

## 9 Pipe Friction Losses

### 1. Reynolds' Number

Reynolds' number  $R_e$  is a dimensionless flow value. In the case of a flow around geometrically similar bodies or through geometrically similar closed channels, similar flow patterns result from the same  $R_e$ . For a pipe with a circular cross-section, it is

$$R_e = \frac{v \cdot d}{\nu} \quad (24)$$

In this equation:  $v$  is the median speed of the flow  $v = Q/A$  in m/s,  $d$  the internal diameter of the pipe in m and  $\nu$  the cinematic viscosity in  $m^2/s$ .

### 2. Head loss in Pipes

Experience has showed that the conduction of a liquid through a pipe results in a head loss that can be calculated by the following equation in case of pipes with a circular cross section:

$$H_v = \lambda \cdot \frac{l}{d} \cdot \frac{v^2}{2 \cdot g} \quad (25)$$

In this equation  $\lambda$  is a non-dimensional characteristic of the pipe friction,  $l$  is the length of the pipe with constant diameter in m,  $d$  is the internal diameter of the pipe in m and  $v$  is the medium speed of the flow.

### 3. Flow Types in Pipes

a) Laminar flow: if a liquid flows through a pipe at a low speed, all liquid particles move in ordered tracks parallel to the pipe axis. In the concentric and cylindrical layers, the speeds are the same, which is why this type of flow is known as laminar flow (stratified flow).

The head losses occurring in this form of flow are determined only by the internal friction, that is to say the resistance that is created against a mutual shift of the neighbouring liquid layers. The pipes' roughness has no impact because it is embedded in the wall boundary layer.

In a laminar flow, the pipe friction loss increases linearly with the flow velocity, and it depends only on the viscosity of the liquid.

$$\lambda = \frac{64}{R_e} \quad (26)$$

Laminar flows are actually quite rare since they occur for certain only at Reynolds' numbers of  $R_e \leq 2320$ . In a more favourable flow and in the case of very even pipes, a laminar flow is also possible at  $R_e = 50000$  although not very likely. In the case of water transmission in a DN 100 pipe e.g., there will be a laminar flow only if the flow velocity drops down to  $v \leq 0.03$  m/s. In contrast to that, in the case of viscous fluids: laminar flow will occur even at normal flow velocities in narrower pipes. In the Fig. no. 19, a is a loss curve for the laminar flow.

b) Turbulent flow if the critical  $R_e$ -number  $R_e = 2320$  is exceeded, there is an interference between turbulent flow and stratified flow. This gives rise to velocity fluctuations and transverse movements. Liquid particles from the middle of the pipe migrate to the walls and vice versa.

As the illustration no. 19 shows, in the case of a turbulent pipe flow there is a differentiation between areas A and B. In the A area, the pipe friction loss depends both on the Reynolds' number and on the wall roughness  $k$ . The roughness is expressed by  $d/k$ ,  $d$  being the pipe diameter. The lower limit curve b applies to a hydraulically even wall, in which the unevenness disappears in the very thin laminar layer. However, there is no similarity with the laminar flow because the losses do not increase linearly but to the second power. Over the limit curve c, the pipe friction loss does not depend on the Reynolds' number but on the wall roughness.

### 4. Practical Calculation of the Pipe Friction Losses

a) Water transmission: In the case of a water transmission, the head losses can be seen in the diagram from EDUR work sheet "Pipe Friction Losses". A certain insecurity occurs when assessing the pipe roughness.

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In the diagram, a roughness of  $k = 0.1$  was assumed. When calculating the pipes which consist of seamless steel pipes, it is acceptable to take the unchanged diagram values. Although new steel pipes have a roughness of only  $k = \text{app. } 0.04$ , the roughness increases after a certain operating time, but the pump still shows a sufficient pump capacity. However, the question arises whether incrustation of pipes will also be considered when dimensioning the pump: If cold water is delivered in drinking water quality, even after several years, the increase in pipe friction losses will not exceed 4 %. In the case of poor water quality or in warm or hot water facilities, water treatment is essential since even a minor incrustation leads to considerably more losses. The head loss can increase fourfold, which equals a fourfold increase in energy costs in the case of installations with only dynamic pump head. This does not guarantee absolute security since pipes might gradually become completely blocked in case of certain water qualities.

Pipes made out of synthetic material and drawn copper pipes or stainless steel pipes are considered smooth. If the water quality is good, there will be almost no increase in roughness even after a long use. In these cases, values from the pipe friction diagram can be multiplied by 0.7.

b) Transmission of viscous fluids. The worksheet "Pipe Friction Losses" does not apply to viscous fluids. If these are present, the flow resistance coefficient  $\lambda$  can be calculated through the formula of Colebrook whose solution is not a problem when applying a programmable calculator:

$$\frac{1}{\sqrt{\lambda}} = -2 \cdot \lg \left( \frac{2,51}{Re \cdot \sqrt{\lambda}} + \frac{k}{3,71 \cdot d} \right) \quad (27)$$

$\lambda$  is naturally evident in the diagram, Fig. no. 19 that was obtained with the above mentioned equation.

