MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE

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Methodological Guidelines

for Laboratory Works

on the Subject

«TECHNICAL MECHANICS of LIQUID and GAS»

(for 2-year full-time and 1–2-year part-time students education level "bachelor"
specialty 192 – Building and civil engineering)

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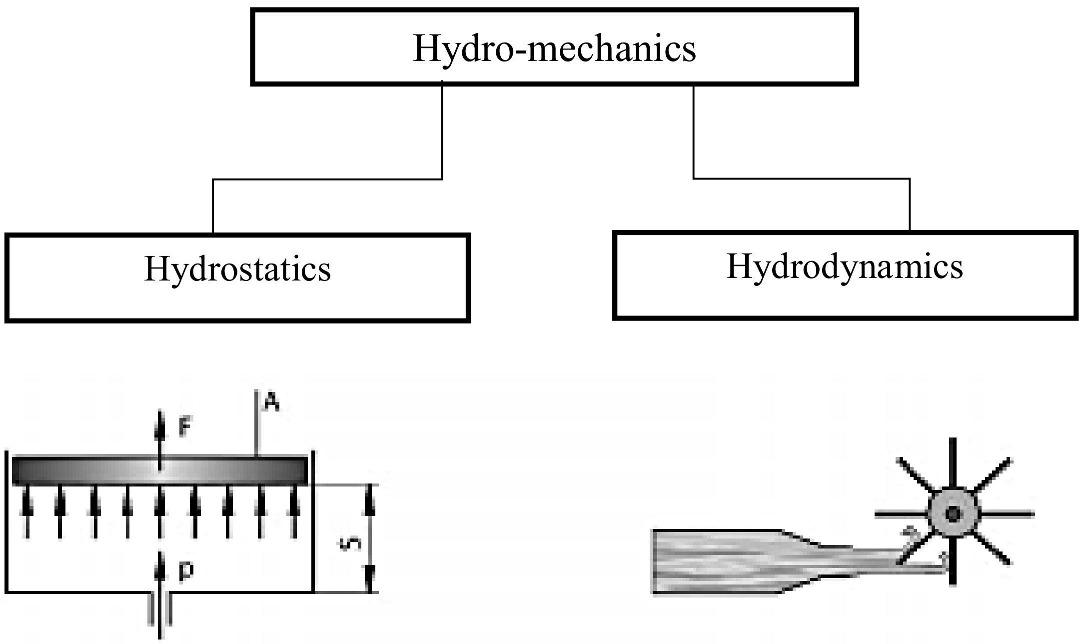
INTRODUCTION

Methodological guidelines for performance laboratory works on the subject "Technical Mechanics of Liquid and Gas" (for 2d-year full-time and 1–2-year part-time students education level "bachelor" specialty 192 – Building and civil engineering). Their main task is to help students studying this discipline to acquire the skills of applying theory in solving specific hydraulic problems, to master the technique of hydraulic calculations.

Hydraulics is the science of force and movement transmitted by means of liquids. It belongs alongside hydro-mechanics. A distinction is made between (Fig. 1.1):

– hydrostatics – dynamic effect through pressure times area;
– hydrodynamics – dynamic effect through mass times acceleration.



Force effect through pressure area

Force effect through mass acceleration

Figure 1.1 – Discipline study scheme

When learning the subject "Technical Mechanics of Liquid and Gas", laboratory work has the particular importance. Methodological guidelines are based on laboratory equipment of "Engineering Hydraulics and Pumps" by the department of Water Supply, Sewerage and Water Treatment of O. M. Beketov National University of Urban Economy in Kharkiv.

Description of each laboratory work is performed according to the scheme:

- general information on a topic that illustrates or confirms laboratory work;
- the structure of the laboratory work;
- description of the laboratory installation;
- the order of the work;
- processing of experimental data;
- the form of the journal in which the measurement results are recorded;
- review questions.

1 THEORETICAL MATERIAL

1.1 Basic Physical Properties of Liquids and Gases

Density or Mass Density. Density or mass density of a fluid is defined as the mass of a fluid to its volume. Thus mass per unit volume of a fluid is called density. It is denoted the symbol ρ (rho). The unit of mass in SI unit is kg per cubic metre, i.e. kg/m^3. The density of liquids may be considered as constant while that of gases changes with the variation of pressure and temperature.

Mathematically, mass density is written as:

$$\rho = \frac{Mass}{Volume} = \frac{m}{V}\left(\frac{kg}{m^3}\right). \tag{1.1}$$

The value of density of water is 1 gm/cm^3 or 1 000 kg/m^3.

Specific Weight or Weight Density. Specific weight or weight density of a fluid is the ratio between the weight of a fluid to its volume. Thus weight per unit volume of a fluid is called weight density and it is denoted by the symbol γ.

The mathematically, specific weight is written as:

$$\gamma = \frac{Weight}{Volume} = \frac{G}{V}\left(\frac{N}{m^3}\right). \tag{1.2}$$

Density and specific weight are related by:

$$\rho = \frac{\gamma}{g} \Rightarrow \gamma = \rho \cdot g\,, \tag{1.3}$$

where g is acceleration due to gravity, 9,81 m/s^2.

Specific gravity of liquids. Specific gravity, SG – is a dimensionless unit defined for liquids as the ratio of the density of the liquid to the density of water at a specified temperature 4 ºC.

The Kinematic Viscosity. The value v obtained by dividing viscosity ρ by density ρ is called the kinematic viscosity or the coefficient of kinematic viscosity:

$$\upsilon = \frac{\mu}{\rho}, \tag{1.4}$$

where μ is the coefficient of dynamic viscosity.

1.2 Flow of Fluids

The study of fluid motion with the forces causing flow is called dynamics of fluid flow, which is analyzed by Newton′s second law of motion.

Path line. The path followed by a single fluid particle over a given when the fluid is in motion is called the path line.

Stream line. Stream line is the tangent drawn at any point on an imaginary line in the flowing fluid, and gives the direction of motion at the point.

The following are the different types of flow:

Steady flow is that type of flow in which the velocity, pressure, density etc. at a point do not change with time.

Unsteady flow is that type of flow in which the velocity, pressure, density etc. at a point change with time.

Uniform flow is that type of flow in which the velocity is equal at all points (i.e. flow through a pipe of constant diameter).

Non-uniform flow is that type of flow in which the velocity is different at different points (i.e. flow through a pipe of varying diameter).

Laminar flow is that type of flow in which the fluid particles move in a straight path.

Turbulent flow is that type of flow in which the fluid particles move in a zig-zag path.

Compressible flow is that type of flow in which the density is not constant for the fluid flow.

Incompressible flow is that type of flow in which the density is constant for the fluid flow.

Rotational flow is that type of flow in which the fluid particles rotate about their own axis.

Irrotational flow is that type of flow in which the fluid particles do not rotate about their own axis.

One-dimensional flow is that type of flow in which the velocity is a function of time and one space co-ordinate only.

Two-dimensional flow is that type of flow in which the velocity is a function of time and two space co-ordinates.

Three-dimensional flow is that type of flow in which the velocity is a function of time and three space co-ordinates.

1.2.1 The Equation of Continuity of the Liquid for Incompressible and Compressible Flows

Continuity equation is based on the principle of conversation of mass. According to it, the quantity of fluid flowing per second is the same at all sections of the flow. Consider two section of a pipe as shown in Figure 1.2.

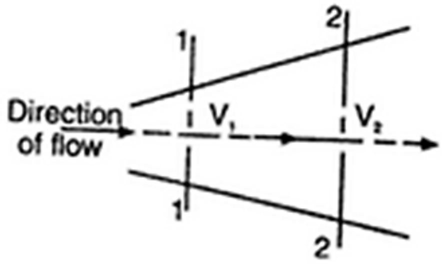


Figure 1.2 – The section of a pipe

Let A_1, A_2 – area of pipe at section 1–1 and 2–2 corresponding;
V_1, V_2 – velocity at section 1–1 and 2–2 considered;
ρ_1, ρ_2 – density at section 1–1 and 2–2 considered.
Rate of flow at section 1–1 equal rate of flow at section 2–2:

$$\rho_1 \cdot A_1 \cdot V_1 = \rho_2 \cdot A_2 \cdot V_2 . \tag{1.5}$$

This equation is known as continuity equation which is applicable to compressible as well as incompressible fluids. If the fluid is incompressible, then $\rho_1 = \rho_2$. Thus equation of continuity of flow is:

$$A_1 \cdot V_1 = A_2 \cdot V_2 , \tag{1.6}$$

where Q – is discharge per second or volumetric flow rate;
A – is area of cross-section considered;
V – is average velocity of the fluid.

