Work 197. Mechanics of a flow

Purpose

Measuring basic characteristics of a laminar flow of a liquid. Determination of the dependences of the flow rate on the tube cross-area and of the hydraulic impedance on the tube diameter. Verifying the Hagen–Poiseuille law.

Tasks to solve

1) Check the equality of flow rates in tubes of different diameters.
2) Determine the coefficient of dynamic viscosity of a liquid.

Safety notes

1. The apparatus is connected to the 220 V power mains.
2. Do not cover openings on the apparatus which are necessary for ventilation.
3. Do not thrust any things into the apparatus: it can lead to short circuit.
4. Before using the ultrasonic probe, ascertain its integrity. If the sensor is broken, replace it.
5. Unplug the sensors by holding the socket. Do not pull the wire!
6. Peak voltage on the sensor's contacts can achieve 300 V. Do not touch the sockets while the apparatus is in work!
7. Do not apply the apparatus to people or other objects except special test samples used in this work.
8. Do not unplug the tubes with liquid from each other.
9. Do not drink the Doppler liquid.
10. Important! When starting the pump programme (with the "Start" knob), assure that the flow rate control handwheel is in the leftmost position (rotate it anti-clockwise), corresponding to the minimal flow speed.

Experimental setup

1. Ultrasonic scanner FlowDop (see figure 1)
2. Ultrasonic probe (2 MHz)
3. Setup for measurements (prisms, tubes of different diameters (1/2", 3/8", and 1/4"), Multiflow pump, Doppler liquid
4. Stand pipes for measuring the pressure
5. Ultrasound gel

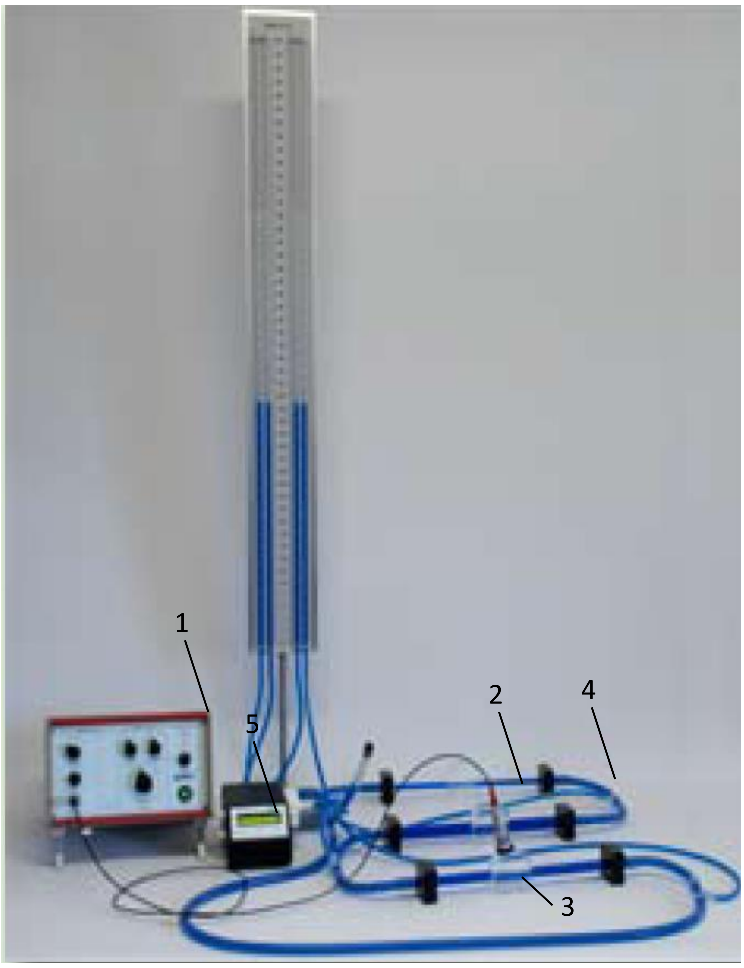

Figure 1. General view of the experimental setup for investigation of the flow mechanics: (1) ultrasonic scanner FlowDop; (2) ultrasonic probe (2 MHz); (3) prism; (4) set of tubes; (5) Multiflow pump.

