

ENSC 283: Friction and Minor Losses in Pipelines**Objective**

- To measure flow losses and pressure characteristics of different pipes and piping components.

Apparatus

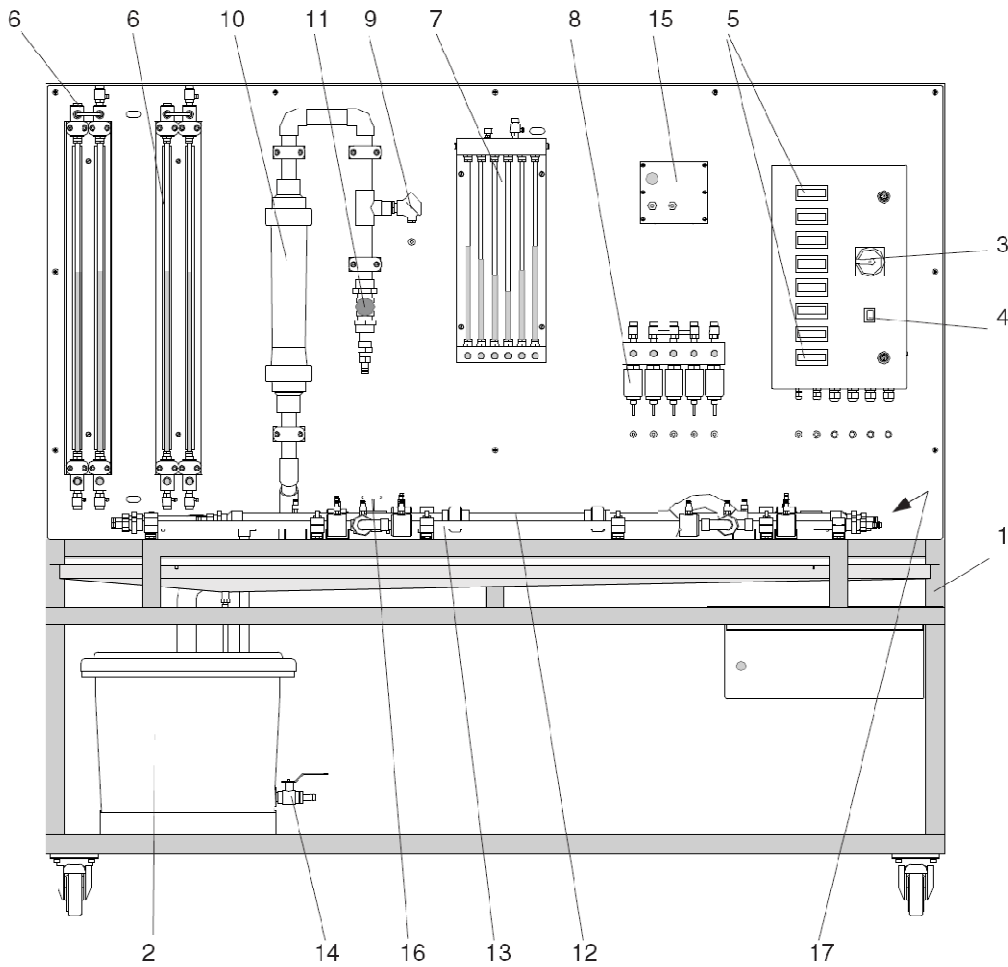
The experimental setup shown in Fig. 1 is equipped with independent pressure measuring systems, which enable one to measure relative and absolute pressure over a wide range. A variable-area flow meter is used for measuring the volumetric flow rate. Water is fed into the system using a centrifugal pump. Water first passes through flow meter and the inlet valve. Then, water enters the selected pipe section via the inlet hose, see Fig. 2. The pressure is measured at measuring glands at the beginning and the end of the measuring section. Finally, water returns into the tank using a second hose. Using the experimental setup, overall pressure loss can be measured in the following components:

- PVC, copper, galvanized steel pipes.
- Turns, bends.
- Sudden expansions or contraction.
- Slanted seat, membrane, and check valves.

Moreover, the employed setup can be connected to a PC to record the measurements for further investigations. The flow rate, differential pressure, excess pressures and the temperature are also shown on digital displays in the switch cabinet.

The pressure drop can be measured using double tube manometer or differential sensor. The double tube manometer allows both differential pressures and gauge pressures to be measured in mm column of water. The measuring range of double tube manometer is 0 - 680 mm column of water. The differential pressure is measured with the bleed valve closed and the excess pressure with the bleed valve open. The measuring points are connected to the bottom of the level tubes using quick action hose couplings. The differential pressure unit has 2 connections, P1 and P2 (1), between which differential pressure up to a maximum of 200 mbar can be measured.