1.2.2 Energies of flowing fluid

The following are the energies of flowing fluid:
- potential energy;
- kinetic energy;
- pressure energy.

Pressure energy of a liquid particle is the energy possessed by the liquid particle by virtue of its pressure.

Kinetic energy of a liquid particle is the energy possessed by the liquid particle by virtue of its motion.

Potential energy of a liquid particle is the energy possessed by the liquid particle by virtue of its position.

Bernoulli's *theorem* states that for any mass of flowing fluid when there is continuous connection between all the particles of flowing fluid, the total energy remains the same at all sections of flow provided there is no loss of energy.

Bernoulli's equation. Bernoulli's equation is obtained by integrating the Euler's equation of motion. Bernoulli's equation states *"For a steady, ideal flow of an incompressible fluid, the total energy which consists of pressure energy, kinetic energy and datum energy, at any point of the fluid is constant"*.

Mathematically,

$$z_1 + \frac{p_1}{\rho g} + \frac{\alpha V_1^2}{2g} = z_2 + \frac{p_2}{\rho} + \frac{\alpha V_2^2}{2g}, \tag{1.7}$$

where $\frac{P}{\rho g}$ – pressure energy per unit weight or pressure head (energy);

$\frac{\alpha V_1^2}{2g}$ – kinetic energy per unit weight or kinetic head (energy);

Z_1 – datum energy per unit weight or datum head (potential energy).

Bernoulli's equation for real fluids

$$z_1 + \frac{p_1}{\rho g} + \frac{\alpha V_1^2}{2g} = z_2 + \frac{p_2}{\rho g} + \frac{\alpha V_2^2}{2g} + h_{L1-2}, \tag{1.8}$$

where $h_{L1\text{-}2}$ – loss of energy between section 1 and 2.

There are two varieties of energy loss:

- energy loss in length (see lab. № 1);
- local losses (see lab. № 2).

Thus, the general expression of the loss of resistance (loss of energy) by Bernoulli's equation is as follows:

$$h_L = \Sigma h_l + \Sigma h_{loc}. \tag{1.9}$$

The Darcy-Weisbach equation for determining the loss of resistance by the length when the fluid moves through the pipe:

$$h_l = \lambda \frac{l}{d} \cdot \frac{V^2}{2g}, \qquad (1.10)$$

where λ – the friction coefficient of the pipe;

l – the length of the pipe section;

d – the pipe diameter;

V – velocity;

g – acceleration of gravity.

The formula of Y. Weisbach for determining the local losses is:

$$h_{loc} = \xi \cdot \frac{V^2}{2g}, \qquad (1.11)$$

where ξ – is the coefficient of local resistance.

1.2.3 Types of Fluid Flow

Based on the range of Reynold's number, the flow of fluid is classified as laminar flow, transition flow and turbulent flow.

1. **Laminar flow:** In the laminar flow region, the flow is characterized by the smooth motion of the laminae or layers. When there is no macroscopic mixing of adjacent fluid layers for the flow in the laminar regimes, the Reynold's number is less than 2 000.

2. **Turbulent flow:** In the turbulent flow region, the flow is characterized by the random motion of the fluid particles in three dimensions in addition to mean motion. There is considerable macroscopic mixing of adjacent fluid layers and significant velocity fluctuations. For the turbulent flow, the Reynold's number is greater than 4000.

3. **Transition flow:** In the transition flow region, the flow is in transition between laminar and turbulent flows. The Reynold's number lies between 2 000 and 4 000.

A distinction is made between laminar and turbulent flow as shown in Figure 1.3.

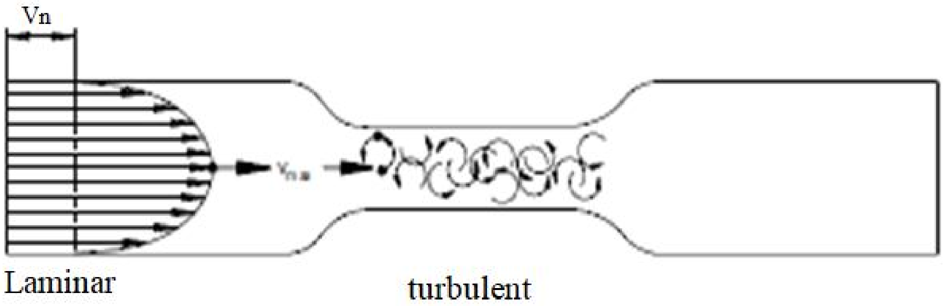


Figure 1.3 – Laminar and turbulent flow

A method of calculating the type of flow in smooth pipe is enabled by the Reynold's number (Re). this is dependent on:

- the flow velocity of the liquid V (m/s);
- the pipe diameter d (m);
- and the kinematic viscosity ν (m^2/s) (see Appendix B).

The Reynold's number set criteria by which the fluid flow regime may be distinguished:

$$\mathrm{Re} = \frac{\rho V d}{\mu}, \tag{1.12}$$

where ρ is the density (kg/m^3);

V is the velocity of fluid (m/s);

d is the diameter of the pipe (m);

μ is the absolute or dynamic viscosity (Pa·s or ms/m^2).

Thus, Reynold's number may be distinguished also as:

$$\mathrm{Re} = \frac{Vd}{\nu}. \tag{1.13}$$

The physical variable "kinematic viscosity" is also referred to simply "viscosity".

A value for Re calculated with this formula (1.9) can be interpreted as follows:

- laminar flow: Re < 2 300;
- turbulent flow: Re > 2 300.

The value 2 300 is termed the critical Reynold's number (Re_{crit}) for smooth round pipes.

Turbulent flow does not immediately laminar on falling below number (Re_{crit}).

The laminar range is not reached ½ number (Re_{crit}).

2 LABORATORY WORKS

Laboratory Work № 1

Determination of the Friction Coefficient of the Pipe in the Motion of the Fluid in Pressure Pipeline

General Information

Solving many problems of hydraulics is to find the dependence of the change in the flow velocity in length. To do this, we use two equations of hydrodynamics:

1) The equation of continuity of the liquid flows:

$$U_1 A_1 = U_2 A_2 = \dots = U_n A_n = const = Q. \qquad (2.1)$$

2) Bernoulli's equation:

$$z_1 + \frac{p_1}{\gamma} + \frac{\alpha V_1^2}{2g} = z_2 + \frac{p_2}{\gamma} + \frac{\alpha V_2^2}{2g} + h_L. \qquad (2.2)$$

But these two equations have 3 unknowns: velocity, pressure, and loss of resistance, so for their solution it is necessary to have the third equation for which unknown values are found. This equation is the dependence of the cost of resistance on the average velocity.

It is known that the quantitative determination of energy expenditure and the study of methods for their calculation is one of the main tasks of hydraulics. Experiments show that in many cases the loss of resistance is proportional to the square of the average fluid velocity, so it is customary to express in hydraulics energy expenditure in proportion to the velocity of the head:

$$\Sigma h_{loc} = \Sigma \xi \cdot \frac{V^2}{2g}, \qquad (2.3)$$

where ξ is the coefficient of local resistance.

Such a resistance loss record is convenient in that it contains a high-speed pressure by Bernoulli's equation. The coefficient of resistance ξ is thus the ratio of the lost head to the speed.

There are two varieties of energy loss: energy loss in length and local losses. Thus, the general expression of the loss of resistance by Bernoulli's equation is as follows:

$$h_L = \Sigma h_l + \Sigma h_{loc}. \qquad (2.4)$$

Loss of energy in length causes the hydraulic resistance to the length of the flow due to the friction forces. Losses of energy in length are distributed evenly in areas of rectilinear and uniform motion and to a small extent unevenly in areas of uneven motion. These energy losses in pure form arise on direct pipes of a constant intersection, i.e., under uniform motion of a liquid, grow in proportion to the length of the pipe.

In general, the loss of resistance in length can be obtained from Bernoulli's equation:

$$h_l = (Z_1 + \frac{P_1}{\gamma} + \frac{\alpha V_1^2}{2g}) - (Z_2 + \frac{P_2}{\gamma} + \frac{\alpha V_2^2}{2g}). \quad (2.5)$$

For a horizontal pipe of constant intersection, expression (1.5) will have the form:

$$h_l = \frac{P_1}{\rho g} - \frac{P_2}{\rho g}. \quad (2.6)$$

Loss on length can be determined by the general formula (1.3):

$$h_l = \zeta_l \frac{V^2}{2g}, \quad (2.7)$$

where ζ is the coefficient of flow rate of the fluid over the length of the pipe having the form

$$\zeta_l = \lambda \frac{l}{d}. \quad (2.8)$$

As a result, we have the Darcy-Weisbach equation for determining the loss of resistance by the length when the fluid moves through the pipe:

$$h_l = \lambda \frac{l}{d} \cdot \frac{V^2}{2g}. \quad (2.9)$$

where λ – the friction coefficient of the pipe;

l – the length of the pipe section;

d – diameter of the pipe;

V – velocity;

g – acceleration of gravity.

