Ministry of Education of the Russian Federation

Tomsk State University of Architecture and Building

> *"Knowledge not tested by*
> *experiment is fruitless"*
> *Leonardo da Vinchi*

LABORATORY WORK ON HYDRAULICS WITH THE USE OF PORTABLE LABORATORY "DROPLET"

Methodical instructions to laboratory work

Tomsk – 2006

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The “Instructions” give the basic theoretical information, as well as the contents and order of carrying out laboratory works on mechanics of liquids (hydraulics) with the use of “Droplet”, a portable laboratory developed by the above mentioned authors. This laboratory was given the first prize at the All-Union Contest of teaching equipment in 1990, and was recommended to production in quantity. Currently, over 300 educational establishments have this laboratory at their disposal and appreciated the high level of its engineering novelty (patents of Russian Federation №, №: 1721326, 1742655) and its advantages as compared with similar devices: it has no engines, pumps and valves; does not require supply of water and electricity; can be placed in a case; is convenient for demonstration at lectures and classes; saves about 20 m^2 of laboratory premises and has the low price.

The methodical instructions are intended for the students of building, technology and mechanics. They are recommended to issuing by the Presidium of Scientific-methodic Council on Hydraulics at the State Committee of Public Education of the USSR of January 17, 1991.

The methodical instructions are published by the decision of the department of heat-and-gas supply No 5 of 09.04.01. They are approved and allowed to be used in academic process by O.G. Kumpyak, vice-rector for academic work.

Contents

Work 1. Examination of physical properties of a liquid

The work purpose: mastering techniques of measuring density, thermal expansion, viscosity and surface tension of liquids.

1.1. General Information.

The liquid is a low-compression body changing its form under the action of relatively small forces. Basic characteristics of a liquid are the following: density, compressibility, viscosity, thermal expansion and surface tension.

Density is the relation of a liquid mass m to its volume W: $\rho=m/W$.

Compressibility is a liquid property to reduce the volume under the action of pressure. It is estimated by the *compression coefficient* β_P indicating a relative decrease in the liquid volume W when pressure p is greater by one: $\beta_P = (\Delta W/W)/\Delta p$.

Thermal expansion, the liquid property to change its volume when heated, is defined by the *coefficient of thermal expansion* β_T that is equal to a relative increment in the volume W with a one-degree change in the temperature at the constant pressure: $\beta_T=(\Delta W/W)/\Delta T$. As a rule, the liquid volume increases at heating.

Viscosity is the liquid property to resist the slip ratio of its layers. It is defined by a *dynamic coefficient of viscosity* μ that is measured in pascal-seconds (Pa·s) and is equal to the tangential stress between adjacent layers, if their relative movement speed coincides numerically with the layer thickness.

The kinematic coefficient of viscosity ν is determined by the equation $\nu=\mu/\rho$ and is measured in square meters per second (m^2/s) or stokes ($1\ St = 1\ cm^2/s$). These coefficients are specified by a kind of liquid and do not depend on the flow rate and considerably decrease with the temperature increase.

Surface tension, the liquid property to form a surface layer of mutually attracting molecules, is defined by a *surface tension coef-*

ficient σ equal to the force on the length unit of a free surface contour ρ, β_P, β_T, ν and σ values at 20 °C are given in Table 1.1.

Table 1.1

Liquid	ρ, kg/m^3	$\beta_P \cdot 10^3$, MPa^{-1}	$\beta_T \cdot 10^3$, $^{\circ}$C^{-1}	$\nu \cdot 10^6$, m^2/s	$\sigma \cdot 10^3$, N/m
Water fresh	998	0,49	0,15	1,01	73
Alcohol ethyl	790	0,78	1,10	1,52	23
Oil:					
motor M-10	900	0,60	0,64	800	25
industrial 20	900	0,72	0,73	110	25
transformer	890	0,60	0,70	30	25
AMG - 10	850	0,76	0,83	20	25

1.2. Description of Device № 1

The device for examination of the liquid physical properties consists of five instruments placed in the same transparent case (Fig. 1.1) on which there are parameters for processing the experimental data. Instruments 3 through 5 begin operating when device № 1 is turned over. Thermometer 1 shows the temperature of the environment and, consequently, the liquid temperature in all the instruments.