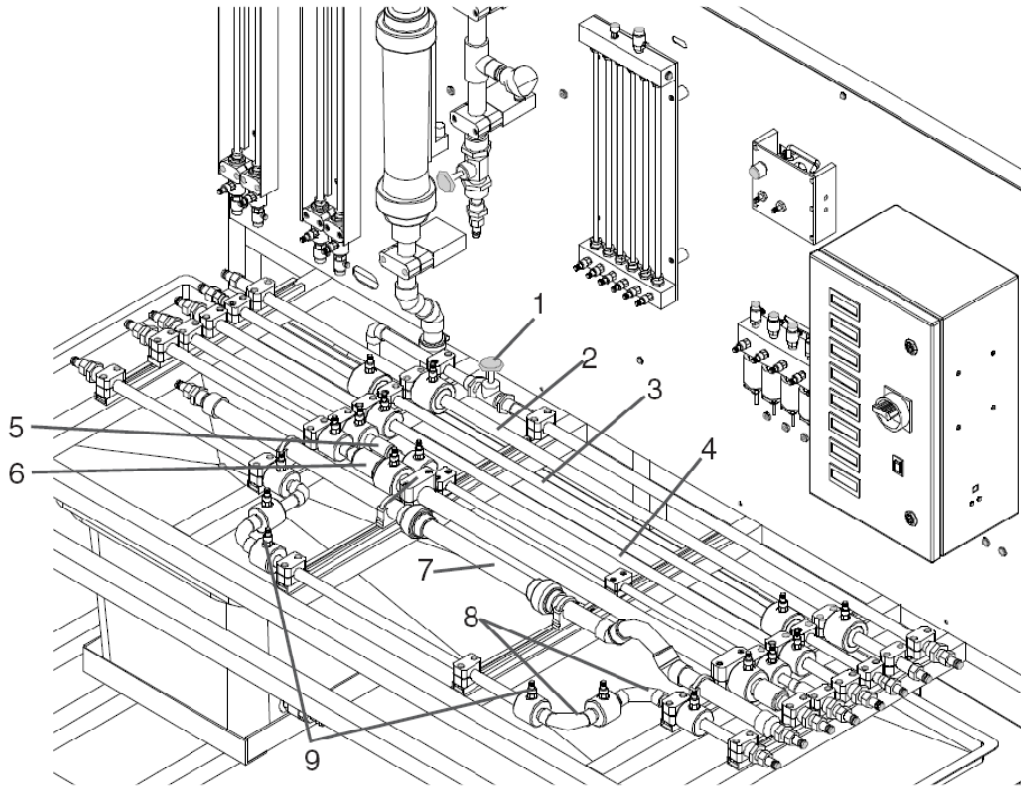
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|---|--|----|-----------------------------------|
| 1 | Laboratory trolley | 10 | Vane impeller flow meter |
| 2 | Water tank with immersion pump | 11 | Inlet regulator valve |
| 3 | Master switch | 12 | Interchangeable measuring objects |
| 4 | Switch for pump | 13 | Various measuring sections |
| 5 | Digital displays for flow and pressure | 14 | Tank drain valve |
| 6 | Double level tube manometer | 15 | Differential pressure sensor |
| 7 | Six tube manometer | 16 | Return valve |
| 8 | Electronic pressure sensor | 17 | Return pipe |
| 9 | Thermometer | | |

Figure 1- Components of experimental apparatus.

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- | | | | |
|---|---|---|---|
| 1 | Return pipe with return valve to water tank | 6 | Cross-section expansion PVC 20-32 |
| 2 | Galvanized steel pipe, 1/2" | 7 | Section for interchangeable measuring objects |
| 3 | Cu-pipe 18 x 1 | 8 | Pipe bend, pipe angle PVC 20x1.5 |
| 4 | PVC-pipe 20 x 1.5 | 9 | Self closing measuring glands |
| 5 | Cross-section constriction PVC 20-16 | | |

Figure 2- View of the setup test section.

Software

The software has two main windows, “system diagram” and “measurement diagram”. The system diagram is a clearly arranged representation of the measuring task. The lower button can be used to toggle between different measuring tasks, including: Pipe, Nozzle/orifice, Pitot tube, Pipeline fittings, and Venturi tube.

Pressures can be represented as water columns or using a differential pressure gauge. To change the setting, use the “View” option in the menu. The flow, pressures and temperature are displayed online.

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The “Start” option takes you to the “measurement diagram” option. This window can be used to create the diagrams.

In the measurement diagram window, click on Start in the menu bar to record, load and save a curve. Clicking on the button with the red spot records measured data and adds it to the active data series.

In summary the following steps should be followed:

- Open the “measurement diagram” window under “Start” in the menu bar.
- Create a new measuring series (“New series”) under “File” in the menu bar.
- If necessary, specify the axes for the diagram. This setting is made using “View” and “choose axis” in the window that is subsequently opened. You can select a maximum of four different y-axes and one x-axis.
- You can then record measured data using the record button or by selecting the “take record” option under “Edit” in the menu bar.
- After recording the measuring series, you can save it to the hard disk or an alternative medium using the “save series” command in the “File” menu.