The Darcy-Weisbach equation is valid for both laminar and turbulent flows. Different formulas will be used to calculate the friction coefficient of the pipe λ, which determines the accuracy of the hydraulic calculations.

Therefore, the study of physical factors influencing its magnitude, the definition of methods for its calculation was the subject of extensive theoretical and experimental studies of many engineers and scientists.

In the case of a uniform flow of fluid in a pipe, the right-hand sides of equation (1.9) and the equation of uniform motion equate:

$$h_l = \frac{\tau_0 l}{\rho g R}, \tag{2.10}$$

where $\boldsymbol{\tau_0}$ is the tensile stress on the pipeline.

$$\lambda \frac{l}{d} \cdot \frac{V^2}{2g} = \frac{\tau_0 l}{\rho g R}. \tag{2.11}$$

It is known that for a circular pipe d = 2R, then we get:

$$\lambda = \frac{4\tau_0}{\rho V^2}. \tag{2.12}$$

Thus, the friction coefficient of the pipe is a value proportional to the ratio of the friction voltage on the pipe wall to the dynamic pressure calculated at the average volumetric flow rate.

Modern formulas for calculating the coefficient λ presuppose its dependence on two dimensionless parameters: the relative equivalent wall of the walls and the Reynold’s number.

λ generally varies according to Reynold’s number and the pipe wall roughness.

To study the factors influencing the magnitude of the coefficient λ, and the theoretical developments in the problem of fluid flow in pipes, Prandl, Karman, Nikuradze and others were of great importance (tab. B.2).

Description of the Experimental Installation

Work on determination of the friction coefficient of the pipe on a pipe of a constant section (fig. 2.1), installed horizontally.

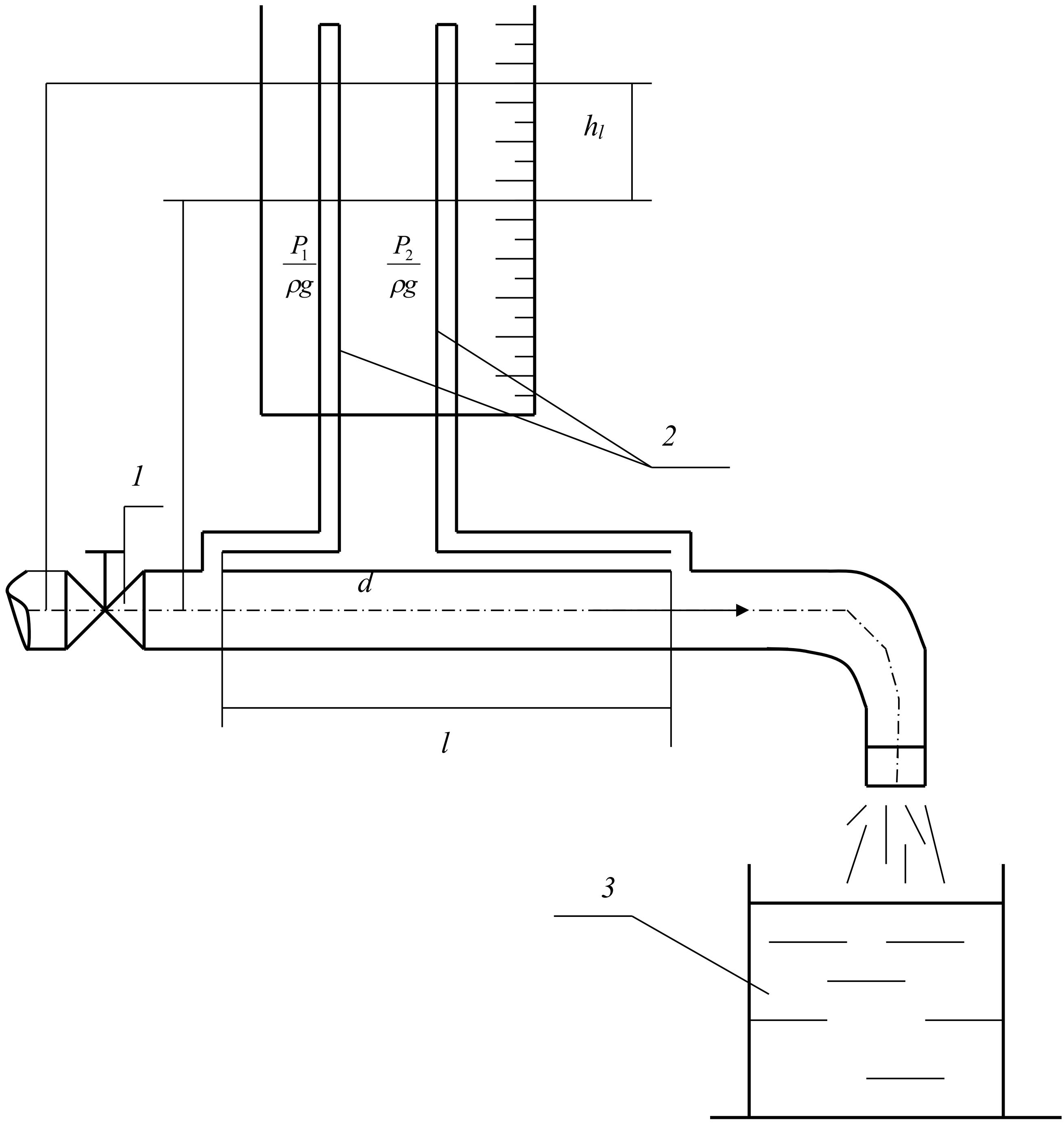


Figure 2.1 – The scheme of installation

On the pipeline there are two piezometers installed at a distance of l. To control the flow of water through the pipeline, at its beginning, valve 1 is installed. Measurement of water flow during experiments is carried out in a volumetric manner using the measuring reservoir 3.

Structure of Work

1. Experimental determination of the friction coefficient of the pipe λ for a constant cross-sectional pressure pipeline.

2. Comparison of the obtained values of λ with the computed empirical formulas given above.

The Order of Work Execution

1. Measure the diameter of the pipeline and its length (distance between the piezometers).

2. Using a valve 1 in the pipeline, a constant flow of water is established.

3. Using a measuring tank, measure the volume of water W. Which enters the reservoir 3 in time T.

4. Measure the water temperature t ^{0}C with a thermometer.

5. Record the readings of the two piezometers installed on the pipeline. If the water level in the piezometers varies, it is necessary to record the average water level.

6. When carrying out the following experiments with the help of valve 1, we change the flow (on a larger or smaller side) and do the same measurements.

Measurement results are recorded in appropriate logs of the laboratory works.

Processing of Experimental Data

1. In terms of water W and time T, we determine the volumetric flow rate. In hydraulics, the flow rate is designated as Q. The following equation applies:

$$Q = \frac{W}{T}, \tag{2.13}$$

where Q – flow rate, m^3/s;

W – volume, m^3;

t – time, s.

2. According to the measured diameter of the pipe d we determine the area of the living section:

$$A = \frac{\pi \cdot d^2}{4}. \tag{2.14}$$

3. For the flow rate Q and the plane of the living section A, determine the velocity of the water:

$$A = \frac{Q}{\omega}.$$

4. Determine the kinematic coefficient of viscosity v for temperature water (Table B.1).

5. Given the velocity and kinematic viscosity coefficient ν (Table B.1), we calculate Reynold's number Re by formula (1.13):

$$\mathrm{Re} = \frac{Vd}{v}.$$

6. For the difference of the impressions of the piezometers, we determine the losses of the resistance along the length of the pipeline by the formula (1.6).

7. Using the Darcy-Weisbach equation formula (1.10), we calculate the experimental values of the friction coefficient of the pipe:

$$\lambda_{екс} = \frac{2gdh_l}{lV^2}.$$

8. Depending on the value of the Reynold's number, we the friction coefficient of the pipe λ according to one or more empirical formulas, which are proved in the "General Information" section, and compare the friction coefficient of the pipe λ_{exp} and λ_{teor} (tab. B.2).

All results of calculations are recorded in the journal (tab. 2.1).