1.3. The work order

1.3.1. Determining the coefficient of the liquid thermal expansion

Thermometer 1 has a glass cylinder with a capillary filled with thermometric liquid, and a scale. The thermometer operation is based on thermal expansion of liquids. Variation in ambient temperature results in a corresponding change in the volume of the thermometric liquid and in its level in the capillary tube. The liquid level indicates the temperature value on the scale.

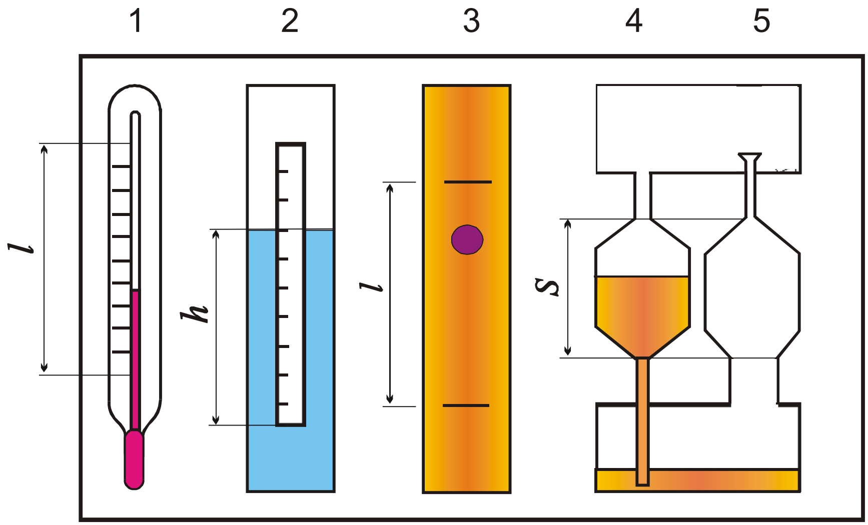


Fig. 1.1. Scheme of device № 1:
1 - thermometer; 2 - areometer; 3 - Stock's viscosimeter; 4 - capillary viscosimeter; 5 - stalagmometer

The coefficient of thermometric liquid thermal extension is determined mentally, i.e., it is supposed that the ambient temperature has risen from the lower (zero) to the upper limiting values of the thermometer and the liquid level in the capillary tube has risen by value l. To determine the coefficient, it is necessary:

1. To calculate the total number of sexagesimal divisions ΔT and measure the space l between the first and the upper and the lower scale marks.
2. To compute an increment in the thermometric liquid volume $\Delta W=\pi r^2 l$, where r is a radius of the thermometer capillary tube.
3. To find the value of the thermal expansion coefficient $\beta_T = (\Delta W/W) / \Delta T$, with allowance for the initial (at 0 °C) volume

of the thermometric liquid W, and to compare this value with the reference one β^*_T (Table 1.1).

4. To put down the values of the used magnitudes in Table 1.2.

Table 1.2

Liquid	r, cm	W, cm^3	ΔT, ^oC	l, cm	ΔW, cm^3	β_T, $^oC^{-1}$	β^*_T, $^oC^{-1}$
alcohol							

1.3.2. Liquid density measurement with an areometer

Areometer 2 is used for determining the liquid density by a float method. It is a hollow glass cylinder with a millimeter scale and a load in the lower part (in the bottom). Due to the load the areometer floats in the examined liquid in a vertical state. The depth of its sinking is the measure of the liquid density, and it is read out from the scale on the upper edge of the liquid meniscus around the areometer. In ordinary areometers the scale is calibrated on density from the very beginning.

During the laboratory work, it is necessary to perform the following operations.

1. To measure the depth of the areometer sinking h by its millimeter scale.
2. To compute the liquid density from the formula $\rho=4m/(\pi d^2h)$, where m and d are areometer weight and diameter respectively. This formula is obtained by equating the areometer gravity $G=mg$ to the buoyancy (Archimedes's) force $P_A=\rho gW$, where the volume of the areometer immersed part is $W=(\pi d^2/4)h$.
3. To compare the experimental density value ρ with the reference one ρ^* (Table 1.1) and to put down the values in Table 1.3.