In the case of the usual viscous fluids like diesel fuel, heating oil or cooling brine, no noticeable sedimentation is to be expected. Safety margins are therefore not necessary.

The following roughness values are to be expected:

Technically even pipes:	$k = 0.0014$
Seamless steel pipes:	$k = 0.04$
Zinc plated steel pipes:	$k = 0.1$
Cast pipes:	$k = 0.3$

After the flow resistance coefficient  $\lambda$  has been determined, the loss of head can be calculated with equation (25).

c) Head loss through individual resistances. The losses in armatures and shaped pieces are stated on the back of the worksheet "Pipe Friction Losses" in terms of equal pipe lengths. Thus a completely open slider in DN 50 has the same head loss as DN 50 pipe with the length of 0.7 m. These pipe lengths will be added to the extended pipe length when calculating the overall head loss of an installation.

The advantage of this method in comparison with the usual calculation with the resistance coefficients  $\zeta$  is that the calculation can also be made with viscous fluids whose resistance coefficients are not known.

Resistance Coefficient  $\lambda$  for Laminar and Turbulent Pipe Flow as Function of the Reynolds' Number  $Re$

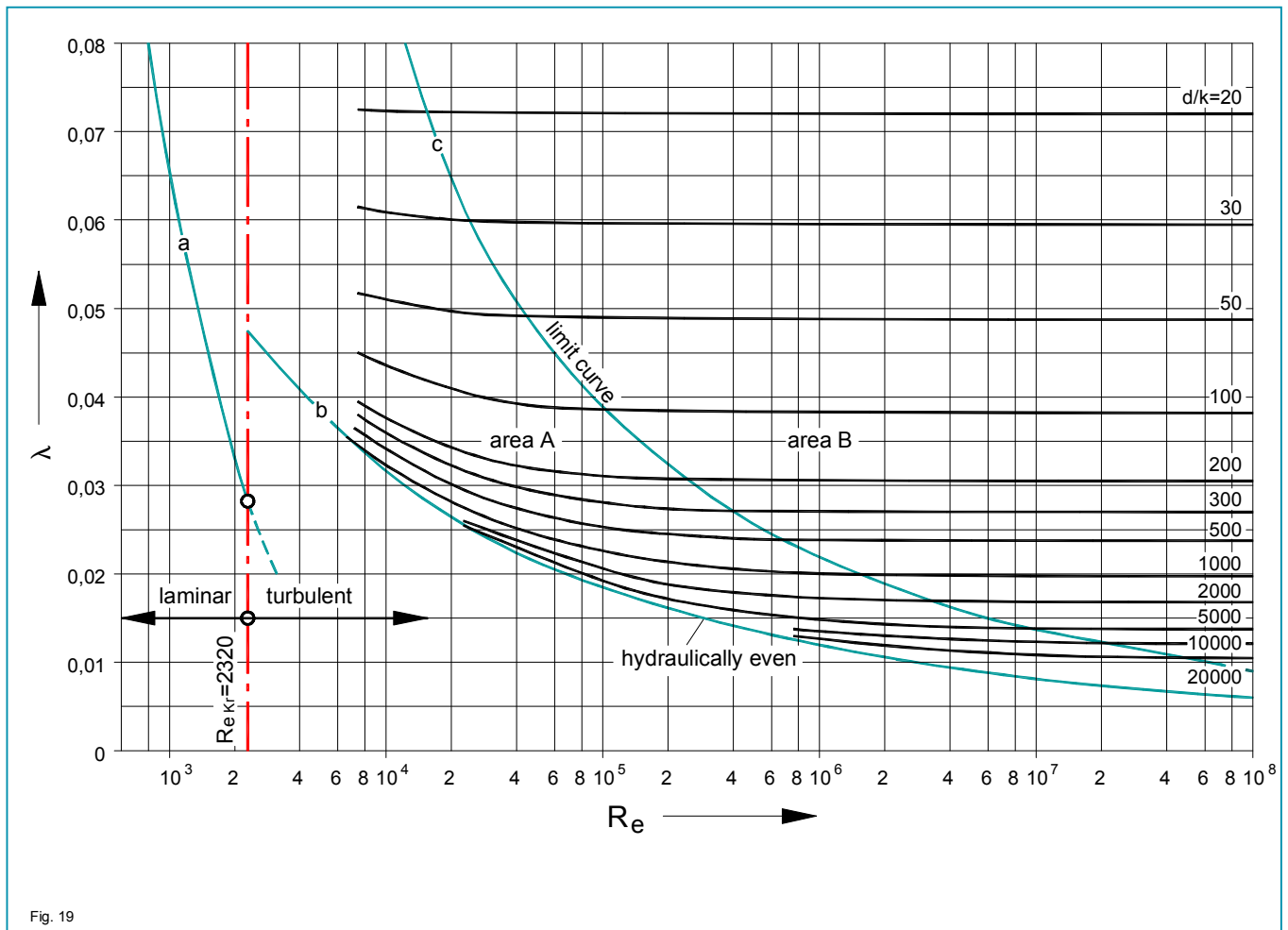


Fig. 19