Table 2.1 – Journal of Laboratory Work № 1

№	Name of characteristics, calculation formulas, dimensions	Numerical values of characteristics					
		1 experiment		2 experiment		3 experiment	
1	2	3		4		5	
1	The volume of water entering the measured reservoir for a certain time, lliter						
2	Duration of leakage T, sec.						
3	Water temperature, t, ^{0}C						
4	Diameter of pipe, d, mm						
5	Length of pipe, l, sm						
6	Section number	1	2	1	2	1	2
7	Readings for piezometers $\frac{P}{\rho g}$, *cm*						
8	Volumetric flow rate, $Q = \frac{W}{T}$, cm^3/sec						
9	The area of the pipe section $A = \frac{\pi \cdot d^2}{4}$, cm^2						
10	Average velocity $V = \frac{Q}{A}$, cm/sec						
11	The kinematic viscosity coefficient $\nu = f(t\ ^0C)$, cm^2/sec						
12	The Reynold's number experiments $\mathrm{Re} = \frac{Vd}{\nu}$						
13	Loss of pressure on the length, $h_l = \frac{P_1}{\rho g} - \frac{P_2}{\rho g}$, cm						
14	The friction coefficient of the pipe by experiment $\lambda_{EXP} = \frac{2gdh_l}{lV^2}$						

1	2	3	4	5
15	The friction coefficient of the pipe under the empirical formulas: 1. 2. 3.			
16	Conclusions:			

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Review Questions

1. What do you know about head loss, what are the methods of their definition?
2. Explain the cause of head loss?
3. How to determine the loss of pressure by the calculation method?
4. Write the formulas for determining local pressure losses and pressure losses over the length?
5. What are hydraulically smooth and hydraulically rough pipes? Why is this notion conditional?
6. What factors influence the hydraulic friction coefficient in a laminar and turbulent motion in hydraulically smooth pipes, in the transition zone of resistance and hydraulically rough tubes?
7. What is the physical content of the friction coefficient of the pipe?
8. What factors can determine the friction coefficient of the pipe?

Laboratory Work № 2

Determination of Coefficients of Local Resistances at Pressure Driven Liquids

General Information

Local energy losses are caused by local hydraulic supports, that is, the supports that arise in places with a sharp change in the magnitude and direction of velocity, in areas with a sharp change in the configuration of the flow. As a rule, there are vortices in these places.

Consequently, local energy losses occur only in certain areas of the flow and are local in nature. In such areas, the work of friction forces is much greater than on straight lines with uniform motion.

Different shaped parts and fittings (expansion, contraction, valves, turns, knees, latches, valves), which need to be installed due to the construction and operation of the pipelines, must be taken into account in the local resistance to the pipes.

Local supports cause changes in the velocity of the fluid or the value (expansion and contraction), or in the direction (knees). In all cases there is a redistribution of speeds.

To overcome local impediments, part of the flow energy, called the local loss of resistance, is spent. In practical calculations it is accepted to express it in fate of specific kinetic energy (high-speed head):

$$h_{loc} = \xi \cdot \frac{V^2}{2g}. \tag{2.15}$$

This is the formula of Y. Weisbach, where ξ is the coefficient of local resistance. Its size depends on the type of local resistance the Reynold’s number and to some extent on the wall, and for the various locking devices (latches, taps) – from the degree of their opening.

In view of the large complexity of the phenomena occurring in a fluid flowing through local resistance, only in some cases ξ_{loc} can be found theoretically (sudden pipe expansion or contraction). In most cases, ξ_{loc} is determined experimentally and expressed by empirical formulas, graphs and tables. The values of these coefficients for different local resistance are given in all hydraulics guides.

The guides give the coefficients of local resistance for a turbulent motion regime with large Reynold’s number, where the viscosity of the fluid does not detect itself, but with laminar or near it, the motor coefficient of local resistance depends on the Reynold’s number.

For small values, the effect of resistance, caused by the actions of viscosity forces and proportional velocity in the first degree. The coefficient of resistance in this case is inversely proportional to the Reynold's number:

$$\xi_{loc} = \frac{A}{\mathrm{Re}}, \tag{2.2}$$

where A – became, depending on the type of local resistance, the degree of compression of the flow (guides on hydraulics).

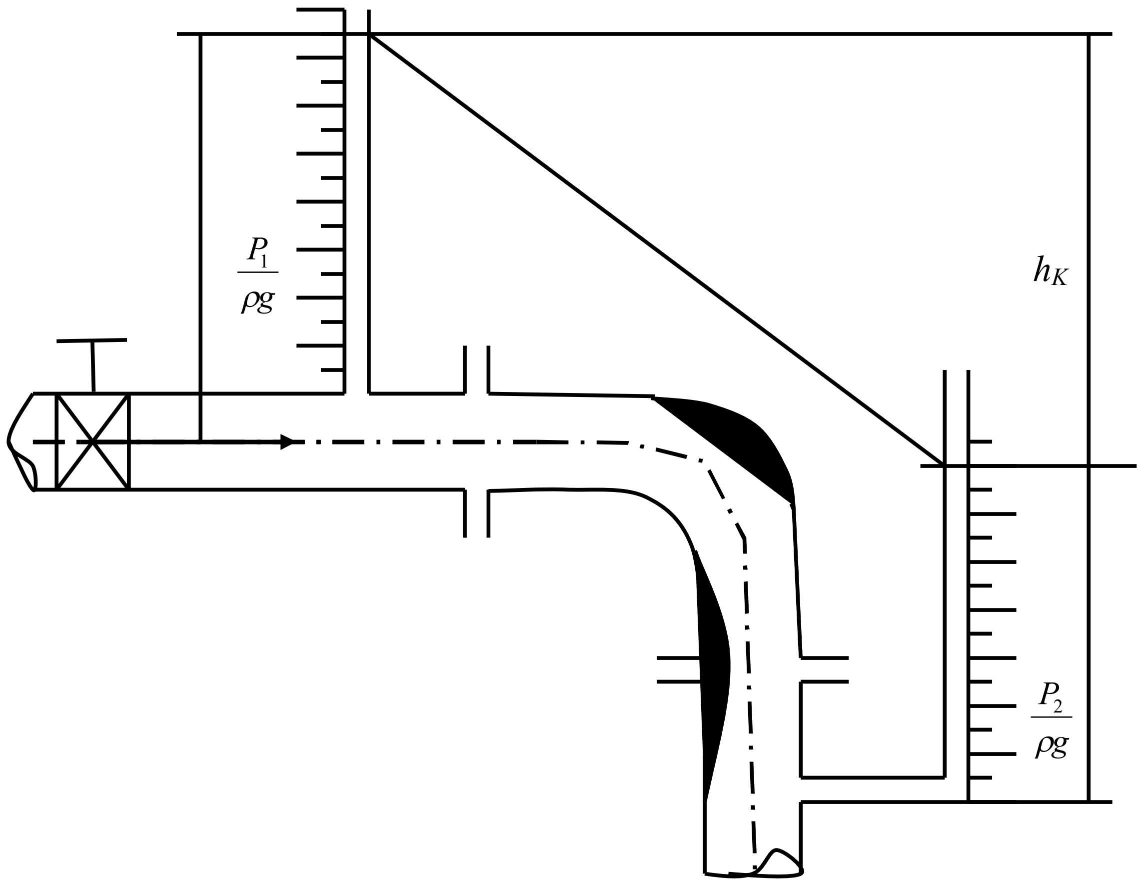

Figure 2.2 – The scheme for experimental determination coefficient of local resistance

This dependence was obtained theoretically when the formula of the hydraulic friction coefficient was deduced for a laminar regime in a circular cylindrical tube.

But experimental studies have shown that with increasing Reynold's number, which still corresponds to the laminar regime, the values of ξ_{loc} increase. This phenomenon is due to the appearance of vortices in local pillars.

At large Reynold's numbers, tearing currents are formed, which is the cause of local resistance at large Reynold's numbers. This is a quadratic resistance zone, where ξ_l = const for a specific local resistance. In the first approximation we can say that at different transitions in local pillars, ξ_{loc} does not depend on the values of *Re* if Re ≥ 3 000, but with smooth transitions Re > 1 000.

The resistance coefficient for small Reynold's number is modest approximately determined by the formula A.D. Aldshula:

$$\xi_{loc} = \frac{A}{\mathrm{Re}} + \xi_{loc.q} \tag{2.3}$$

where is $\xi_{loc.q}$ – coefficient of local resistance for a quadratic zone.

Structure of Work

1. Experimental determination of the coefficients of local resistance: rotation of the pipe on the corner 90º (see Appendix C).
2. Comparison of the experimental values of ξ_{loc} with reference.

