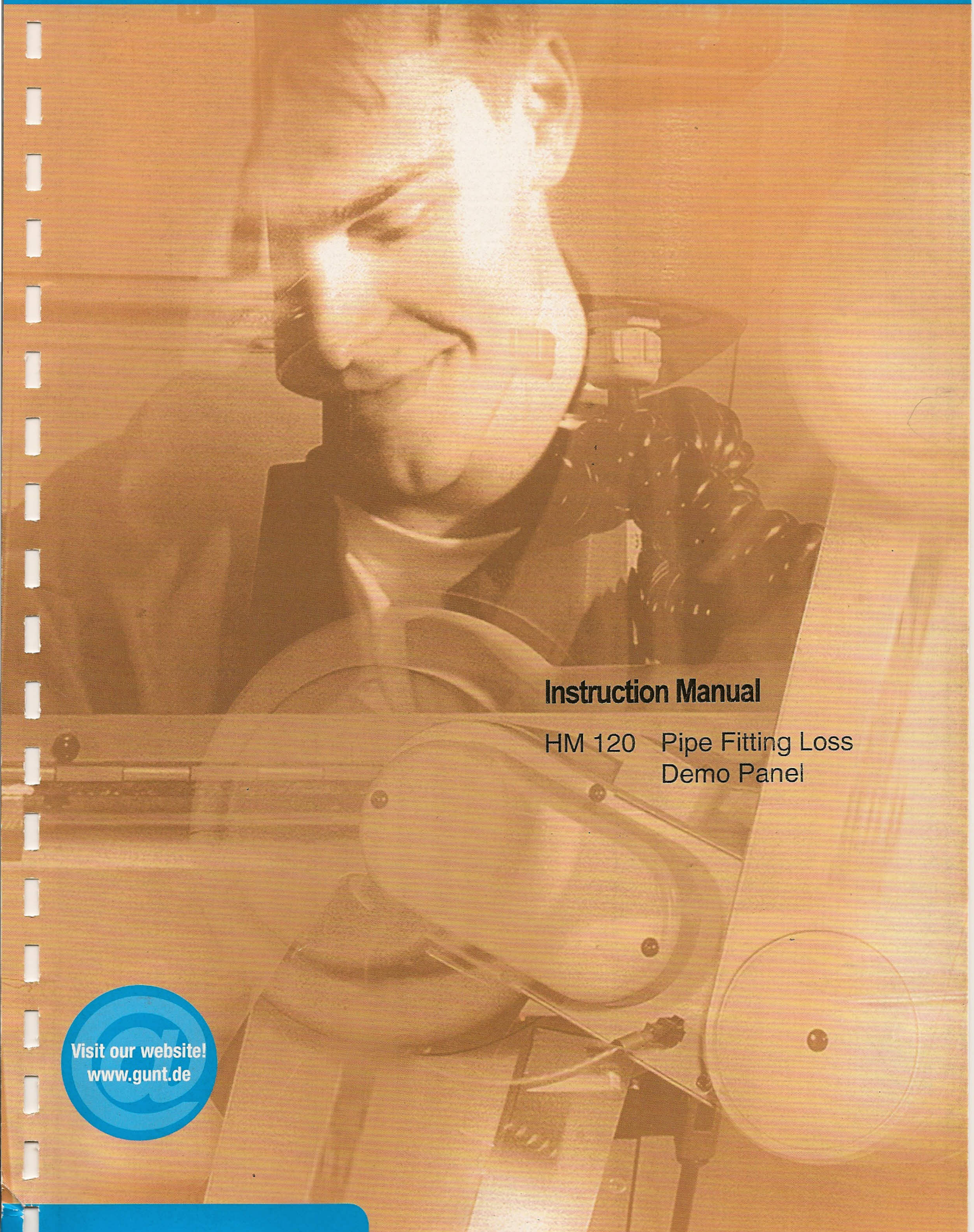
SYSTEME FÜR DIE TECHNISCHE AUSBILDUNG
EQUIPMENT FOR ENGINEERING EDUCATION

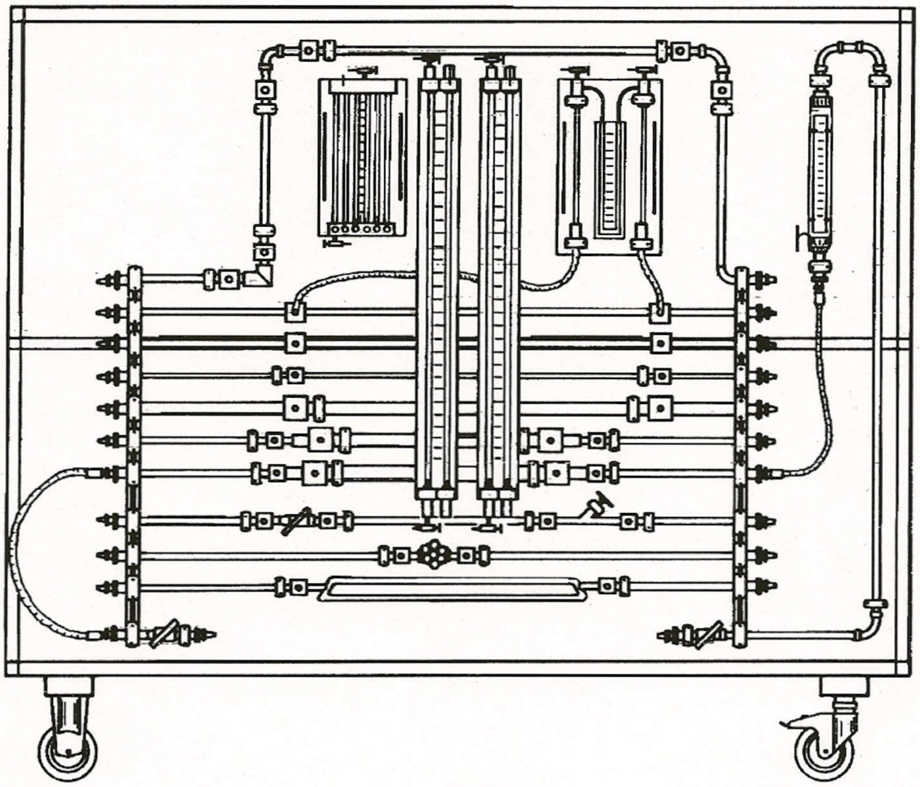
gunt HAMBURG



Instruction Manual

HM 120 Pipe Fitting Loss Demo Panel

HM 120 Mobile Panel for Investigating Pipe Systems



Instruction Manual

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HM 120 Mobile Panel for Investigating Pipe Systems

1 Introduction

The HM120 demonstration panel for investigating pipe systems enables experimental examination of system losses in pipes and special pipeline elements. The following individual topics can be explored using the test bench:

- Influence of different pipe diameters
- Influence of different materials and degrees of surface roughness
- Influence of flow velocity
- Losses due to pipe bends and elbows
- Losses due to changes in cross-sectional area
- Losses due to shut-off devices
- Determining coefficients of resistance and loss levels
- Measuring opening characteristics in valves and gates
- Comparison between experiments and calculations
- Observing the influence of defects

Furthermore, the student acquires general skills in the preparation and implementation of series of experiments and experience of handling pressure and flow measuring equipment. Work sheets have been developed in accordance with these experiment instructions which facilitate methodical evaluation of the experiments.

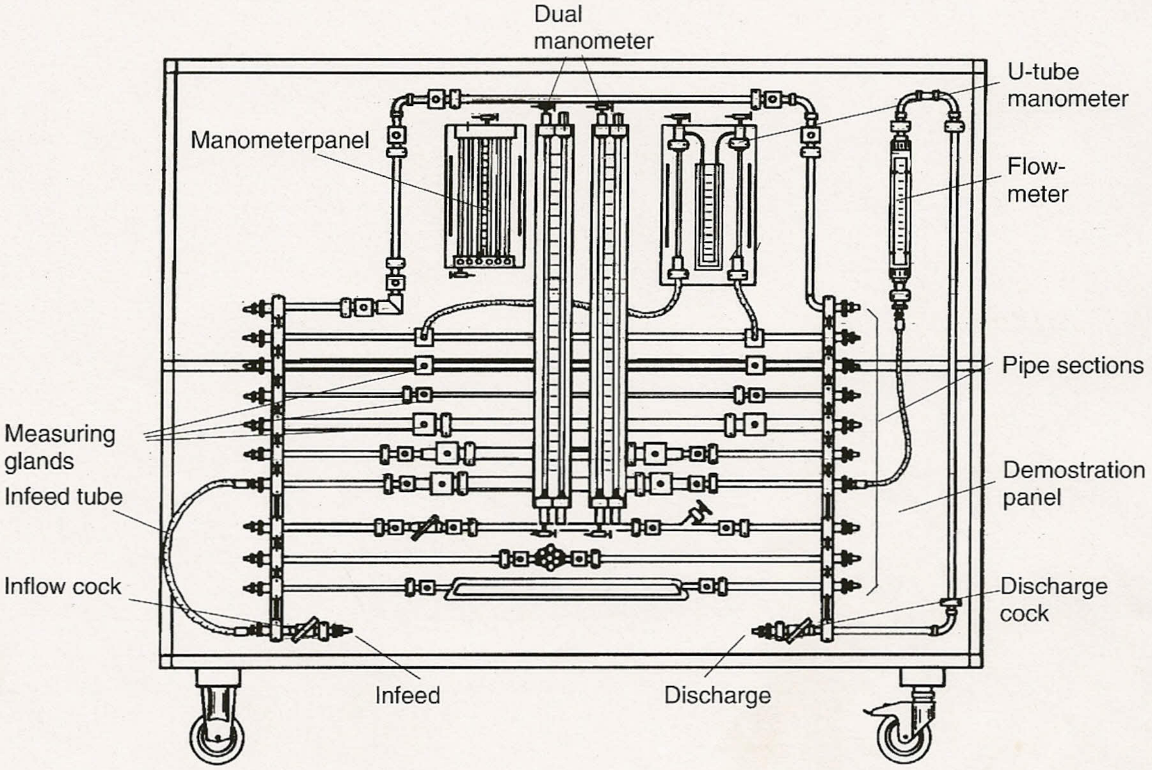
In connection with the set of pumps HM120.1, the demonstration panel is independent of the water main, and can therefore be used in a variety of locations such as training, seminar and lecture rooms.