Table 1.3

Liquid	m, g	d, cm	h, cm	ρ, g/cm^3	ρ^*, g/cm^3
Water					

1.3.3. Determining viscosity by Stokes viscosimeter

Stock's viscosimeter 3 is rather simple. It contains a cylinder vessel, filled with the examined liquid, and a ball. The instrument makes it possible to determine the liquid viscosity during the ball fall in the following way:

1. Turn instrument № 1 in the vertical plane to 180° and use a stopwatch to fix the time t it takes the bead to pass the distance l between the two marks in instrument 3. The bead is to fall along the vessel axis without touching the vessel walls. The experiment is to be made three times after which the arithmetic mean value of time t is defined.
2. Compute the experimental value of kinematical coefficient of the liquid viscosity

$$\nu = g\, d^2\, t\, (\rho_ш/\rho - 1) \,/\, [18l + 43{,}2l\,(d/D)],$$

where g is acceleration of gravity;

d, D are diameters of the bead and cylindrical vessel respectively;

ρ, $\rho_ш$ are densities of the liquid and the bead material respectively.

3. To compare the experimental value of viscosity coefficient ν with the table value ν^* (Table 1.1) and to put down the value of the parameters in Table 1.4.

Table 1.4

Liquid	ρ, kg/m^3	t, ^oC	l, m	d, m	D, m	$\rho_ш$, kg/m^3	ν, m^2/s	ν^*, m^2/s
M-10					0,02			

1.3.4. Viscosity measurement by a capillary viscosimeter

Capillary viscosimeter 4 is a vessel with a capillary tube. Viscosity is determined from the time it takes the liquid to escape through a capillary tube. The procedure is as follows:

1. To turn instrument № 1 upside down (Fig. 1.1) in a vertical plane and to fix by a stopwatch the time t necessary for the liq-

uid volume to run out through a capillary tube between the marks (at a height *S*) from viscosimeter vessel 4 and at temperature *T* on the thermometer 1.

2. To compute the value of viscosity kinematical coefficient $\nu = Mt$ (*M* is the instrument constant), to compare it with the tabled value ν^* (Table 1.1) and to put down the data in Table 1.5.

Table 1.5

Liquid	M, m^2/s^2	t, s	ν, m^2/s	T, ^OC	ν^*, m^2/s
M-10					

1.3.5. Measuring surface tension by stalagmometer

Stalagmometer 5 is used to determine liquid surface tension by the method of drop separation. It includes a vessel with a capillary tube with the expanded tip to store a liquid drop. The surface tension strength at the moment of drop separation is equal to the drop’s weight (gravity), therefore it is defined on the liquid density and the number of drops obtained at the dump of the vessel of the given volume. To measure surface tension, it is necessary:

1. To turn instrument № 1 upside down and count the number of drops in the stalagmometer 5 for the volume height *S* between the two marks. The experiment should be made three times and arithmetical mean of the number of drops n should be calculated.
2. To calculate the experimental value of the surface tension coefficient $\sigma = K\rho/n$ (*K* is stalagmometer constant) and to compare it with the table value σ^* (Table 1.1). The data should be put down in Table 1.6.

Table 1.6

Liquid	K, m^3/s	ρ, kg/m^3	n	σ, N/m	σ^*, N/m
M-10					

WORK 2. STUDYING INSTRUMENTS FOR MEASURING PRESSURE

The work purpose. Studying the structure and operation of liquid instruments for measuring pressure.

2.1. General Information

Hydrostatic pressure is normal (regular) compression stress in a stationary liquid, i.e. force per the unit surface square. Unit of pressure measurement in the international system is considered (to be) Pascal (Pa = N/m^2).

Absolute, atmospheric, manometric and vacuum-gauge pressures are distinguished.

Absolute (full) *pressure p* is calculated from the absolute vacuum. *Atmospheric pressure p_a* is caused by gravity of the atmosphere air and in normal conditions is taken equal to 101325 Pa or 760 mm of mercury. The pressure excess over the atmospheric is called *manometric* (excessive) *pressure* ($p_m = p - p_a$), and the pressure lower than atmospheric is called *vacuum-gauge pressure* ($p_v = p_a - p$).

Instruments for measuring atmospheric pressure are called *barometers*, manometric - *manometers* and for vacuum - *gauge pressure - vacuummeters*. According to operational principle and the type of a working element, the instruments are divided into liquid, mechanical and electrical.