Description of the Experimental Installation

The experimental installation (see Fig. 2.2) consists of a pipeline 1 which draws water to the installation, the control crane 2 and the turning 5. The crane 2 sets the water level in the piezometers 3 and 4 at a height convenient for reference. The valve is installed to regulate the flow of water on the pipeline. To determine the water flow during the experiment is a measuring tank.

The Order of the Work

1. Before the beginning of the laboratory work lead installation in the working position. In this case, valve 2 must be closed, and the second valve is open.
2. Opening the valve 2 expel air from the pipeline and piezometers and set the required flow of water.
3. Once the movement in the pipe is constant, which is confirmed by the constant level of water in the piezometers, determine the volumetric flow rate of water. For this, the stopwatch determines the time *T*, fill the volume *W*.
4. It is necessary to conduct at least three experiments, which differ from each other by water flow.

Processing of Experimental Data

1. In terms of water W and time T, we determine the volumetric flow rate:

$$Q = \frac{W}{T}. \tag{2.16}$$

2. At the flow Q and the plane of the living section ω, determine the average velocity of water movement

$$V = \frac{Q}{A}, \tag{2.17}$$

where

$$A = \frac{\pi \cdot d^2}{4}. \tag{2.18}$$

3. Determine the specific kinetic energy (high-speed pressure) in the cross section:

$$h_v = \frac{\alpha V^2}{2g}. \tag{2.19}$$

4. According to the established values of the specific potential energy (readings of the piezometers) and the specific kinetic energy (high-pressure $\frac{\alpha V^2}{2g}$), we find the total energy in the sections before and after the local supports:

$$E = Z + \frac{P}{\rho g} + \frac{\alpha V^2}{2g}. \tag{2.20}$$

5. For the difference of the values of total specific energies we find the loss of the pressure of local resistances:

$$h_{loc} = E_1 - E_2. \tag{2.21}$$

When the diameter of the pipeline to the resistance and behind it is the same, we determine the loss of pressure as follows:

$$h_{loc} = (Z_1 + \frac{P_1}{\rho g}) - (Z_2 + \frac{P_2}{\rho g}). \tag{2.22}$$

6. By formula (2.3), we compute the experimental values of the coefficients of local resistances:

$$\xi_{loc} = \frac{2g h_{loc}}{V^2}. \tag{2.23}$$

7. The obtained data of the coefficients of local resistances are compared with the reference data.

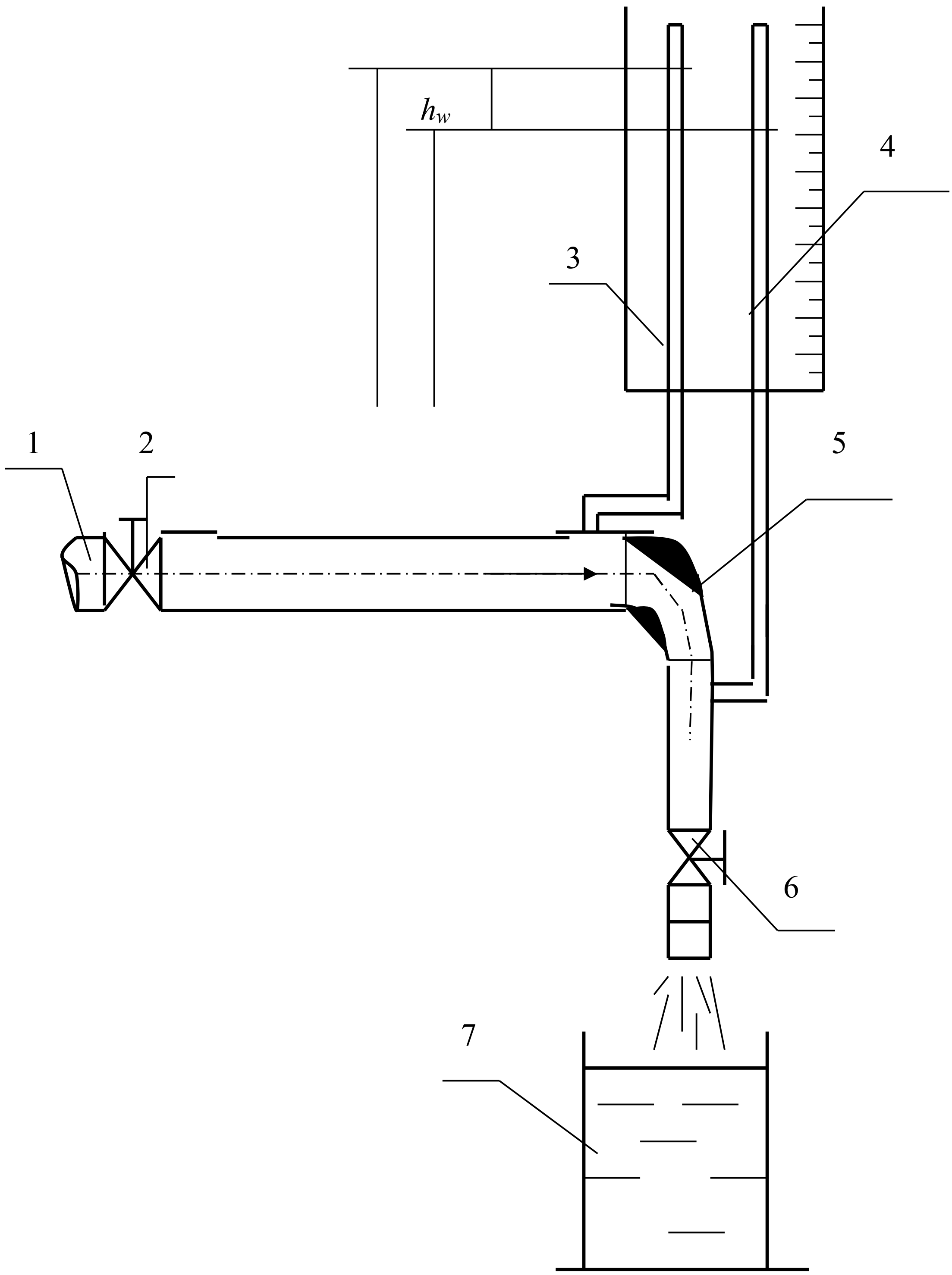

Figure 2.2 – The scheme of installation for experimental determination coefficient of local resistance

Table 2.2 – Journal of Laboratory Work № 2

<table>
<tr><th rowspan="3">№</th><th rowspan="3">Name of characteristics, calculation formulas, dimensions</th><th colspan="6">Numerical values of characteristics</th></tr>
<tr><th colspan="2">1</th><th colspan="2">2</th><th colspan="2">3</th></tr>
<tr><th colspan="2">experiment</th><th colspan="2">experiment</th><th colspan="2">experiment</th></tr>
<tr><td>1</td><td>2</td><td colspan="2">3</td><td colspan="2">4</td><td colspan="2">5</td></tr>
<tr><td>1</td><td>The volume of water entering the measured reservoir for a certain time, liter</td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>2</td><td>Duration of leakage, T, sec</td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>3</td><td>Diameter of pipe:
- to the resistance d_1, mm
- by the resistance d_2, mm</td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>4</td><td>Numbers of section (piezometers)</td><td>1</td><td>2</td><td>1</td><td>2</td><td>1</td><td>2</td></tr>
<tr><td>5</td><td>Specific potential energy (readings of the piezometers), cm</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>6</td><td>Volumetric flow rate,
$Q = \frac{W}{T}$, cm^3/sec</td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>7</td><td>Area of live pipeline crossings
$A_1 = \frac{\pi \cdot d_1^2}{4}$; $A_2 = \frac{\pi \cdot d_2^2}{4}$, cm</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>8</td><td>Average velocity
$V_1 = \frac{Q}{A_1}$; $V_2 = \frac{Q}{A_2}$, sm/sec</td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>9</td><td>Specific kinetic energy (high-pressure) in cross-sections; $\frac{\alpha V_1^2}{2g}$; $\frac{\alpha V_2^2}{2g}$, cm</td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>10</td><td>Total specific energy in cross-sections
$E_1 = Z_1 + \frac{P_1}{\rho g} + \frac{\alpha V_1^2}{2g}$;
$E_2 = Z_2 + \frac{P_2}{\rho g} + \frac{\alpha V_2^2}{2g}$, cm</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

1	2	3	4	5
11	The magnitude of local pressure losses $h_{loc} = E_1 - E_2$			
12	The local resistence coefficient on the results of the experiment $\xi_{loc} = \frac{2gh_{loc}}{V^2}$			
13	The local resistence coefficient oper is based on empirical formulas and information (Appendix C)			
14	Conclusions:			

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Review Questions

1. What locks are local?
2. What are the reasons for the occurrence of local head loss and what formula can you find their significance?
3. What is the coefficient of local resistance and how are they determined?
4. For which local resistance, the coefficient can be determined theoretically?
5. How to determine local pressure loss if the average speed to resistance and behind it are different in value?
6. How to determine the loss of pressure in the sudden expansion of the pipe?