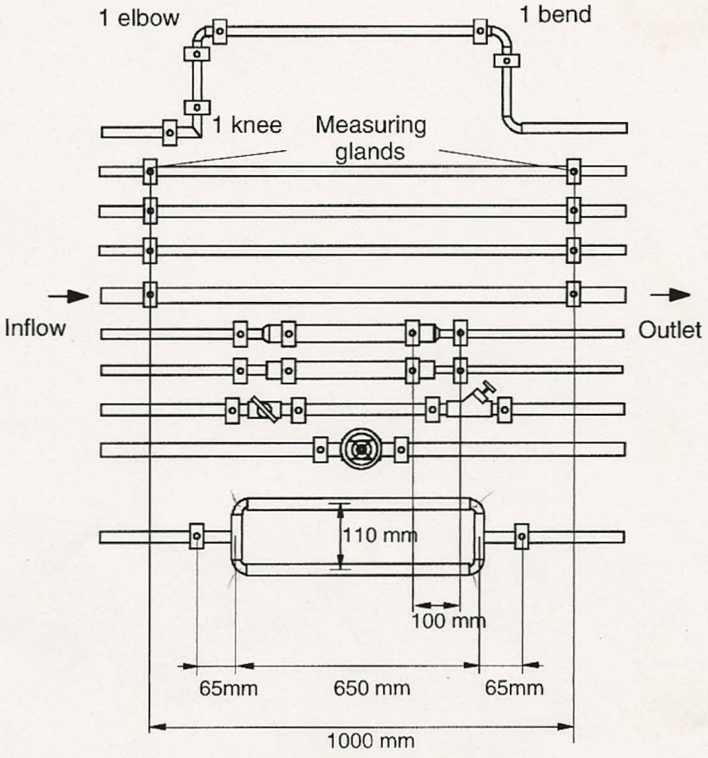
2 Unit description

The HM120 demonstration panel contains a fully fitted test stand for measuring losses in pipelines. The demonstration panel is distinguished by the following features:

- The entire layout of the experiment is clearly arranged on an **upright panel**.
- **Mobility** and easy manoeuvering of the demonstration panel thanks to four castors
- The dimensions allow it to be rolled through conventional doorways
- Two braked castors ensure **stability**
- By using the set of pumps **HM 120.1**, the system can be operated **independently of the water main**
- **Flow measurement** via variable-area flowmeters
- 4 independent **pressure measuring systems** for measuring differential pressure and loss level
- Trouble-free **pressure tapping** via annular chambers
- Quick, easy **connection** between measuring points and pressure gauges via tubes with rapid action hose couplings
- **10 different** pipe sections permanently installed
- Pipe sections are **interchangeable**, enabling the use of individual pipe sections
- Straightforward **selection of pipe sections** via tubes with rapid action hose couplings
- Standardised **measuring length 1m** for measuring pipe friction

2.1 Layout of the test stand





2 Cu pipe 18 x 1
3 St pipe, galvanized 1/2"
4 PVC pipe 20 x 1.5
5 PVC pipe 32 x 1.7
6 + 7 continuous/discont. change in cross-sectional area 20-32
8 ball-cock NW20 / Slanted seat valve NW20
9 gate NW 20
10 double line PVC 20 x 1.5

Arrangement of pipe sections

2.2 Function of the test stand

Following infeed, the water first passes the inflow cock. This blocks the water supply when the tubes are switched over.

The water is then directed to the selected pipe section via the infeed tube.

Pressure is measured at measuring glands at the beginning and end of the measuring section.

After passing through the pipe section, the water is fed to the flowmeter via a second tube.

The flow can be halted via a cock in the discharge.

2.3 Technical data

Main dimensions of the test stand

Length	2250	mm
Width	600	mm
Height	1800	mm
Weight	85	kg

Flow measurement

Variable-area flowmeter

Percentual scale		
max. flow rate (100%)	1600	l/h

Pressure measurement

Dual manometer

Filling	Water	
Absolute and differential pressure measurement		
Measuring range	850	mm of water

U-tube manometer

Filling	Mercury	
Absolute and differential pressure measurement		
Measuring range	-200 ... 200	mbar
	-2000.. 2000	mm of water

6-tube manometer panel

Filling	Water	
Absolute and differential pressure measurement		
Measuring range	300	mm of water

Pipe sections

Pipe section with knee, bend and elbow,
20 x 1.5, PVC

HM 120 Mobile Panel for Investigating Pipe Systems

Pipe section, straight, 18 x 1, Cu, 1000 mm long

Pipe section, straight, 1/2", St, galvanized, 1000 mm long

Pipe section, straight, 20 x 1.5, PVC, 1000 mm long

Pipe section, straight, 32 x 1.7, PVC, 1000 mm long

Pipe section, continuously expanded and tapered, 20 x 1.5 to 32 x 1.7, PVC

Pipe section, discontinuously expanded and tapered, 20 x 1.5 to 32 x 1.7, PVC

Pipe section with ball-cock NW 20 and slanted seat valve NW 20

Pipe section with gate NW 20

Pipe section with double line 20 x 1.5, PVC

3 Performing out the experiment

3.1 Commissioning

Set up the test stand and lock the brakes to prevent it from rolling away.

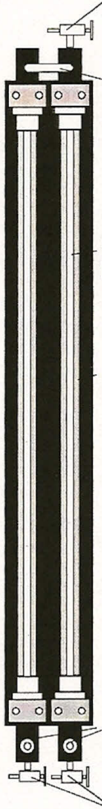
- Choose an even, waterproof surface (water may escape when changing the connection tubes)
- Connect the infeed connection to the water main
- Connect the discharge to a suitable drain

Check the test stand for leaks

- Seal the measuring glands with dummy plugs
- Connect the pipe section to the infeed tube
- Connect the pipe section to the discharge tube
- Open the outlet cock
- Slowly open the inflow cock and vent the pipe section
- Close the outlet cock. The pipe system is now under full pressure from the water main
- Check all pipes and connections for leaks
- Repeat this procedure for all pipe sections

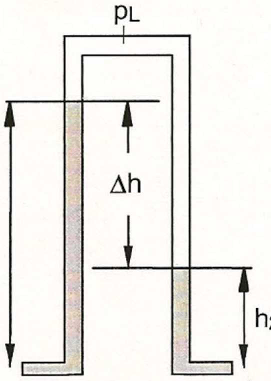
3.2 Dual manometer

The dual manometer enables both differential pressure and absolute pressure (where it is necessary to make allowance for atmospheric air pressure) to be measured in mm of water.



- The measuring range is 0 - 850 mm of water
- The manometer consists of two glass level tubes with a metal mm scale behind them.
- Both level tubes are connected to one another at the top and have a common vent valve.
- Differential pressure is measured with the vent valve closed, and absolute pressure (in relation to air pressure) with the vent valve open.
- The measuring points are connected to the lower ends of the level pipes with rapid action hose couplings.
- Each level pipe has a discharge valve at its bottom end.

3.2.1 Measuring differential pressure



For this purpose, the vent valve is closed. A cushion of air with pressure p_L is created above the two columns of water. This produces the following equation for the pressures to be measured, p_1 and p_2

$$p_1 = p_L + h_1\,\rho\,g\,,$$

$$p_2 = p_L + h_2\,\rho\,g\,.$$

The differential pressure is then

$$\Delta p = p_1 - p_2 = p_L + h_1\,\rho\,g - p_L - h_2\,\rho\,g.$$

The pressure p_L is extracted, producing

$$\Delta p = \Delta h\,\rho\,g \quad \text{with} \quad \Delta h = h_1 - h_2\,.$$

The zero point for differential pressure measurement can be set via the pressure p_L.

For a maximum measuring span, it is expedient to position the zero point or mid-point $\frac{h_1 + h_2}{2}$ at the centre of the measuring scale $\frac{h_{max}}{2}$

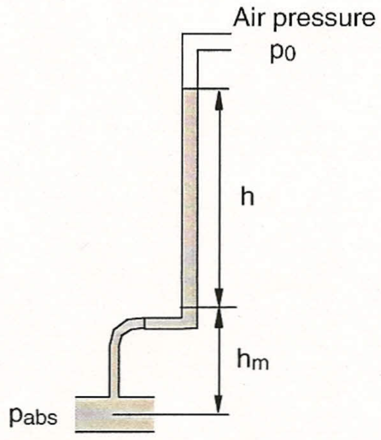
$$\frac{h_1 + h_2}{2} = \frac{h_{max}}{2} = \frac{p_1 - p_L + p_2 - p_L}{2 \rho g} .$$

This produces the following equation for the pressure of the air cushion

$$p_L = \frac{p_1 + p_2 - h_{max} \rho g}{2} .$$

The pressure is set via the vent valve; please also refer to section 3.3.2.

3.2.2 Measuring absolute pressure



For measuring absolute pressure, the vent valve is open and the pressure p_L refers to the atmospheric air pressure p_0.

In this case, it is also necessary to consider the height h_m between the measuring point and the zero point of the manometer

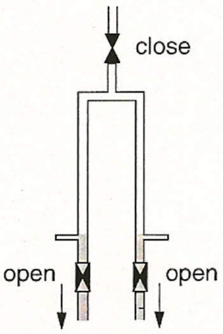
$$p_{abs} = p_0 + (h + h_m) \rho g .$$

3.3 Connecting and operating the manometer

- Close the inflow to the pipe section
- Open the discharge from the pipe section
- Connect the manometer to the pipe section to be measured using the connection tubes

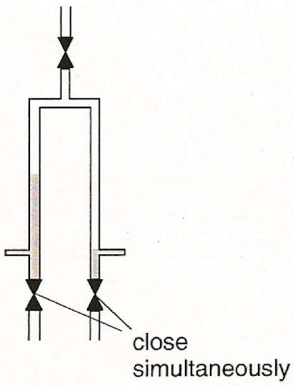
IMPORTANT! Seal all other measuring glands in the pipe section with dummy plugs.

3.3.1 Venting



- Close the vent valve at the top
- Open both discharge valves at the bottom
- Slowly open the inflow cock to the pipe section

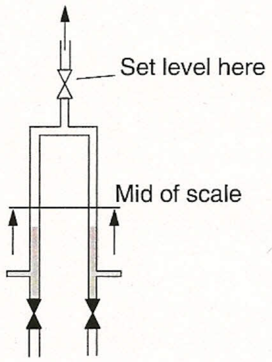
The pipe section and connection tubes are vented by the powerful water flow.



When there are no further air bubbles in the connection tubes:

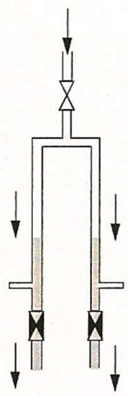
- Close the discharge from the pipe section
- Slowly close both discharge valves at the bottom **simultaneously**. Take care to ensure that both water columns rise evenly and there is no overflowing between the level tubes

3.3.2 Setting the zero position



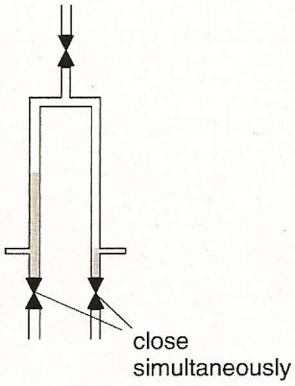
In order to guarantee the maximum possible measuring span, the zero position of the manometer should be situated in the centre of the scale.

- Close the discharge from the pipe section; the flow rate is zero.
- The level is equal in both measuring tubes
- Carefully set the level to the centre of the scale using the vent valve.