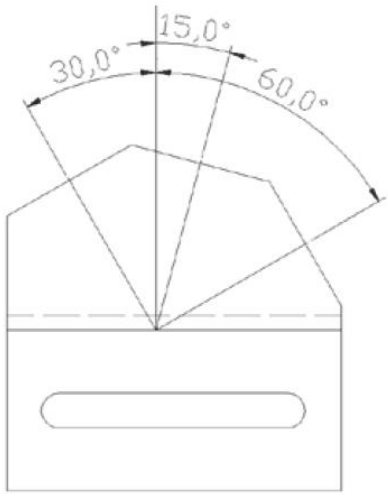

Figure 2. Prism for studying the flow mechanics.

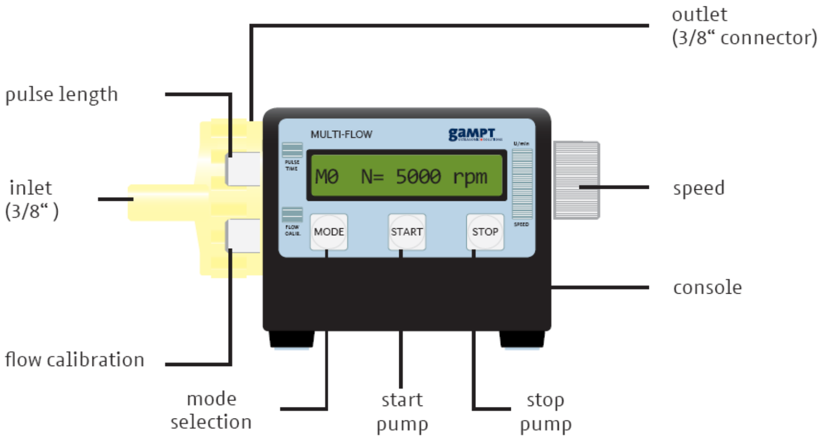

Figure 3. Scheme of the Multiflow pump.

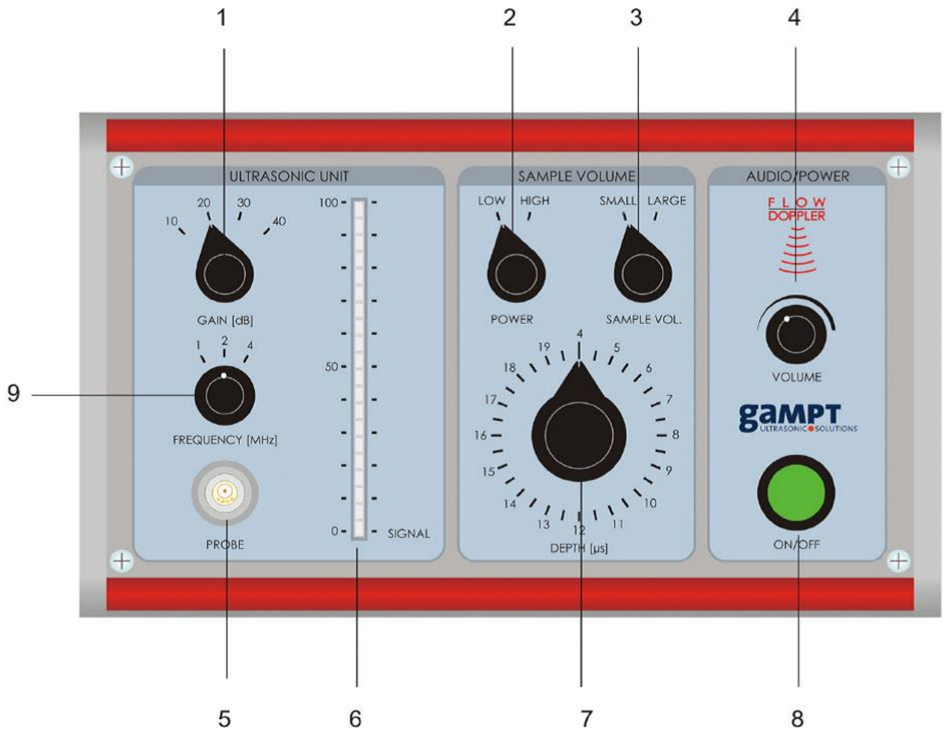

Figure 4. Front panel of the ultrasonic scanner Flow-Dop.