Laboratory Work № 3, 4

Determination of Loss of Resistance when Sudden Expansion Pipe or Sudden Contraction Pipe

General Information

In addition to energy losses to overcome the friction resistance, there are local energy losses in the flow of liquid through the crane, a grid, expansion or contraction of the pipe, valve, knee, etc.

Local supports cause a change in fluid velocity by value (sudden pipe contraction or expansion). In these cases, there is a redistribution of speeds.

The local head loss is defined as part of the high-speed head.

Liquid energy losses with sudden expansion or contraction (Fig. 2.4) are equal to the speed pressure corresponding to the lost speed, and can be calculated by the formula:

$$h_{loc} = \alpha_0 \cdot \frac{\left(V_1^2 - V_1^2\right)}{2g}, \tag{2.24}$$

where α_0 – is the coefficient reflecting the ratio of the actual mass to the amount of motion corresponding to the average velocity

$$\alpha_0 = \frac{\int AV_i^2 dA}{AV^2}, \tag{2.25}$$

where V_1 – velocity in the pipe to the expansion;

V_2 – velocity in the pipe after expansion.

The values of the coefficient α_0 are assumed to be 1,035.

What are the actual costs with a sudden expansion.

A stream coming from a pipe having a smaller diameter does not immediately fill a pipe with a larger diameter – there is a separation surface and a vortex on it (see Fig. 2.3).

At a certain distance from the expansion, the flow captures the entire cross section of a larger diameter. In a circular space between the jet and the walls of the pipe, the fluid is in the vortex. In this area there are significant losses of pressure.

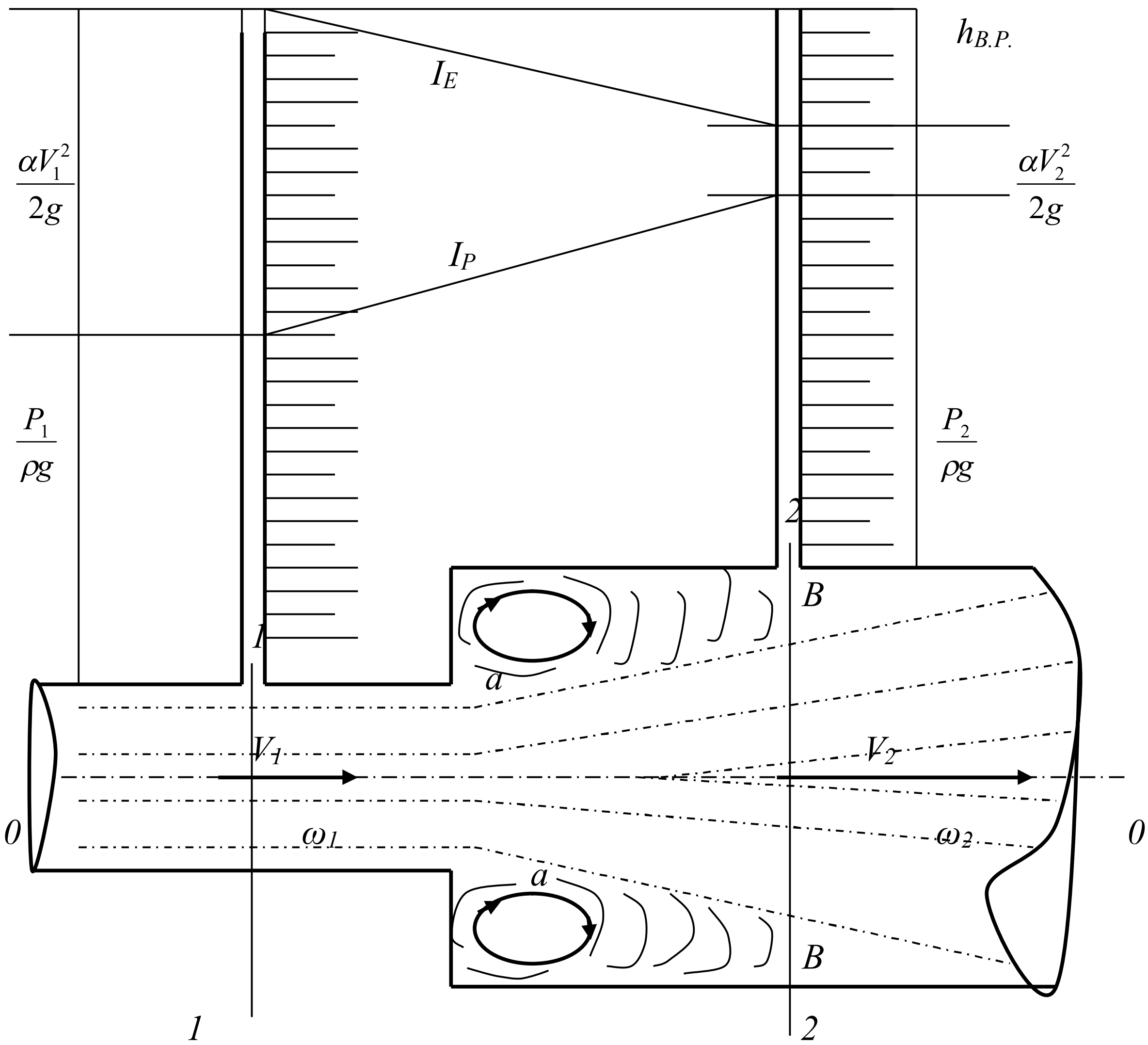

Figure 2.3 – The scheme of installation for experimental determination of the local loses when sudden expansion pipe

When the section 2-2 is chosen where the flow is already stabilized, assuming that $\alpha_1 = \alpha_2 = 1$, according to Bernoulli's equation, we can write:

$$z_1 + \frac{p_1}{\gamma} + \frac{\alpha V_1^2}{2g} = z_2 + \frac{p_2}{\gamma} + \frac{\alpha V_2^2}{2g} + h_{L1-2}. \quad (2.26)$$

We choose for the plane of comparison the plane, which runs along the axis of the pipe 0-0. Then $Z_1 = Z_2$ and Bernoulli's equation are rewritten as follows:

$$\frac{p_1}{\gamma} + \frac{\alpha V_1^2}{2g} = \frac{p_2}{\gamma} + \frac{\alpha V_2^2}{2g} + h_{L1-2}. \quad (2.27)$$

Hence the loss of pressure at a sudden expansion:

$$h_L = \frac{\alpha(V_1^2 - V_2^2)}{2g} + \frac{P_1 - P_2}{\gamma}. \tag{2.28}$$

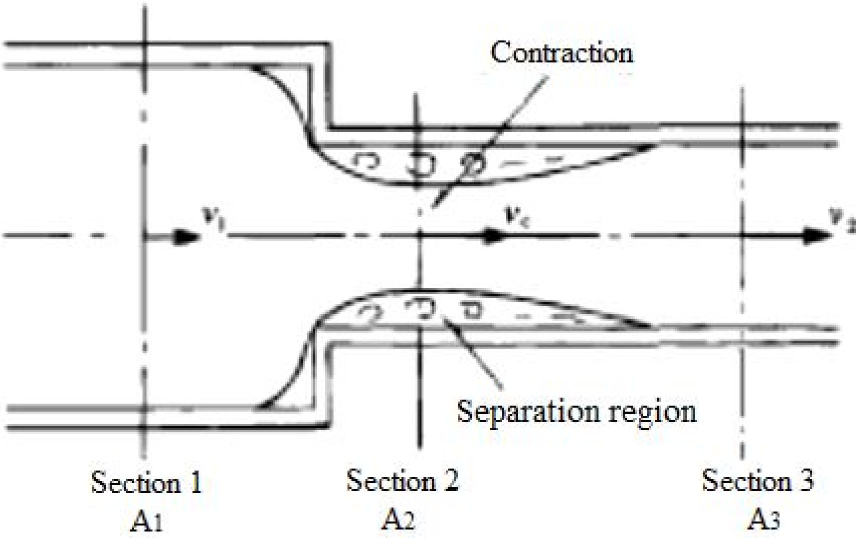

Figure 2.4 – Sudden contraction pipe

Structure of Work

1. Experimental determination of the coefficients of local resistance: sudden expansion pipe and sudden contraction pipe.
2. Comparison of the obtained experimental values ξ with reference.