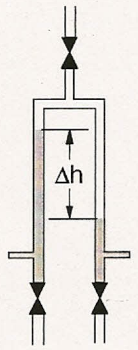
IMPORTANT! The level can only be adjusted upwards with the vent valve. If the level is too high, it can be lowered again as follows:

- Close the inflow to the pipe section
- Open the discharge from the pipe section
- Open the vent valve at the top and the two discharge valves at the bottom. The manometer will empty



- Close the vent valve at the top
- Open the inflow to the pipe section
- Simultaneously close both discharge valves at the bottom
- Set the level to the centre of the scale as described above.

3.3.3 Performing the measurement



Regulate the required flow rate using the discharge cock. The inflow to the pipe section should be completely open. Check on the flowmeter.

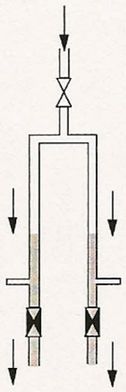
Read the differential pressure as the difference in height between the two water columns.

If the display fluctuates, estimate the average value. With differential pressure measurements, reproducible readings are more important than absolute precision.

IMPORTANT! With a large flow rate, the differential pressure may rise to such an extent that water overflows into the measuring tube with the lower pressure via the upper connection hose. If necessary, the zero position should be re-set (see 3.3.2) or the mercury U-tube manometer with the larger measuring range should be used.

Differential pressure measurement is always performed with the vent valve closed.

3.3.4 Concluding the measurement

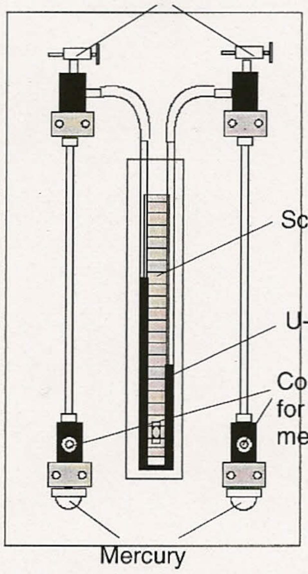


- Once the measurement is complete, close the inflow to the pipe section
- Open the discharge from the pipe section
- Open the vent valve and both discharge valves.

The manometer will empty and the pipe section will be pressureless.

The connection tubes can now be disconnected and changed over.

3.4 U-tube manometer



If the differential pressure to be measured exceeds the measuring range of the dual manometer with water filling, the mercury U-tube manometer may be used instead.

The U-tube manometer has a measuring range of ± 200 mbar, corresponding to 4000 mm of water.

It is also possible to measure absolute pressure with this manometer by opening one of the vent valves.

A sliding scale enables the display to be set precisely to zero.

3.4.1 Safety instructions for the mercury manometer

IMPORTANT! As the manometer is filled with **mercury**, particular caution should be exercised when handling it.

- It is essential to prevent the poisonous mercury from escaping. For this reason, **never exceed the maximum differential pressure of 400 mbar**.
- Similarly, **never close the inflow abruptly**, since the flow energy of the discharging water could cause such a vacuum that the mercury is sucked out of the manometer.
- For safety reasons, there are valve floats on the surface of the mercury which seal the connection hoses if the mercury level is too high.
- Furthermore, so-called **mercury traps** are built into the connections which largely prevent mercury from escaping into the water cycle.

- Particular caution is required during installation and transportation. The filled U-tube manometer should always be stored in an **upright position**.
- Should mercury escape in spite of this, the relevant **safety instructions on handling mercury** should be observed.

3.4.2 Venting

Connect the manometer as described under 3.2.

- Open both vent valves on the manometer
- Carefully open the inflow cock on the pipe section to be measured
- Once no further air bubbles are visible in the pipes, close both vent valves simultaneously

Measurement is performed as described under 3.3.3.

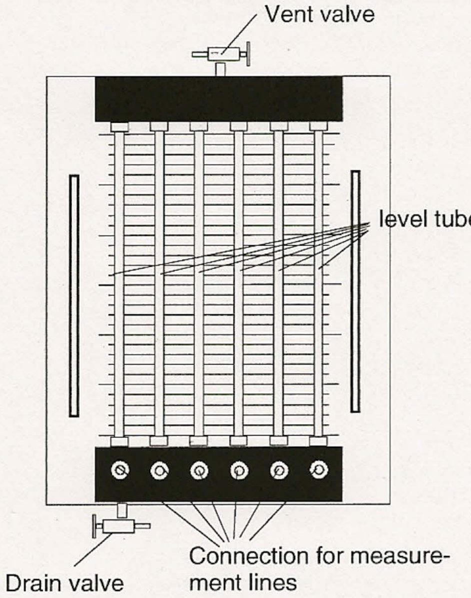
3.4.3 Concluding the measurement

- Once measurement is complete, close the inflow to the pipe section
- Open the discharge from the pipe section
- Open the vent valves on the manometer

The manometer and the connection tubes will empty and the pipe section will be pressureless.

The connection tubes can now be released and changed.

3.5 6-tube manometer panel

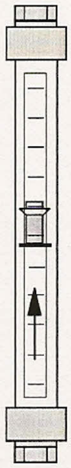


The 6-tube manometer panel consists of 6 glass level tubes with a mm scale behind them.

- The measuring range is 300 mm of water
- All level tubes are connected to one another at the top and have a common vent valve.
- Differential pressure is measured with the vent valve closed, and absolute pressure with the vent valve open.

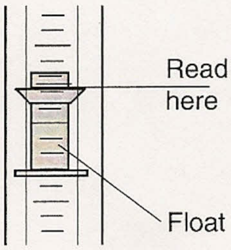
Functioning, connection and operation are analogous to the two manometers described above in sections 3.2 and 3.4.

3.6 Flow measurement



A variable-area flowmeter with the following characteristics is used to measure flow rate.

- Plastic measuring tube
- Interchangeable stainless steel float
- Interchangeable percentual scale
- Max. flow rate (100%) 1900 l/h

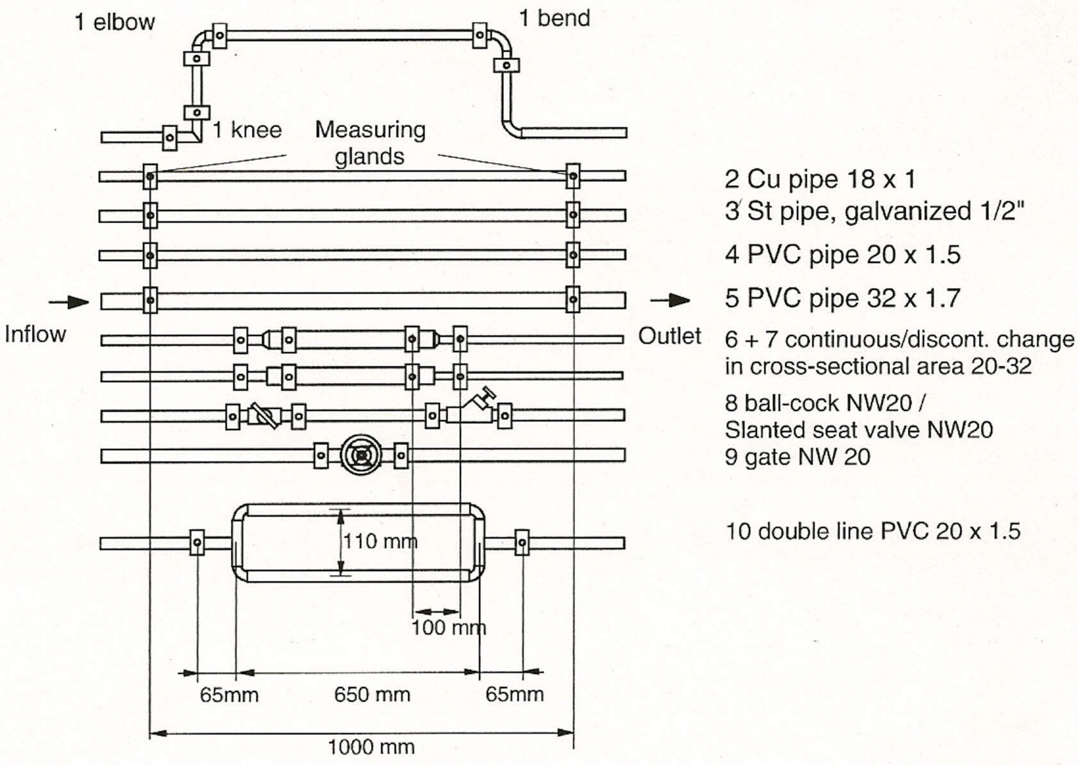


The flow rate can be read from the upper edge of the conical attachment.

Air bubbles or dirt particles on the float may affect measurement precision.

To flush them out, operate the test stand at maximum flow rate. To do so, open all cocks fully.

3.7 Overview of pipe sections



Arrangement of pipe sections

4 Experiments

The following sections 4, 5 and 6 describe examples of experiments which can be implemented with this device. The selection of experiments does not claim to be exhaustive, but should instead provide ideas for devising your own series of experiments.

The descriptions of experiments are divided into a section on **basic principles** containing the main formulae, the section on actually **performing the experiment**, including recording measurements, and the **comparison between calculations and experiments**.

The measurements listed should not be viewed as guideline or calibration values which must be adhered to in all circumstances. Deviations may occur to a greater or larger extent in your own experiments, depending on the design of the individual components and the skill of the individual performing the experiment.

4.1 Pipe flow with friction

4.1.1 Basic principles

The following experiments are intended to determine the **pressure loss p_V** and/or the **loss level h_V** in pipe flow hampered by friction.

With **turbulent pipe flow**, which is defined as a Reynolds' number Re>2320, pressure loss is proportional to

- The length l of pipe
- Coefficient of pipe friction λ
- Density ρ of the flow medium
- Square of the flow velocity v.

Furthermore, pressure loss increases as the pipe diameter d decreases.