Description of the scanner's front panel:

1. Signal gain switcher
2. Switcher of the pack time or of the transmitter power
3. Switcher of the receiver time window or of the sample volume
4. Signal level (volume)
5. Socket for the probe
6. Indicator of the input signal
7. Time window of the receiver (when switcher "3" is in position "Small")
8. Power on-off

Brief theory

Continuity equation for a flow in tubes of various diameters is written as

$$S_1 v_1 = S_2 v_2 = const = Q, \qquad (1)$$

where v_1 and v_2 are the mean speeds of the flow in its two segments (in the two tubes), S_1 and S_2 are the tubes' cross-areas, and Q is the flow rate (liquid discharge).

Static pressure in moving liquid is smaller than in motionless liquid, and the faster is the flow speed the smaller is the pressure (the Bernoulli equation). If we consider a horizontal tube (so that the pressure of the liquid column shouldn't be taken into account), the net pressure p_0 is defined by the formula

$$p_0 = p + \frac{1}{2}\rho v^2, \qquad (2)$$

where ρ is the density of the liquid, v is the speed, and p is the hydrostatic pressure. p_0 is a constant only if there is no internal friction in liquid. In the presence of the internal friction, the net pressure is reduced depending on the viscosity η, tube length l, tube cross-area S, and the flow speed v. When the speed is relatively low (and the flow is laminar), the Hagen–Poiseuille law is fulfilled in thin tubes, which states that the pressure drop is proportional to the flow rate:

$$\Delta p = RQ. \qquad (3)$$

Here R is the hydraulic impedance which equals to

$$R = \frac{8\eta l}{\pi r^4}, \qquad (4)$$

where r is the tube radius.

Thus, decreasing the vessel diameter two times results in 16-fold increase of its hydraulic impedance.

Conducting the measurements

Preparations

1. Connect and tune the setup.
2. Check that there are no air bubbles in the tubes.
3. Turn the switchers "Power" and "Sample vol." to positions "High" and "Large," respectively.

Measurements

1. Before you begin the measurements, put off red caps from upper ends of the vertical pipes.
2. Turn on the ultrasonic scanner FlowDop and launch the programme FlowView on the laptop.

3. Turn on the Multiflow pump by a tumbler on its rear side and press the knob "Start." In the second regime (controlled by the "Mode" knob, regime M1), set the flow rate to 1 l/min using the handwheel on the side of the pump.
4. Apply a small amount of gel onto the 1/2" glass tube (the biggest diameter) and put above it a prism of a suitable size. Check that there are no air bubbles between the tube and the prism.
5. Apply a small amount of gel to a prism face corresponding to the angle of 15° and place the ultrasonic sensor (2 MHz, red) above.
6. In the FlowView programme choose the proper tube diameter in the "Parameter" tab (figure 5).

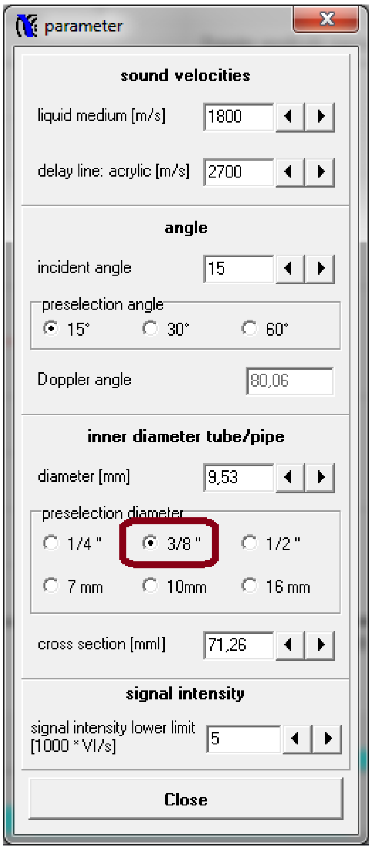

Figure 5.