Description of the Experimental Installation

The experimental installation (see Fig. 2.5) consists of two consecutive tubes of different diameters 5, 7. On the pipeline, there are local supports: sudden expansion pipe, sudden contraction pipe.

On each local support, two piezometers are installed 1-2, 3-4. Piezometers are deduced on a piezometric shield, each of them coincides with the reference plane 0-0, which is located on the bottom of the pipe axis. Valves 6 and 8 are installed to regulate the flow of water on the pipeline.

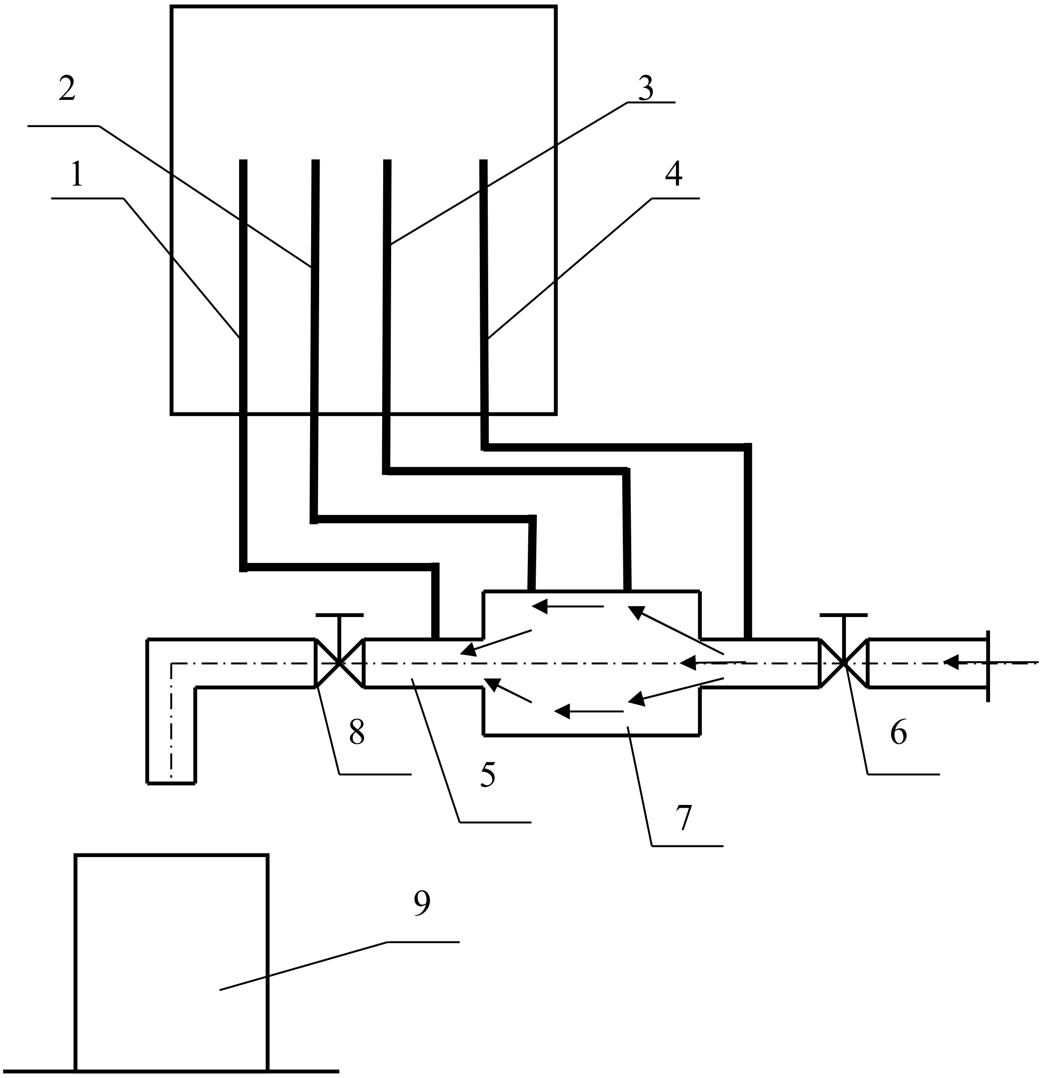

Figure 2.5 – The experimental installation for determination of loss of resistance when sudden expansion pipe or sudden contraction pipe

The Order of the Work

1. Before the beginning of the laboratory work, bring the installation to the working position. The valve 6 must be closed, and the valve 8 is open.

2. Opening the valve 6, remove the air from the pipeline and the piezometers and set the required flow of water.

3. After the movement in the pipe is constant, which is confirmed by the constant level of water in the piezometers, determine the volumetric flow rate of water. For this, the stopwatch determines the time *T*, fill the volume *W*.

4. For each local resistance, take off impressions of the piezometers.

5. It is necessary to conduct at least three experiments, which differ in the flow of water.

Processing of Experimental Data

1. In terms of water *W* and time *T*, we determine the volumetric flow rate:

$$Q = \frac{W}{T}. \tag{2.29}$$

2. At the flow *Q* and the plane of the living section ω, determine the velocity of water movement:

$$V_1 = \frac{Q}{A_1}, \text{ and } V_2 = \frac{Q}{A_2}, \tag{2.30}$$

where

$$A_{1,2} = \frac{\pi \cdot d_{1,2}^{\;2}}{4}. \tag{2.31}$$

4. Determine the specific kinetic energy (high-pressure) in the cross-sections:

$$h_v = \frac{\alpha_0 (V_1^2 - V_2^2)}{2g}. \tag{2.32}$$

5. By the formula derived from Bernoulli's equation, that is, actual costs

$$h_L = \frac{\alpha_0 (V_1^2 - V_2^2)}{2g} + \frac{P_1 - P_2}{\gamma}. \tag{2.33}$$

6. Comparing the obtained values, we determine the percentage mistakes:

$$\Delta = \frac{h_v - h_L}{h_L} \cdot 100\%. \tag{2.34}$$

Table 1.3 – Journal of Laboratory Work № 3 “Sudden contraction pipe”

№	Name of characteristics, calculation formulas, dimensions	Numerical values of characteristics					
		1 experiment		2 experiment		3 experiment	
1	2	3		4		5	
1	The volume of water entering the measured reservoir for a certain time, l						
2	Duration of leakage T, sec						
3	Diameter of pipe: - to the resistance d_1, mm - by the resistance d_2, mm						
4	Numbers of section (piezometers)	1	2	1	2	1	2
5	Specific potential energy (readings of the piezometers), cm						
6	Volumetric flow rate $Q = \frac{W}{T}$, cm^3/sec						
7	Area of live pipeline crossings $A_1 = \frac{\pi \cdot d_1^2}{4}$; $A_2 = \frac{\pi \cdot d_2^2}{4}$, cm^2						
8	Average velocity $V_1 = \frac{Q}{\omega_1}$; $V_2 = \frac{Q}{\omega_2}$, cm/sec						
9	Specific kinetic energy (high-pressure) in cross-sections; $\frac{\alpha V_1^2}{2g}$; $\frac{\alpha V_2^2}{2g}$, cm						
10	Total specific energy in cross-sections $E_1 = Z_1 + \frac{P_1}{\rho g} + \frac{\alpha V_1^2}{2g}$; $E_2 = Z_2 + \frac{P_2}{\rho g} + \frac{\alpha V_2^2}{2g}$, cm						
11	The magnitude of local pressure losses $h_{loc} = E_1 - E_2$, cm						

1	2	3	4	5
12	The magnitude of local pressure losses by theoretical formula: $h_v = \frac{\alpha_0 (V_1^2 - V_2^2)}{2g}$			
13	Determine the mistake in percent $\Delta = \frac{h_v - h_L}{h_L} \cdot 100\%$			
14	Conclusions:			

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Table 1.3 – Journal of Laboratory Work № 4 “Sudden expansion pipe”

№	Name of characteristics, calculation formulas, dimensions	Numerical values of characteristics					
		1 experiment		2 experiment		3 experiment	
1	2	3		4		5	
1	The volume of water entering the measured reservoir for a certain time, *l*						
2	Duration of leakage T, sec						
3	Diameter of pipe: - to the resistance – d_1, mm - by the resistance – d_2, mm						
4	Numbers of section (piezometers)	1	2	1	2	1	2
5	Specific potential energy (readings of the piezometers), cm						
6	Volumetric flow rate, $Q = \frac{W}{T}$, cm³/sec						
7	Area of live pipeline crossings $A_1 = \frac{\pi \cdot d_1^2}{4}$; $A_2 = \frac{\pi \cdot d_2^2}{4}$, cm²						
8	Average velocity $V_1 = \frac{Q}{A_1}$; $V_2 = \frac{Q}{A_2}$, cm/sec						
9	Specific kinetic energy (high-pressure) in cross-sections; $\frac{\alpha V_1^2}{2g}$; $\frac{\alpha V_2^2}{2g}$, cm						

1	2	3	4	5	6	7	8
10	Total specific energy in cross-sections $E_1 = Z_1 + \frac{P_1}{\rho g} + \frac{\alpha V_1^2}{2g}$; $E_2 = Z_2 + \frac{P_2}{\rho g} + \frac{\alpha V_2^2}{2g}$, cm						
11	The magnitude of local pressure losses $h_{loc} = E_1 - E_2$, cm						
12	Conclusions:						

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Review Questions

1. What is the cause of local pressure loss?
2. What are the associated pressure losses due to sudden flow expansion? Draw the appropriate layout.
3. Write down and decipher the Bord's formula for running pressure as a result of sudden flow expansion?
4. Draw a diagram that describes the sudden expansion of the flow. Explain what is the loss of pressure in this case?
5. For which local resistance, the coefficient ξ can be determined theoretically?
6. Write down and decipher Weisbach's formula for determining head loss in local pillars. To which section is the velocity V to the resistance, in the support itself or outside it?