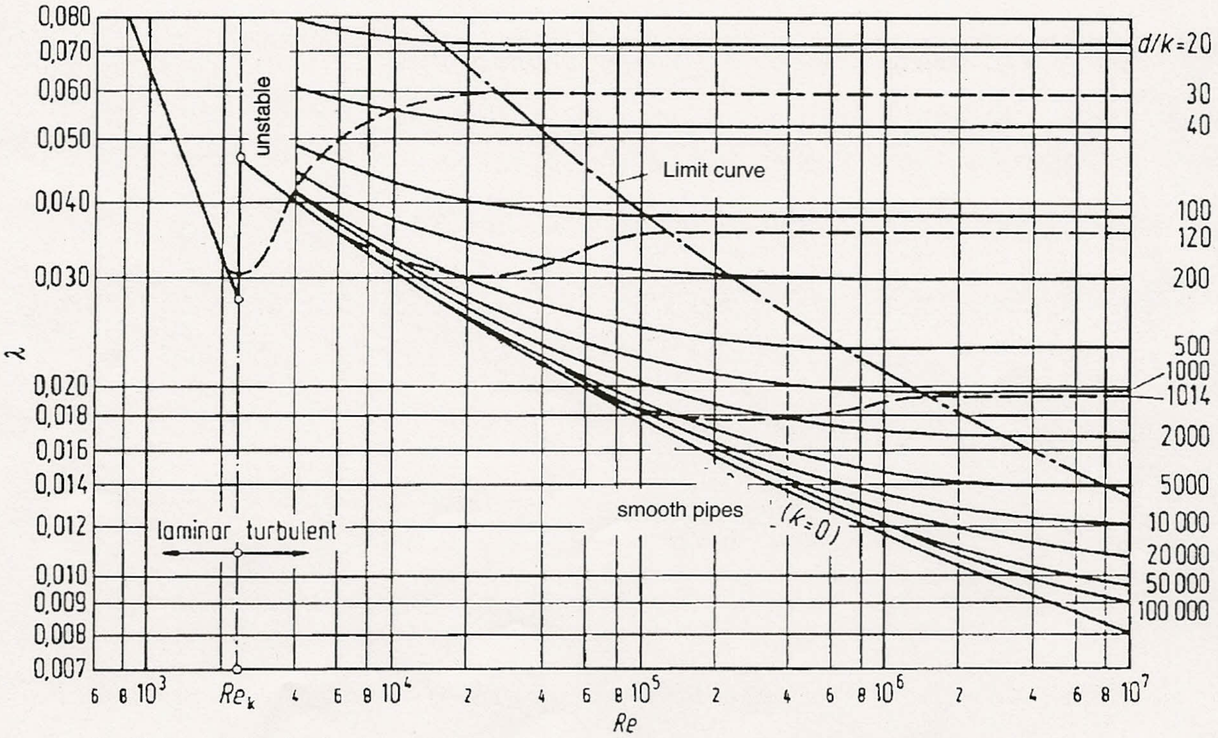
It is calculated as follows

$$p_v = \frac{\lambda\, l}{2\, d}\, \rho\, v^2 .$$

The relevant loss level h_V is calculated as follows

$$h_v = \frac{\lambda\, l}{d}\, \frac{v^2}{2\, g} .$$

In the case of turbulent pipe flow (Re>2320), the coefficient of pipe friction λ depends on the pipe roughness k and the Reynolds' number Re. Pipe roughness k indicates the height of the wall elevations in mm. The roughness of the experimental pipes is listed in the Appendix in Table 7.1.1. The correlation between Re, λ and k is portrayed in the diagram according to **Colebrook and Nikuradse**, which relates wall roughness k to the pipe diameter d.



Coefficient of pipe friction λ according to Colebrook and according to Nikuradse (dotted line) (source: Dubbel, Taschenbuch für den Maschinenbau)

The **Reynolds' number Re** is calculated from the pipe diameter d, flow velocity v and kinematic viscosity ν

$$Re = \frac{v\, d}{\nu}.$$

Table 7.1.2 shows the kinematic viscosity of water depending on temperature.

The **flow velocity v** is calculated from the volume flow $\dot{V}$ and the pipe cross-section

$$v = \frac{4\, \dot{V}}{\pi\, d^2}.$$

For **hydraullically smooth pipes (Re < 65 d/k)** and Reynolds' numbers in the range from 2320< Re < 10^5, the coefficient of pipe friction is calculated according to the **Blasius** formula

$$\lambda = \frac{0.3164}{\sqrt[4]{Re}}.$$

For **pipes in the transition region to rough pipes (65 d/k < Re < 1300 d/k**, shown in the diagram as the area beneath the limit curve), the coefficient of pipe friction is calculated according to **Colebrook**

$$\lambda = \left[2\,\lg\left(\frac{2.51}{Re\,\sqrt{\lambda}} + \frac{0.27}{d/k}\right)\right]^{-2}.$$

This is an implicit formula which must be solved iteratively. First, you estimate λ, insert it in the formula and calculate an initial approximation. This approximation is included in the equation again and a second approximation calculated.

If the estimated value is taken from the diagram according to Colebrook and Nikuradse, the first approximation is generally sufficiently precise and the values differ only in the third place after the decimal point.

4.1.2 Performing the experiment

The following experiment compares pipes of different materials (copper and galvanized steel) but the same cross-section (internal diameter 16 mm). The measurement length is 1000 mm.

The flow rate $\dot{V}$ is specifed in % of the maximum flow rate of the variable-area flowmeter, in this case 1600 l/h corresponding to $44.4 \cdot 10^{-5}$ m^3/s.

The displays of the dual manometer and flow-rate meter are noted in tables (Appendix 7.3.1, Work Sheet 1).

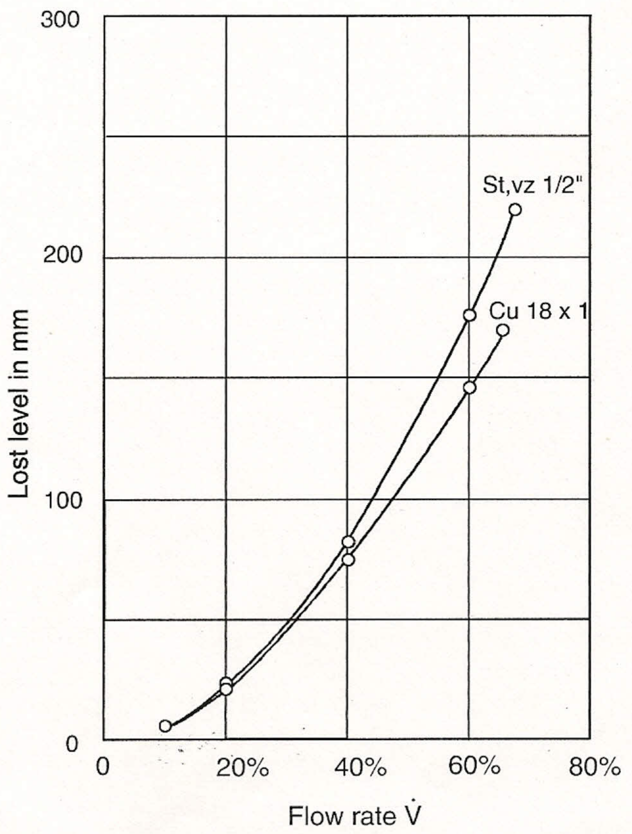
Connection of the manometer and the measurements are performed as described in section 3.3.

Measurement results Pipe section 2 : copper pipe 18 x 1, d_i = 16 mm, l = 1000 mm			
Volume flow $\dot{V}$ in %	h_1 in mm	h_2 in mm	Loss level h_v in mm
10	535	530	5
20	535	515	20
40	535	462	73
60	523	378	145
66	515	346	169

Measurement results Pipe section 3: galvanized Steel 1/2", d_i = 16 mm, l = 1000 mm			
Volume flow $\dot{V}$ in %	h_1 in mm	h_2 in mm	Lost level h_v in mm
10	495	490	5
20	498	475	23
40	502	421	81
60	506	332	174
67.5	505	287	218

The measured loss levels can now be plotted over the flow rate. This indicates the quadratic function of flow rate and thus of flow velocity.

The graph clearly shows the higher flow resistance of the galvanized steel pipe.



2 PVC pipes (pipe sections 4 and 5) with an external diameter of 20 and 32 mm are then examined. The corresponding internal diameters are 17 and 28.6 mm. The measurement length l is again 1000 mm.

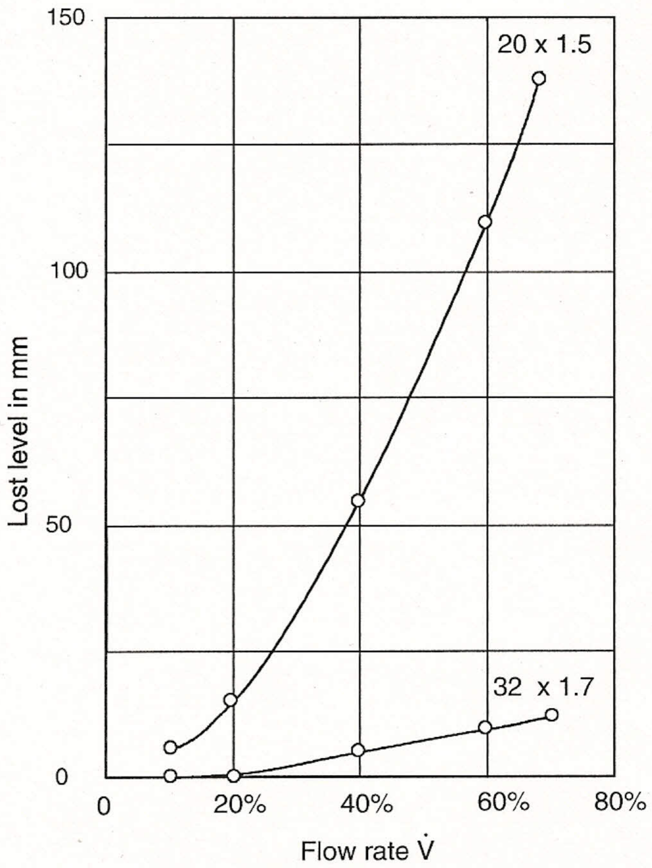
This produces the following measurements:

Measurement results Pipe section 4: PVC 20 x 1.5, d_i = 17 mm, l = 1000 mm			
Volume flow $\dot{V}$ in %	h_1 in mm	h_2 in mm	Lost level h_v in mm
10	417	413	4
20	415	401	14
40	407	352	55
60	389	281	108
68	379	242	137

Measurement results Pipe section 5: PVC 32 x 1.7, d_i = 28.6 mm, l = 1000 mm			
Volume flow $\dot{V}$ in %	h_1 in mm	h_2 in mm	Lost level h_v in mm
10	430	430	0
20	424	424	0
40	402	398	4
60	365	356	9
70	340	329	11

The measurements can be plotted in a graph.

An enlargement of the pipe diameter results in a disproportional reduction of losses. In this case, a cross-section enlargement by a factor of 2.83 (17 to 28.6) reduces losses by a factor of 12.45 !



4.1.3 Comparison with the equation

At this point, the measured loss levels are compared with the values calculated. For the calculation, it is first necessary to know the wall roughness of the pipes used.

Wall roughness of experimental pipes		
Material	Surface	Wall roughness k
Copper pipe, Cu	technical smooth	0.001 mm
PVC-pipe	technical smooth	0.001 mm
Steelpipe, St	galvanized	0.1 mm

According to Table 7.1.2, the kinematic viscosity of water at a temperature of 20°C is given as $\nu = 1.004 \cdot 10^{-6}$ m²/s. By using these data, it is possible to calculate the loss levels.