7. Close the "Parameter" tab and start the experiment with the "Start" button.

8. Measure the speed v and the flow rate Q (figure 6).

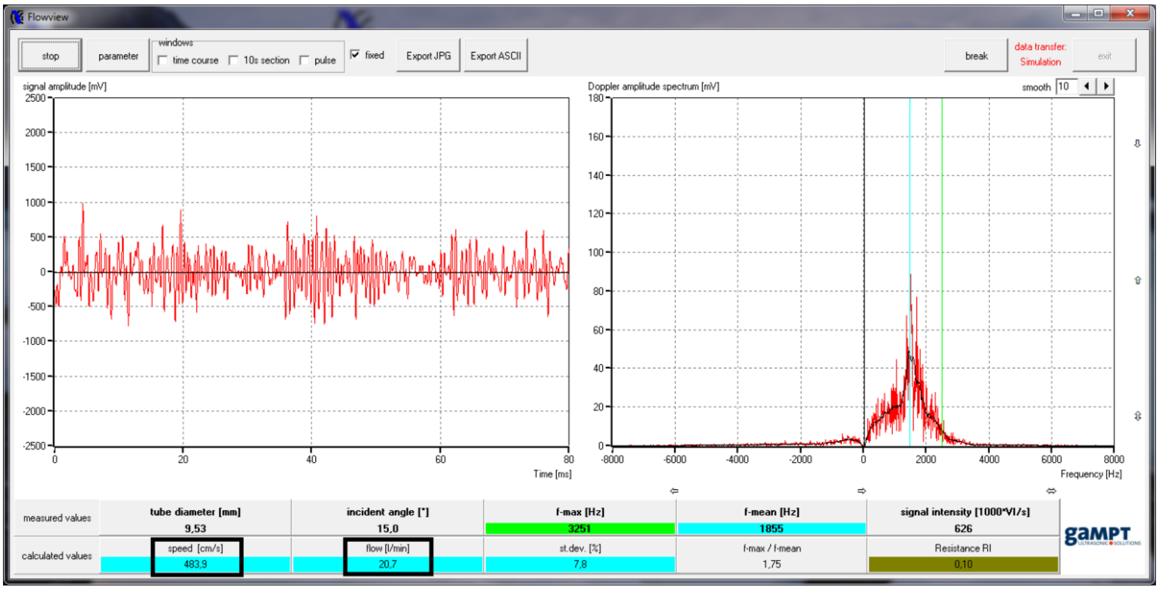

Figure 6. Main window of the programme.

9. Write down the results into the table 1.
10. Measure the difference of the liquid levels between the pipe attached to the investigated tube and the right pipe. Calculate the pressure drop as

$$\Delta p = \rho g \Delta h\,, \qquad (5)$$

where ρ is the density of water (1000 kg/m^3), g is the gravitational acceleration (9.8 m/s^2), and Δh is the difference between the liquid levels in the water columns.
11. Calculated the hydraulic impedance of each tube using the formula

$$R = \Delta p / Q\,, \qquad (6)$$

where Q is the flow rate (measured in m^3/s!).
12. Fill in the table 2 with your results.
13. Find the viscosity for each flow as

$$\eta = \frac{R\pi r^4}{8l}\,, \qquad (7)$$

where the tube length is l = 0.3 m (30 cm).
14. Calculate the mean values of viscosity and hydraulic impedance and write them down in table 3.
15. Repeat the experiment (steps 3–14) for the flow rates of 1.5 and 2 l/min.
16. Repeat steps 3–15 for the tubes with the diameters of 3/8" and 1/4".
17. Build the graphs showing the dependencies of the flow speed v and the hydraulic impedance R on the inner diameter of the tube d. The inner diameter is displayed in the operating window.
18. Make necessary conclusions.

Table 1

Tube	1/2"		3/8"		1/4"	
Preset flow, l/min	*v*, cm/s	*Q*, l/min	*v*, cm/s	*Q*, l/min	*v*, cm/s	*Q*, l/min
1						
1.5						
2						

Table 2

Tube	1/2"		3/8"		1/4"	
Preset flow, l/min	Δp, Pa	R, Pa·s/m^3	Δp, Pa	R, Pa·s/m^3	Δp, Pa	R, Pa·s/m^3
1						
1.5						
2						

Table 3

d, mm	R, Pa·s/m^3	η, Pa·s

Questions

1. Elastic waves. Wave equations. Velocity of elastic waves. Sound waves.
2. Doppler effect for sound waves.
3. Viscosity of liquids. Laminar and turbulent flow. Reynolds number.
4. Hydraulic impedance. The Hagen–Poiseuille law.