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9. Metodychni rekomendatsii do praktychnykh zaniat ta vykonannia rozrakhunkovo–hrafichnoho zavdannia ta samostiinoi roboty z navchalnoi dystsypliny «Inzhenerna hidravlika» (Engineering hydraulics) (dlia studentiv 2–3 kursiv dennoi ta zaochnoi form navchannia spetsialnosti 192 –Budivnytstvo ta tsyvilna inzheneriia, spetsializatsii (osvitni prohramy) «Tsyvilna inzheneriia (Vodopostachannia ta vodovidvedennia)», «Hidrotekhnika (Vodni resursy)»)/ Kharkiv. nats. un–t misk. hosp–va im. O. M. Beketova ; uklad. : O. P. Galkina. – Kharkiv : KhNUMH im. O. M. Beketova, 2020. – 97 s.

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APPENDIXES

APPENDIX A

Example of a Title Page

MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE

O.M.BEKETOV NATIONAL UNIVERSITY OF URBAN ECONOMY IN KHARKIV

Department of Water and Wastewater Engineering

JOURNAL

of

Laboratory Works on Discipline

"TECHNICAL MECHANICS of LIQUID and GAS"

Presented by :
Student of the group ________
____

Supervised by :
Associate Professor, PhD Galkina O. P.
Associate Professor, PhD Shevchenko T. O.

Kharkiv – 20__

APPENDIX B

Table B.1 – Kinematic viscosity coefficient for fresh water

Temperature, °C	Kinematic viscosity coefficient, ν, cm²/s	Temperature, °C	Kinematic viscosity coefficient, ν, cm²/s
0	0,0179	16	0,0112
1	0,0173	17	0,0109
2	0,0167	18	0,0106
3	0,0162	19	0,0104
4	0,0157	20	0,0101
5	0,0152	25	0,0090
6	0,0147	30	0,0081
7	0,0143	35	0,0072
8	0,0139	40	0,0066
9	0,0135	45	0,0060
10	0,0131	50	0,0055
11	0,0128	60	0,0047
12	0,0124	70	0,0040
13	0,0120	80	0,0037
14	0,0117	90	0,0033
15	0,0114	100	0,0029

Table B.2 – The friction coefficient (λ or *f*) for smooth pipes with friction equations [Source: Nakayama, Y. and Boucher, R. F., (1998), p. 115-116]

Equation's	*Friction coefficient (f) formulas*	*(Re) range*	*Notes*
Darcy Weisbach	$f = 64\,Re^{-1}$	$< 3 \times 10^3$	Laminar
Blasius	$f = 0{,}3164\,Re^{-1/4}$	$3 \times 10^3 \sim 1 \times 10^5$	Turbulent
Nikuradse	$f = 0{,}0032 + 0{,}221 Re^{-0{,}237}$	$1 \times 10^5 \sim 3 \times 10^6$	Turbulent
Karman-Nikuradse	$f = 1 / [2\log_{10}(Re\sqrt{f}) - 0{,}8]^2$	$3 \times 10^3 \sim 3 \times 10^6$	Turbulent
Itaya	$f = 0{,}314 / [0{,}7 - 1{,}65\log_{10}(Re) + (\log_{10} Re)^2]$	-	Turbulent
Prandtl[1]:	$\frac{1}{\sqrt{f}} = 2\log_{10}(R\sqrt{f}) - 0.8$		**Turbulent**

[1] Prandtl's universal law of friction for smooth pipes is applicable for arbitrarily large Reynold's number but is somewhat difficult to manipulate mathematically. Fortunately, (Equation's Blasius) covers the cases in hydraulic control because the pipes are smooth and the flow velocities are normally kept below 15 ft/sec to avoid large surges with sudden valve closures, and this results in Reynold's numbers less than 100 000.

APPENDIX C

Table C.1 – Table for the form coefficient loss factor ξ for

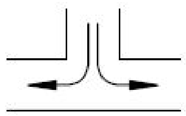
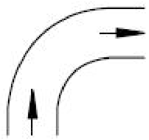
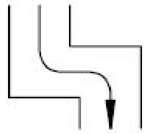
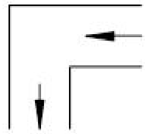
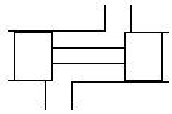
	T-piece	90° bend	Double angle	90° angle	Valve
ξ	1.3	0.5 - 1	2	1.2	5 ... 15
					

Table C.2 – Loss factor ξ for elbows

	θ°	5°	10°	15°	22.5°	30°	45°	60°	90°
ζ	Smooth	0.016	0.034	0.042	0.066	0.130	0.236	0.471	1.129
	Coarse	0.024	0.044	0.062	0.154	0.165	0.320	0.687	1.265

Table C.3 –Loss factor ξ for bends smooth wall Re = 225 000, coarse wall face Re – 146 000

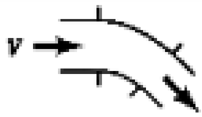
Wall face	θ° R/d =	1	2	3	4	5
Smooth	15°	0.03	0.03	0.03	0.03	0.03
	22.5°	0.045	0.045	0.045	0.045	0.045
	45°	0.14	0.14	0.08	0.08	0.07
	60°	0.19	0.12	0.095	0.085	0.07
	90°	0.21	0.135	0.10	0.085	0.105
Coarse	90°	0.51	0.51	0.23	0.18	0.20

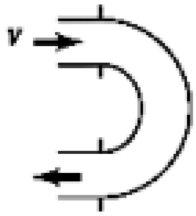
Table C.4 – Loss factor ξ

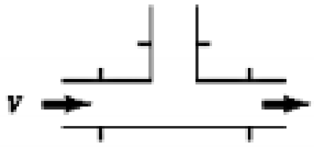
d, mm	20	25	34	39	49
ξ 90°	1.7	1.3	1.1	1.0	0.83

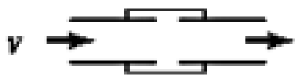
Table C.5 – The local resistance coefficient for pipe components

Component	K_L
a. Elbows	
Regular 90°, flanged	0.3
Regular 90°, threaded	1.5
Long radius 90°, flanged	0.2
Long radius 90°, threaded	0.7
Long radius 45°, flanged	0.2
Regular 45°, threaded	0.4
b. 180° return bends	
180° return bend, flanged	0.2
180° return bend, threaded	1.5
c. Tees	
Line flow, flanged	0.2
Line flow, threaded	0.9
Branch flow, flanged	1.0
Branch flow, threaded	2.0
d. Union, threaded	0.08
e. Valves	
Globe, fully open	10
Angle, fully open	2
Gate, fully open	0.15
Gate, $\frac{1}{4}$ closed	0.26
Gate, $\frac{1}{2}$ closed	2.1
Gate, $\frac{3}{4}$ closed	17
Swing check, forward flow	2
Swing check, backward flow	∞
Ball valve, fully open	0.05
Ball valve, $\frac{1}{3}$ closed	5.5
Ball valve, $\frac{2}{3}$ closed	210









Виробниче-практичне видання

Методичні рекомендації

до лабораторних робіт
з дисципліни

«ТЕХНІЧНА МЕХАНІКА РІДИНИ ТА ГАЗІВ»
(англ. мовою)

*(для студентів 2 курсу денної та заочної форм навчання
та 1–2 курсів скороченої форми навчання
спеціальності 192 – Будівництво та цивільна інженерія)*

Укладачі : **ГАЛКІНА** Олена Павлівна,
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