Calculation of loss levels

Pipe section	Internal diameter d in mm	Volume flow		Flow velocity v in m/s	Reynolds' numberRe	d/k	smooth/ rough
		$\dot{V}$ in %	$\dot{V}$ in m^3/s				
2 Cu 18 x 1	16	67.5	$30 \cdot 10^{-5}$	1.49	23700	16000	smooth
3 St, vz. 1/2"	16	66	$29 \cdot 10^{-5}$	1.44	22900	160	smooth
4 PVC 20 x 1.5	17	68	$30 \cdot 10^{-5}$	1.32	22350	17000	smooth
5 PVC 32 x 1.7	28.6	70	$31 \cdot 10^{-5}$	0.48	13700	28600	smooth

Pipe section	λ calculation according to	Coefficient of pipe friction λ	**Calculated loss level h_v in m**	Measured loss level h_v in m	Deviation
2 Cu 18 x 1	Blasius	0.0255	0.180	0.169	+ 6.5 %
3 St, vz. 1/2"	Colebrook	0.0357	0.235	0.218	+ 7.8 %
4 PVC 20 x 1.5	Blasius	0.0258	0.135	0.137	- 1.3 %
5 PVC 32 x 1.7	Blasius	0.0292	0.012	0.011	+ 9.0%

The consistency between the calculation and the experiment can be described as good.

5 Coefficients of resistance of special pipeline elements

5.1 Basic principles

Special pipeline elements and fittings such as pipe bends or elbows, manifolds, changes in cross-sectional area or valves and flaps create additional pressure losses as well as the wall friction losses.

In the case of changes in cross-sectional area and associated velocity changes, when calculating the total pressure loss, it is necessary to consider components of Bernoulli's pressure loss (dyn. pressure). **Bernoulli's equation** with loss term is as follows

$$\frac{\rho\, v_1^2}{2} + p_1 + \rho\, g\, z_1 = \frac{\rho\, v_2^2}{2} + p_2 + \rho\, g\, z_2 + \Delta p_v \,.$$

Assuming that levels z_1 and z_2 are the same, the measurable **total pressure loss** is calculated as follows:

$$\Delta p_{ges} = p_1 - p_2 = \frac{\rho}{2}\,(v_2^2 - v_1^2) + \Delta p_v \,.$$

This then produces the following formula for **loss level**

$$h_{vges} = \frac{1}{2\,g}\,(v_2^2 - v_1^2) + h_v \,.$$

Apart from a few special cases, in contrast to the wall friction losses examined in the previous section, the additional flow resistance cannot be calculated completely.

Below are the empirically derived coefficients of resistance ζ for the various elements as quoted in the relevant literature. These enable simple calculation of the additional pressure losses

$$p_{vz} = \zeta \rho \frac{v^2}{2}$$

or for loss level

$$h_{vz} = \zeta \frac{v^2}{2\,g}.$$

Thus, for the total loss level, the formula is as follows

$$h_{vges} = \frac{1}{2\,g}(v_2^2 - v_1^2) + \frac{\lambda_1\, l_1\, v_1^2}{2\,g\, d_1} + \frac{\lambda_2\, l_2\, v_2^2}{2\,g\, d_2} + \zeta \frac{v_2^2}{2\,g}.$$

The pipe friction resistance must be determined separately for the section before and after the change in cross-sectional area. The coefficient of resistance, on the other hand, only relates to the velocity v_2 after the change in cross-sectional area.

If the velocities are the same, the dyn. pressure component is eliminated and a joint pipe friction component is specified.

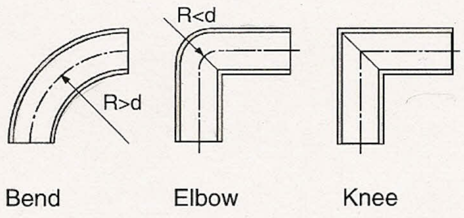
From the measured total loss level and the known pipe friction, it is possible to determine the coefficient of friction ζ

$$\zeta = \frac{2\, h_{vges}\, g}{v_2^2} - \left[1 - \left(\frac{d_2}{d_1}\right)^4\right] - \left[\lambda_1 \frac{l_1}{d_1}\left(\frac{d_2}{d_1}\right)^4 + \lambda_2 \frac{l_2}{d_2}\right].$$

Without a change in cross-sectional area ($d_1/d_2 = 1$), the expression is simplified as follows

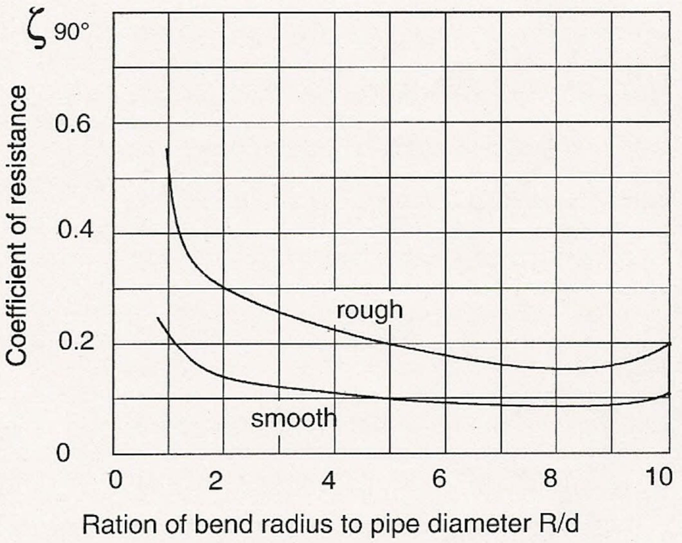
$$\zeta = \frac{2\, h_{vges}\, g}{v^2} - \lambda \frac{l}{d}.$$

5.2 Pipe bends



With pipe bends, the coefficient of resistance ζ depends on the deflection angle of the flow and the ratio of the elbow radius to the pipe diameter. Furthermore, the coefficient of resistance is influenced by the shape of the elbow.

For the special case of a pipe bend with a 90° deflection, the following diagram applies to smooth and rough pipes.



For pipe angles, i.e. bend radii which are smaller than the pipe diameter (R/d<1), the coefficients of resistance of knee sections apply approximately. For example, for a 90° knee section in a smooth pipe a ζ of 1.13 applies, and for rough pipes, a ζ of 1.27.

5.2.1 Performing the experiment

Connect a dual manometer to the measuring glands of the knee (pipe section 1) and perform the measurement as described in section 3.3. Note the displays of the dual manometer and the flowmeter in the table on work sheet 1, 7.3.

In a similar manner, perform the measurement with an elbow and a bend (pipe section 1).

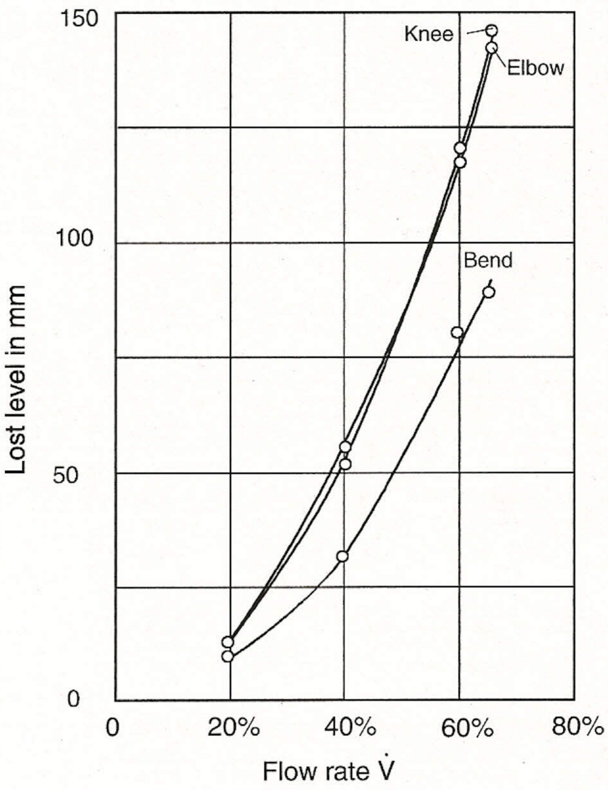
Measurement results pipe section 1: PVC 20 x 1, knee, l=200 mm			
Volume flow $\dot{V}$ in %	h_1 in mm	h_2 in mm	Lost level h_v in mm
20	552	539	13
40	550	498	52
60	550	431	119
66	550	403	147

Measurement results pipe section1: PVC 20 x 1, elbow, l= 91 mm			
Volume flow $\dot{V}$ in %	h_1 in mm	h_2 in mm	Lost level h_v in mm
20	523	510	13
40	520	466	54
60	512	396	116
66	509	366	143

Measurement results pipe section1: PVC 20 x 1, bend, l= 183 mm			
Volume flow $\dot{V}$ in %	h_1 in mm	h_2 in mm	Lost level h_v in mm
20	346	337	9
40	326	295	31
60	290	208	82
66	275	187	88

By plotting the measurements on a graph, it can be seen that losses increase quadratic to the flow rate and hence the flow velocity.

Losses with the knee and the elbow are considerably higher than with the bend.



5.2.2 Calculating the coefficients of resistance

The coefficients of resistance are to be determined from the measurements for the knee, elbow and pipe bend. As no change in cross-sectional area occurs, the simplified formula for ζ can be used in the calculation

$$\zeta = \frac{2\, h_{vges}\, g}{v^2} - \lambda \frac{l}{d}.$$

l is the pipe length between the measuring glands in relation to the centre line of the pipe.

Calculation of the coefficients of Resistance ζ for knee, elbow and bend							
Pipe section	Internal diameter d in mm	length in mm	Volume flow		Flow velocity. v in m/s	Reynolds' numberRe	d/k
			$\dot{V}$ in %	$\dot{V}$ in m^3/s			
1 Knie	17	200	66	$29 \cdot 10^{-5}$	1.28	21700	17000
1 Winkel	17	91	66	$29 \cdot 10^{-5}$	1.28	21700	17000
1 Bogen	17	183	66	$29 \cdot 10^{-5}$	1.28	21700	17000

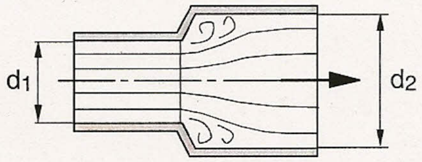
Pipe section	λ calculation according to	Coefficient of pipe friction λ	Measured loss level h_{vges} in m	**Coefficient of resistanceζ**
1 Knie	Blasius	0.0260	0.147	**1.45**
1 Winkel	Blasius	0.0260	0.143	**1.41**
1 Bogen	Blasius	0.0260	0.088	**0.77**

The coefficient of resistance of the knee and the elbow corresponds fairly well to the value for the rough knee bend specified in the literature ($\zeta_{rough} = 1.27$).

The coefficient of resistance for the bend is considerably higher than specified in the literature (for R/d = 2.35, the diagram indicates a reading of $\zeta_{smooth} = 0.14$, and $\zeta_{rough} = 0.28$). The large deviation may be due to an imperfect connection between the pipe and the bend.