Liquid instruments were historically the first to be used. Their operation is based on the principle of balancing the measured pressure p by the gravity of the liquid column h high in the instrument:

$$p = \rho g h,$$

where ρ is liquid density;

g is acceleration of free fall.

Therefore, the pressure value can be expressed by the liquid column height h (mm of mercury column, mm water column). Advantages of liquid instruments in design simplicity and high accuracy; however, they are good at measuring only low pressures.

In *mechanical instruments* the measured pressure causes deformation of a sensitive element (tube, membrane, bellows) that, with the help of special mechanisms is transferred to the indicator. Such instruments are compact and have a wide range of measured pressure.

In *electrical instruments*, the pressure received by a sensitive element is transformed into electric signal. The signal is registered by an indicating (a voltmeter, an ammeter) or a writing (a recorder, an oscillograph) instrument. In the latter case, it is possible to fix pressures at transient (fast-going) processes.

2.2. Description of Device № 2 and liquid instruments

The mercury barometer consists of a vertical glass tube, with a millimeter scale and the closed top (part). The tube is filled with mercury. The lower part of the tube is placed into a bowl filled with mercury. This device was first used by the Italian scientist E. Torrichelli in 1642 to measure atmospheric pressure.

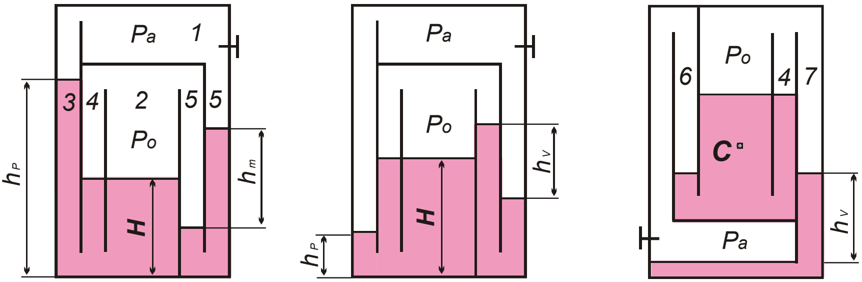
Device № 2 is (made) transparent and has cavity 1, in which atmospheric pressure is constantly maintained, and vessel 2 that is partially filled with water (Fig. 2.1, a). The pressure and the liquid level in vessel 2 are measured with the help of liquid instruments 3, 4 and 5. They are transparent vertical tubes (vessels) with scales marked in length units.

The one-tube manometer (piezometer) 3 is connected with the atmosphere by the upper end and with vessel 2 by the lower end. The piezometer measures the manometric pressure $p_m=\rho g h_p$ at the vessel bottom.

The level gauge 4 is linked by both ends with the vessel and shows the liquid level H in the vessel.

Pressure-vacuum gauge 5 is a U - shaped tube partially filled with liquid. By its left leg (bend) it is connected with (to) vessel 2, and by the right - with cavity 1. The pressure – vacuum gauge serves to determine manometric pressure $p_{mo} = \rho g h_m$ (Fig. 2.1, a) or vacuummetric pressure $p_{vo} = \rho g h_v$ (Fig. 2.1, b) above the liquid free surface in the vessel 2. The pressure in the vessel can be changed by inclining the device.

At the turn of the device in its plan 180^0 anti-clockwise (Fig. 2.1, c) tube 4 remains a level gauge, the pressure-vacuum 5 leg transforms into piezometer 6, and piezometer 3 transforms into *vacuummeter (inverse retroactive piezometer)* 7 that serves for determining the vacuum $p_{vo} = \rho g h_v$ above the liquid free surface in vessel (reservoir) 2.



a) $p_o > p_a$ b) $p_o < p_a$ c) $p_o < p_a$

Fig. 2.1. The scheme of device № 2:
1 - vessel with atmospheric pressure; 2 - experimental container; 3 - piezometer; 4 - level gauge; 5 - pressure-vacuum gauge; 6 - piezometer; 7 - vacuum gauge

WORK 3. HYDROSTATIC PRESSURE MEASUREMENT

The purpose of the work: is acquisition of skills on measuring hydrostatic pressure by liquid devices.