Theory

Assuming steady-state, incompressible, and 1D flow, the energy equation becomes:

$$\frac{p_1}{\rho} + \frac{V_1^2}{2} + gz_1 = \frac{p_2}{\rho} + \frac{V_2^2}{2} + gz_2 + \frac{p_{loss}}{\rho} \quad (1)$$

where p_{loss} is the pressure loss between sections 1 and 2, V is the average velocity, z is the elevation from a reference point, and ρ is the density. Two main sources exist for pressure drop in pipelines:

- 1) Friction loss and wall shear stress.
- 2) Minor loss, which is caused by changes in the geometry.

For fully-developed flow in channels frictional pressure drop can be calculated from Darcy-Weisbach equation:

$$p_{friction} = \rho f \frac{l V^2}{d} \quad (2)$$

where f is the friction factor, d and l are channel diameter and length, respectively. The friction factor is related to the flow regime. Reynolds number is a good criterion for prediction of flow regime:

$$Re = \frac{\rho V d}{\mu} \quad (3)$$

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where μ is the viscosity of the fluid. For laminar flows where $Re < 2300$, f is calculated as:

$$f = \frac{64}{Re} \quad (4)$$

In turbulent flows, i.e., $Re > 2300$, f is a function of both Reynolds number and pipe roughness, k . For hydraulically smooth pipes, $Re < 65 d/k$, and a Reynolds number in the range of $2320 < Re < 10^5$ the pipe friction coefficient is calculated using the Blasius formula:

$$f = \frac{0.3164}{\sqrt[4]{Re}} \quad (5)$$

For rough pipes the pipe friction coefficient is read from Moody diagram or evaluated using Colebrook formula:

$$f = \left[2 \log \left(\frac{2.51}{Re \sqrt{f}} + \frac{0.27k}{d} \right) \right]^{-2} \quad (6)$$

Special pipe components and fittings such as pipe bends or elbows, pipe branches, changes in cross-section, and valves alter flow geometry and produce additional pressure losses apart from the wall friction losses. These minor losses can be calculated from the following relationship:

$$p_{minor} = \rho \zeta \frac{V^2}{2} \quad (7)$$

where ζ is the coefficient of resistance. Therefore, when a fitting or a connection exists in a pipe of length l and the total pressure drop in the system is known, the coefficient of resistance of the fitting is found from the following equation:

$$\zeta = \frac{2p_{loss}g}{\rho V^2} - \frac{fl}{d} \quad (8)$$

Procedure

Before starting the experiment:

- Place experimental unit on a flat surface and secure against rolling away (brake).
- Fill up water tank.
- Connect to power supply.

In this experiment, pipes made of different materials (PVC, copper and galvanized steel) are compared. The measuring length is 1000 mm.

- Connect the double tube manometer to the pressure glands on the pipes.

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- Start the pump and measure the pressure drop across the pipe.
- Repeat the experiment for different flow rates.

Plot the measured values of pressure drop versus Reynolds number and compare it with the values obtained from theoretical relationships.

The changes in cross-section available on the experimental unit take the form of continuous expansion or constriction.

- Connect double tube manometer or differential pressure sensor
- Measure pressure drop for several volume flow rates and evaluate the resistance coefficient of expansion and constriction fittings.

Compare the experimental data with theoretical results, see Discussion 2. It should be noted that $l=145$ mm.

Discussion

- 1) Starting from differential equations governing fully-developed flow in circular pipes, derive equation (4).
- 2) Find an equation for prediction of coefficient of resistance in expansion and constriction junctions.
- 3) How does the flow regime affect the coefficient of resistance in the considered fittings?

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Appendix 1 (Measurements)

Pipe section type	Diameter (mm)	Volumetric flow rate	Inlet pressure	Outlet pressure	Temperature
Galvanized steel, 1/2"	16				
Galvanized steel, 1/2"	16				
PVC, 18 × 1	16				
PVC, 18 × 1	16				
Copper, 20 × 1.5	17				
Copper, 20 × 1.5	17				
Expansion	17 to 28.6				
Expansion	17 to 28.6				
Constriction	17 to 14.5				
Constriction	17 to 14.5				

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Appendix 2 (Calculations)

Wall roughness of experimental pipes		
Material	Surface	Wall roughness k
Copper pipe, Cu	Technically smooth	0.001 mm
PVC pipe	Technically smooth	0.001 mm
Steel pipe, St	galvanized	0.1 mm

Pipe section	Volumetric flow rate (m^3/s)	Reynolds number	d/k
Galvanized steel, 1/2"			
Galvanized steel, 1/2"			
PVC , 18 ×1			
PVC, 18 ×1			
Copper, 20 ×1.5			
Copper, 20 ×1.5			
Expansion			
Expansion			
Constriction			
Constriction			

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Pipe section	Volumetric flow rate	f	Pressure drop (theoretical)	Pressure drop (experimental)	Relative Difference (%)
Galvanized steel, 1/2"					
Galvanized steel, 1/2"					
PVC, 18 × 1					
PVC, 18 × 1					
Copper, 20 × 1.5					
Copper, 20 × 1.5					

Fitting	Volumetric flow rate	f	Pressure drop	Minor pressure drop	Coefficient of resistance (ζ)
Expansion					
Expansion					
Constriction					
Constriction					