5.3 Changes in cross-sectional area

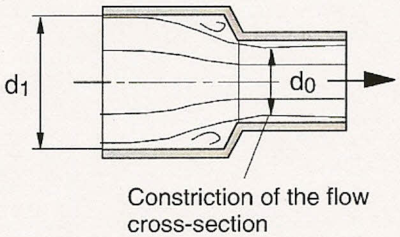
The changes in cross-sectional area present in the test stand consist of a continuous and a discontinuous expansion and taper. For the discontinuous change in cross-sectional area, the coefficient of resistance can be derived from Bernoulli's equation and the principle of linear momentum.



The following applies to the **expansion**

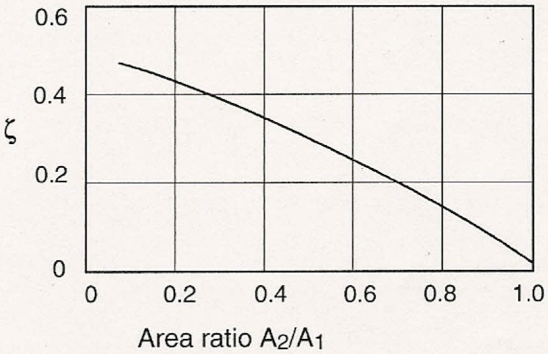
$$\zeta = \left(\frac{A_2}{A_1} - 1\right)^2 = \left(\frac{d_2^2}{d_1^2} - 1\right)^2 .$$

Accordingly, the following applies to the **taper**



$$\zeta = \left(\frac{A_1}{A_0} - 1\right)^2 = \left(\frac{d_1^2}{d_0^2} - 1\right)^2 .$$

In this equation A_0 or d_0 is the constricted cross-sectional area. As this is generally unknown, with tapers, the coefficient of resistance is taken from the following diagram.



Coefficient of resistance for discontinuous taper

With a continuous change in cross-sectional area, the coefficients of resistance can be taken from special diagrams (Section 7.1.3).

5.3.1 Performing the experiment

Connect the dual manometer to the measurement glands of the continuous cross-sectional area expansion (pipe section 6) and perform the measurement as described in section 3.3. Note the displays of the dual manometer and the flowmeter in the table on work sheet 1, 7.3.

In a similar way, perform the measurement with the continuous cross-sectional area taper (pipe section 6).

Measurement results pipe section 6: cross-section expansion 20 - 32 , cont., d_1= 17 mm, d_2 = 28.6 mm, l = 125 mm			
Volume flow $\dot{V}$ in %	h_1 in mm	h_2 in mm	Loss level h_v in mm
10	605	606	-1
20	600	601	-1
40	581	580	-1
60	551	545	6
68	535	528	7

Measurement results pipe section 6: cross section taper 32 - 20 , cont., d_1= 28.6 mm, d_2 = 17 mm, l = 125 mm			
Volume flow $\dot{V}$ in %	h_1 in mm	h_2 in mm	Loss level h_v in mm
10	492	491	1
20	490	480	10
40	478	440	38
60	460	380	80
68	449	345	104

Repeat these measurements using the discontinuous changes in cross-sectional area in pipe section 7.

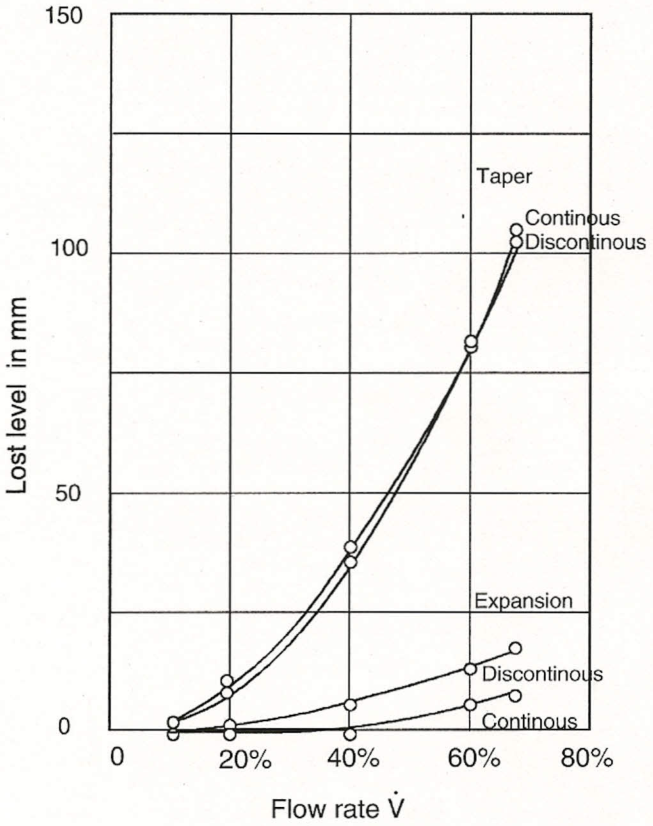
Measurement results pipe section 7: cross section expansion 20 - 32 , discont., d_1= 17 mm, d_2 = 28.6 mm, l = 100 mm			
Volume flow $\dot{V}$ in %	h_1 in mm	h_2 in mm	Lost level h_v in mm
10	410	411	-1
20	405	404	1
40	380	375	5
60	340	328	12
68	318	301	17

Measurement results pipe section 7: cross section taper 32 - 20 , discont., d_1= 28.6 mm, d_2 = 17 mm, l = 100 mm			
Volume flow $\dot{V}$ in %	h_1 in mm	h_2 in mm	Lost level h_v in mm
10	410	409	1
20	406	399	7
40	393	359	34
60	369	290	79
68	355	253	102

5.3.2 Evaluation of the experiment

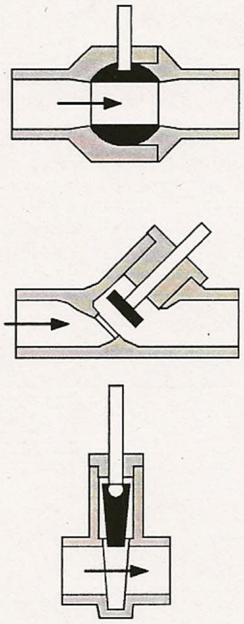
By plotting the measurements on a graph, it can be seen that differential pressure increases quadratic to the flow rate and hence to the flow velocity.

It is interesting to note that virtually no pressure loss occurs with the expansion. There may even be a pressure gain, whereby the increase in pressure resulting from the loss in velocity outweighs the drop in pressure caused by pipe friction.



Furthermore, it is worth noting the slight difference between the continuous and discontinuous changes in cross-sectional area occurring in the elements of the test stand.

5.4 Shut-off devices



The test stand contains the following shut-off devices in pipe sections 8 and 9:

- Ball-cock
- Slanted seat valve or free-flow valve
- Gate

When open, the **ball-cock** has a completely smooth, unrestricted cross-sectional aperture.

Accordingly, the lowest pressure losses are to be expected with this type of shut-off device. Coefficients of resistance of as little as $\zeta_R = 0.03$ can be achieved.

Due to its fissured cross-sectional aperture, the **slanted seat valve** has a considerably higher coefficient of resistance in the range from $\zeta_R = 1.5–2.0$. However, it is still considerably more favourable to flow than a conventional DIN straight seat valve where the flow is deflected twice through 90°. In such a case, it is necessary to calculate a coefficient of resistance of approximately $\zeta_R = 4.0$.

Like the ball-cock, the **gate,** in this case a wedge gate, also has a completely unrestricted cross-sectional aperture, although this shut-off valve has lateral recesses to hold the sealing surfaces which results in the formation of eddies. For this reason, at $\zeta_R = 0.2–0.3$, the coefficient of resistance is not as favourable as with the ball-cock.

5.4.1 Performing the experiment

Connect the dual manometer to the measuring glands of the ball-cock (pipe section 8) and perform the measurement with different flow rates as described in section 3.3. Note the displays of the dual manometer and the flowmeter in the table on worksheet 1, 7.3.

In a similar way, perform the measurement using the slanted seat valve (pipe section 8) and gate (pipe section 9).

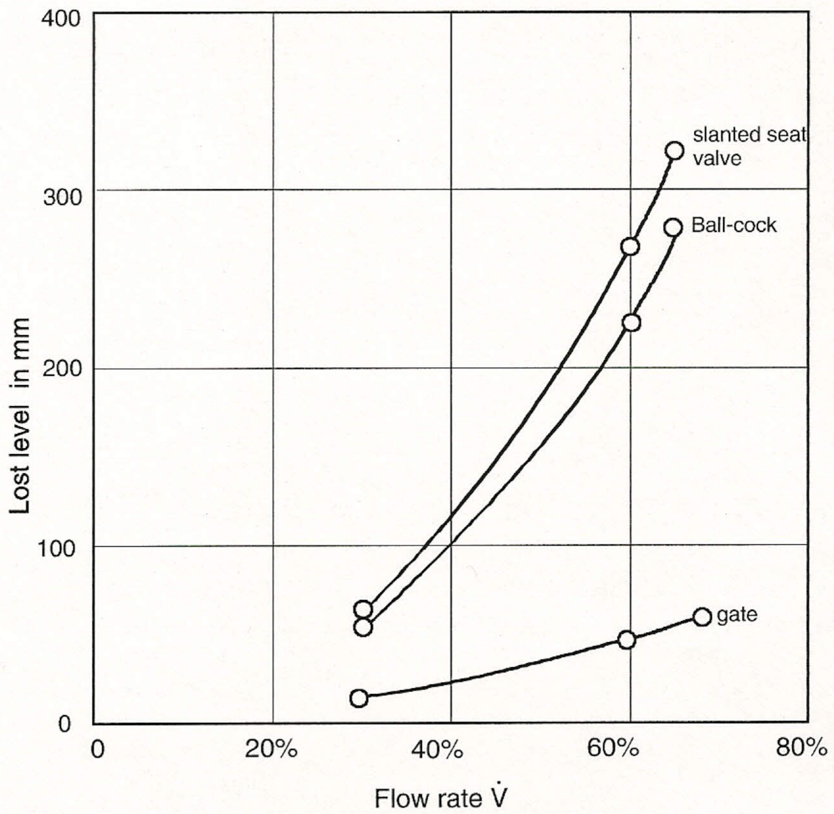
Measurement results pipe section 8: ball-cock l= 146 mm			
Volume flow $\dot{V}$ in %	h_1 in mm	h_2 in mm	Lost level h_v in mm
30	472	420	52
60	500	277	223
65	510	232	278

Measurement results pipe section 8: slanted seat valve l= 240 mm			
Volume flow $\dot{V}$ in %	h_1 in mm	h_2 in mm	Lost level h_v in mm
30	472	410	62
60	510	242	268
65	515	193	322

Measurement results pipe section 9: gate l= 167 mm			
Volume flow $\dot{V}$ in %	h_1 in mm	h_2 in mm	Lost level h_v in mm
30	484	470	14
60	449	400	49
68	430	370	60

By plotting the measurements on a graph, it can be seen that, as expected, the slanted seat valve has the highest losses. The gate is distinguished by very low losses. Contrary to expectations, the ball-cock has an uncharacteristically high flow resistance.

