flow coefficient K_v is between 0 and the K_{vs}.

The flow coefficient K_v for valves is determined for different opening states via the flow rate **Q** and the pressure difference **Δp** between inlet and outlet of the valve.

$$K_v = Q \cdot \sqrt{\frac{1\text{bar}}{\Delta p}}$$