This is due to the internal structure of the model used. The ball-cock was not specifically designed by the manufacturer with the aim of a low flow resistance. Its cross-sectional aperture, at 14 mm, is well below the pipe diameter and the connections have sharp edges.



5.4.2 Calculating the coefficients of resistance

For the shut-off devices ball-cock, slanted seat valve and gate, the coefficients of resistance are then calculated using the following formula

$$\zeta_R = \frac{2\, h_{vges}\, g}{v^2} - \lambda \frac{l}{d}.$$

The distance between the measuring glands is used as the length l .

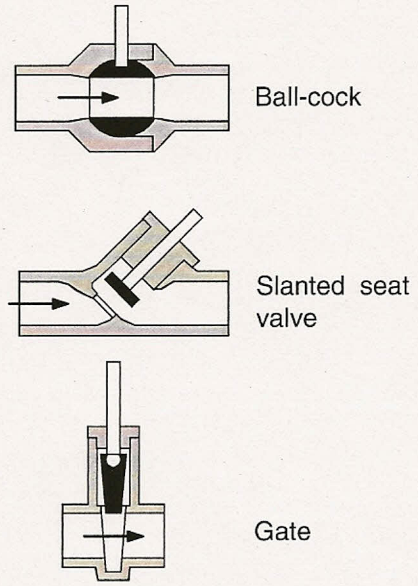
Calculation of the coefficients of Resistance ζ_R for ball-cock, slanted seat valve and gate

Pipe section	Internal diameter d in mm	Length in mm	Volume flow		Flow velocity v in m/s	Reynolds' number Re	d/k
			$\dot{V}$ in %	$\dot{V}$ in m^3/s			
8 Ball-cock	17	146	65	$28.8 \cdot 10^{-5}$	1.26	22000	17000
8 Valve	17	240	65	$28.8 \cdot 10^{-5}$	1.26	22000	17000
9 Gate	17	167	68	$30.2 \cdot 10^{-5}$	1.32	21000	17000

Pipe section	λ calculation according to	Cofficient of pipe friction λ	Measured lost level h_{vges} in m	**Coefficient of resistance ζ_R**
8 Ball-cock	Blasius	0.0260	0.278	**3.21**
8 Valve	Blasius	0.0260	0.322	**3.61**
9 Gate	Blasius	0.0263	0.060	**0.417**

In total, the coefficients of resistance are considerably higher than specified in the literature. For the ball-cock, this is primarily due to the design features mentioned above. In the case of the slanted seat valve and the gate, it should be noted that the data in the literature refers to larger nominal widths. In general, it can be assumed that resistance increases as the dimensions decline.

6 Opening characteristics of shut-off devices



These experiments examine the restriction behaviour of the shut-off devices ball-cock, valve and gate.

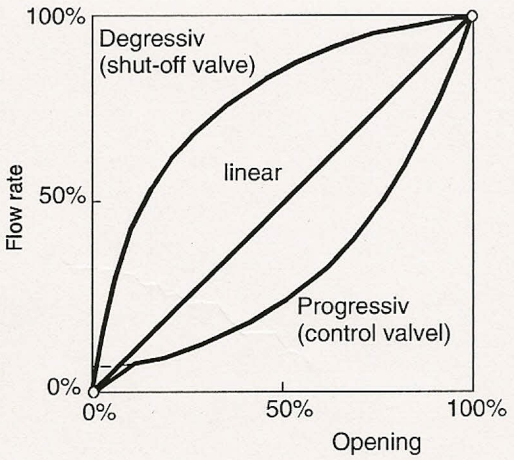
If these shut-off devices are used to halt certain volume flows in the pipeline system, it is essential to achieve good metering properties at low degrees of opening and volume flows.

The optimum solution is a progressive characteristic curve in which the degree of opening increases first slowly and then with increasing acceleration. Adjustment of the shut-off device by a certain absolute amount results in a corresponding percentual change in the volume flow.

For example:

If a valve with a maximum opening of 100% is opened from 1 to 2 revolutions, in other words, by 10% absolute, the volume flow will increase relatively by 10%, e.g. from 1 to 1.1 l/min.

This so-called "equal-percentage" characteristic curve is labelled progressive in the adjacent diagram. In addition, a linear and a degressive characteristic have been drawn in, as occurring in typical shut-off devices.



Opening characteristics of valves

6.1 Performing the experiment

As the pressure differences in closed valves exceed the measuring ranges of the manometers available, pressure is not measured.

- Seal all measuring glands with dummy plugs
- Connect pipe section 8 (ball valve, slanted seat valve) to the infeed and discharge tube
- Open the discharge from the pipe section
- Open the inflow to the pipe section

Ball-cock

- Close the ball-cock completely
- Open the slanted seat valve fully
- Open the ball-cock gradually by the defined angle e.g. 30° and make a note of the flow rate

Slanted seat valve

- Open the ball-cock fully
- Close the slanted seat valve completely
- Gradually open the slanted seat valve by the defined number of revolutions and make a note of the flow rate.

IMPORTANT! As the valve reacts very sensitively at the beginning, only open in small stages of 1/4 revolution initially.

Gate

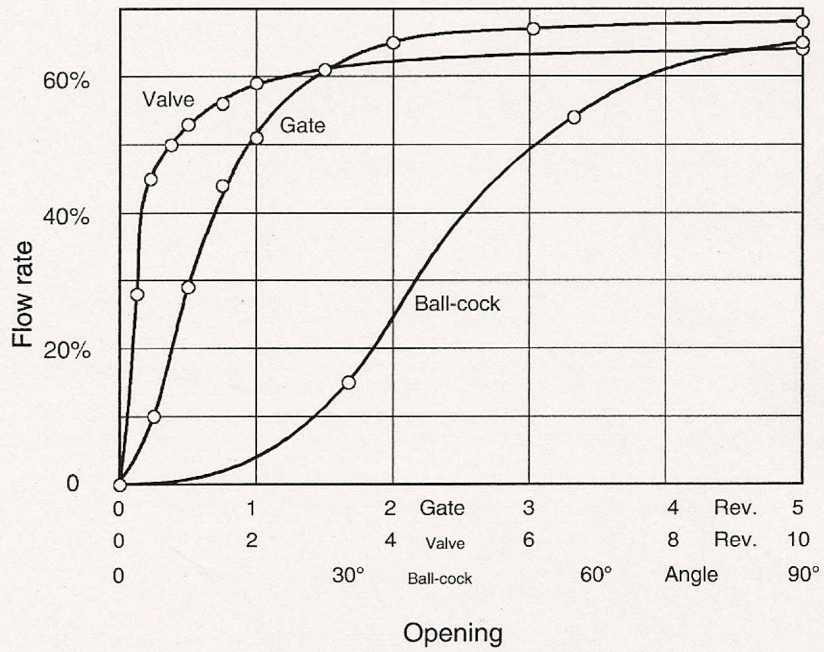
- Connect pipe section 9 to the infeed and discharge tube
- Seal all measuring glands with dummy plugs
- Open the discharge from the pipe section
- Open the inflow to the pipe section
- Close the gate completely

- Gradually open the slanted seat valve by the defined number of revolutions and make a note of the flow rate.

IMPORTANT! As the gate reacts very sensitively at the beginning, only open in small stages of 1/4 revolution initially.

6.2 Evaluation of the experiment

The noted measurements can be plotted in a graph over the opening of the shut-off device.



The valve opens very quickly and is therefore a typical shut-off device. The valve is equally as unsuitable as the gate for restricting a volume flow. The ball-cock, on the other hand, is far better suited as a restrictor device. Admittedly, none of the shut-off devices examined had a purely progressive characteristic curve indicating particularly good restriction characteristics.

7 Appendix

7.1 Tables and diagrams

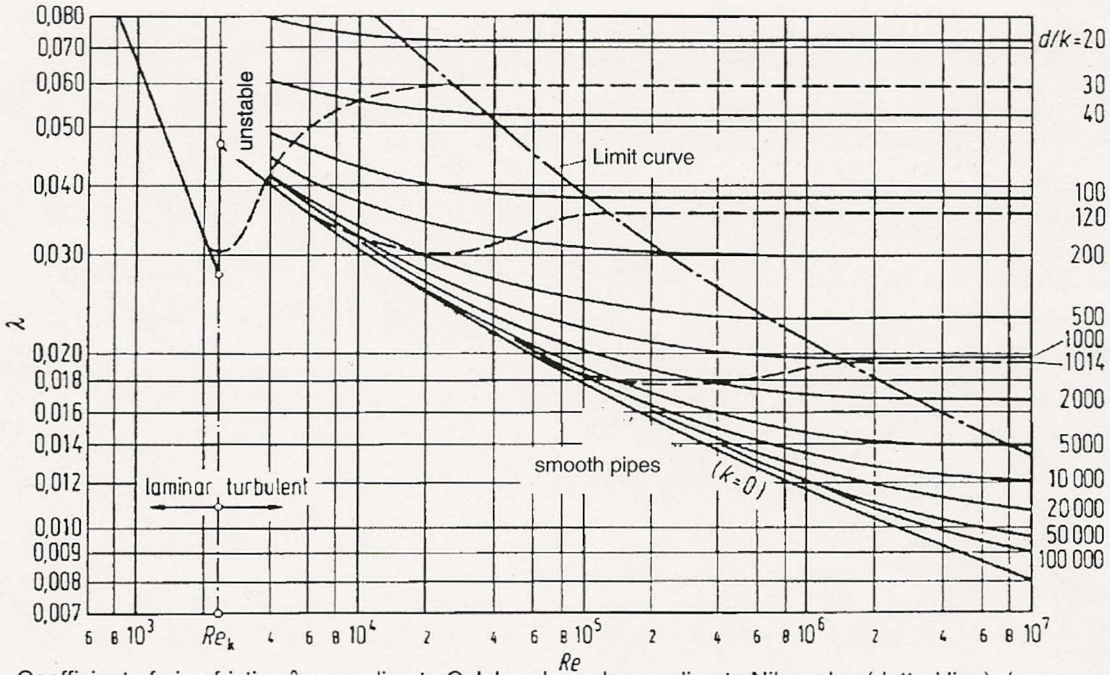
7.1.1 Wall roughness

Wall roughness of the experimental pipes		
Material	Surface	Wall roughness k in mm
Copper pipe, Cu	techn. smooth	0.001
PVC pipe	techn. smooth	0.001
Steel pipe, St	galvanized	0.100

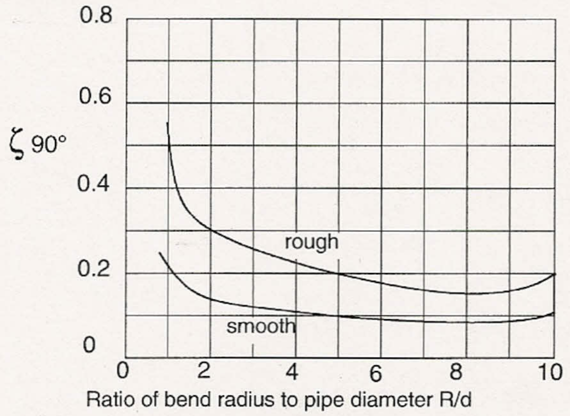
7.1.2 Kinematic viscosity

Kinematic viscosity of water depending on temperature (source: Kalide, Technische Strömungslehre)	
Temperature in °C	Kinem. viscosity ν in 10^{-6} m^2/s
10	1.297
11	1.261
12	1.227
13	1.194
14	1.163
15	1.134
16	1.106
17	1.079
18	1.055
19	1.028
20	1.004
21	0.980
22	0.957
23	0.935
24	0.914
25	0.894
26	0.875
27	0.856
28	0.837
29	0.812
30	0.801

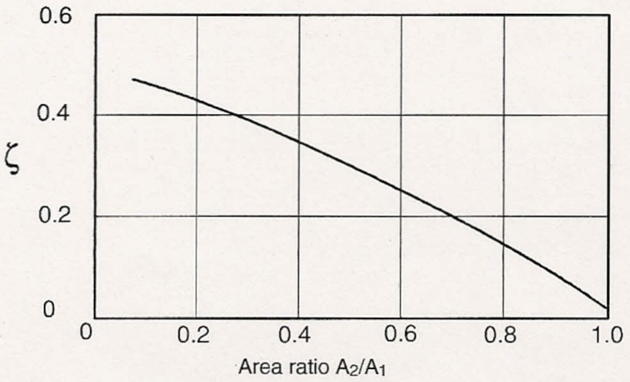
7.1.3 Diagrams



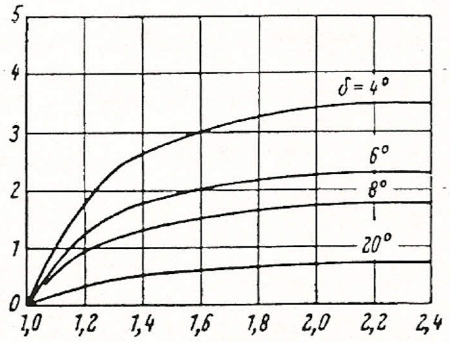
Coefficient of pipe friction λ according to Colebrook and according to Nikuradse (dotted line) (source: Dubbel, Taschenbuch für den Maschinenbau)



Coefficient of resistance ζ in 90°-bends



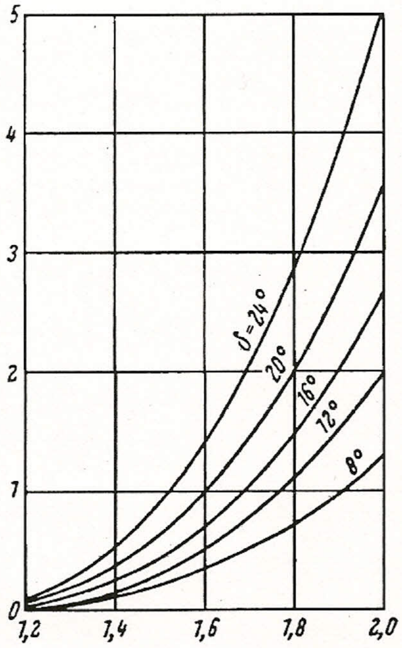
Coefficient of resistance ζ for discontinuous taper



Wall friction factor α witf continuous tapering (nozzle) depending on the tapering angle δ

$$\zeta = \alpha \frac{\lambda_1 + \lambda_2}{2}$$

(source: Kalide, Einführung in die technische Strömungslehre)



Coefficients of friction with continuous expansion (diffusor) depending on the diffusor angle δ

(source: Kalide, Einführung in die technische Strömungslehre)

7.2 Formulae

Volume flow in m^3/s

$$\dot{V}\,[m^3/s] = \frac{\dot{V}\,[\%]}{100\%} \cdot \frac{1600 l/h}{1000\ l/m^3 \cdot 3600 s/h} = \dot{V}\,[\%] \cdot 4.44 \cdot 10^6$$

Flow velocity: $v = \dfrac{4\,\dot{V}}{\pi\, d^2}$

Reynolds' number: $Re = \dfrac{v\, d}{\nu}$

Coefficient of pipe friction according to Blasius (smooth):

$$\lambda = \frac{0.3164}{\sqrt[4]{Re}}$$

Coefficient of pipe friction according to Colebrook (rough),requires an iterative solution , take starting values from diagram

$$\lambda = \left[2\,\lg\left(\frac{2.51}{Re\,\sqrt{\lambda}} + \frac{0.27}{d/k}\right)\right]^{-2}$$

Pressure loss and loss level due to pipe friction

$$p_v = \frac{\lambda\, l}{2\, d}\,\rho\, v^2\ ,\quad h_v = \frac{\lambda\, l}{d}\,\frac{v^2}{2\, g}$$

Pressure loss and loss level due to coefficient of resistance

$$p_{vz} = \zeta\,\rho\,\frac{v^2}{2}\ ,\quad h_{vz} = \zeta\,\frac{v^2}{2\, g}$$

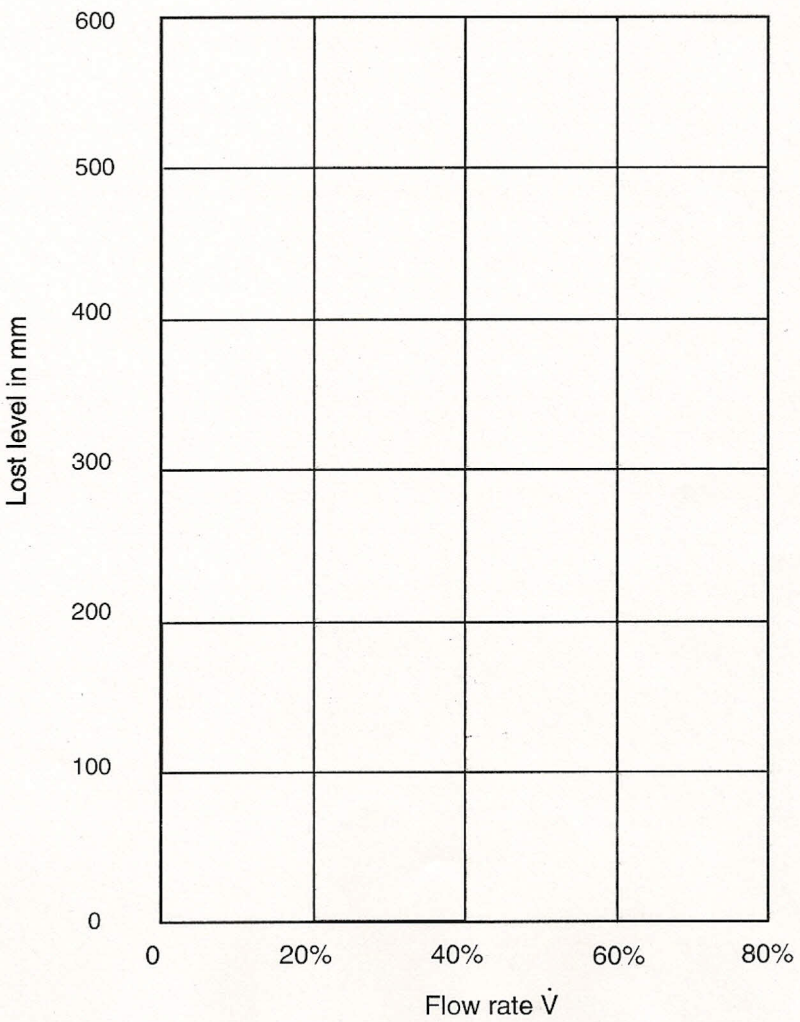
Total loss level in special pipeline elements

$$h_{vges} = \frac{1}{2\, g}\,(v_2^2 - v_1^2) + \frac{\lambda_1\, l_1}{d_1}\,\frac{v_1^2}{2\, g} + \frac{\lambda_2\, l_2}{d_2}\,\frac{v_2^2}{2\, g} + \zeta\,\frac{v_2^2}{2\, g}$$

7.3 Work sheets

7.3.1 Work sheet 1: Measurement results

Measuring results			
Volume flow $\dot{V}$ in %	Level pipe 1 h_1 in mm	Level pipe 2 h_2 in mm	Lost level $h_v = h_1 - h_2$ in mm



7.3.2 Work sheet 2: Calculation model for pipe friction

Calculation of loss levels						
Pipe section	Inner diameter **d** in mm	Volume flow		Flow velocity. **v** in m/s	Reynolds' number Re	Wall roughness ratio **d/k**
		$\dot{V}$ in %	$\dot{V}$ in m^3/s			

Pipe section	λ calculation according to Blasius or Colebrook	Coefficient of pipe friction λ	Calculated loss level h_V in m	Measured lost level h_V in m	Deviation in %

7.3.3 Work sheet 3: Calculation model for coefficients of resistance

Calculation of coefficients of resistanceζ							
Pipe section	Inner diameter d in mm	Lenght l in mm	Volume flow		Flow velocity. **v** in m/s	Reynolds' number **Re**	**d/k**
			$\dot{V}$ in %	$\dot{V}$ in m^3/s			

Pipe section	λ calculation according to Blasius or Colebrook	Coefficient of pipe friction λ	Measured lost level h_{vges} in m	**Coefficient of resistance ζ**

8 Index

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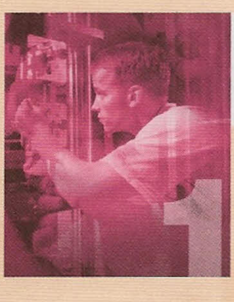
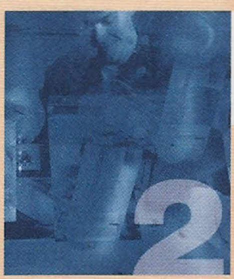
Z

GESAMTPROGAMM
PROGRAM OUTLINE

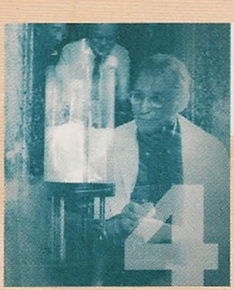


Technische Mechanik und Werkstoffprüfung
Theory of Machines & Properties of Materials

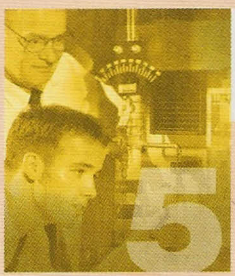


Mechatronik
Mechatronics

Wärmelehre und Versorgungstechnik
Thermodynamics, Heating & Sanitary Systems



Technische Strömungslehre
Fluid Mechanics & Hydrology



Regelungs- und Steuerungstechnik
Process Control Engineering

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