3.1. General information

Absolute pressure in any point of the liquid at rest is determined by the *basic equation of hydrostatics*

$$p = p_o + \rho g H,$$

where p_o is absolute pressure on a free surface of the liquid;

ρ is the liquid density;

H is submersion depth of the point under a free surface.

The pressure in the given point, e.g. at the bottom of the container, is calculated on the readings of different instruments and then the results obtained in two different ways are compared.

3.2. The work order

1. To create pressure higher than atmospheric ($p_o > p_a$) above the liquid in the container, which is shown by a higher liquid level in piezometer 3 than that in the container and by a direct difference in levels in pressure-vacuum gauge 5 (Fig. 2.1, a). For this purpose, the device should be put on the right side, and then, by turning it counter-clockwise, a part of the liquid from the left bend of the pressure-vacuum gauge 5 is poured into container 2.
2. To take the readings: h_p of the piezometer, H of the level gauge and h_m of the pressure-vacuum gauge.
3. To calculate the absolute pressure at the bottom of the container by the piezometer readings and then by the values measured by a level gauge and a pressure-vacuum gauge. To estimate the comparability of the results of the two-way pressure measurement at the container bottom, a relative error δp should be found.
4. To create vacuum ($p_o < p_a$) above a free surface of the liquid in container 2 when the liquid level in piezometer 3 be-

comes lower than that in the container, and on pressure-vacuum gauge 5 there appears a reverse difference h_v (Fig. 2.1, b). For this purpose, the device should be put on the left side, and then, by tilting it to the right, a part of the liquid from container 2 is poured into the left bend of pressure-vacuum gauge 5. Then operations 2 and 3 are performed one after another.

5. To turn the device counter-clockwise (Fig 2.1, c) and determine manometric and vacuummetric pressure in the point ***C***, given by the teacher, by the readings of piezometer 6, and then, for verification to find the pressure by the readings of reverse piezometer 7 and level gauge 4.

While making experiments and processing the data, it is necessary to fill in Table 2.1.

Table 2.1

№	Values names	Symbols, formulas	Experiment conditions	
			$P_o>P_a$	$P_o<P_a$
1.	Piesometric head, m	h_p		
2.	Liquid level in the container, m	H		
3.	Manometric height, m	h_m		--------
4.	Vacuummetric height, m	h_v	--------	
5.	Absolute pressure at the container bottom by piezometer readings, Pa	$p = p_a + \rho g h_p$		
6.	Absolute pressure in the container above the liquid, Pa	$p_o = p_a + \rho g h_m$		--------
		$p_o = p_a - \rho g h_v$	--------	
7.	Absolute pressure at the container bottom by the pressure-vacuum gauge and level gauge readings, Pa	$p^* = p_o + \rho gH$		
8.	Relative error of results of pressure measurement at the container bottom, %	$\delta p = 100(p - p^*)/p$		

Note. Atmospheric pressure p_a = 101325 Pa, water density p = 1000 kg/m^3.

WORK 4. ANALYSIS OF THE LIQUID FLOW COMPONENTS

The work purpose. Observing liquid flows of different components and revealing the factors influencing the components.

4.1. General information

There distinguish two basic conditions of the liquid flow: *laminar* (laminated) and *turbulent* (vortic). At a laminar condition the liquid particles move along parallel trajectories without agitation, therefore, the flow has a laminated components, i.e. the liquid moves in separate layers. The turbulent movement is characterized by fluctuation of pressure and particle velocities which causes intensive agitation of the flow liquid, i.e. turbulent movement.

At a sharp change in cross section or direction of the channel, a *transit jet* separates from the channel and at the wall the liquid starts moving backwards (in the opposite direction) resulting in the liquid rotation between the transit jet and the wall. This area (space) is called a *circulation* (rolling) *zone*.

To visualize currents, the tagged particles (e.g. aluminium particles) are used or coloured (in ink or Indian ink) jets, that show movement trajectories of a multiple liquid particles. They are also called *current lines*, if the flow is *stationary*. At *a stationary* current the averaged mean values of speed (velocity) and pressure in each point of the flow are constant in time. In this case, consumption, i.e., the liquid quantity passing through the given section at a time unit, does not change in time.

4.2. Description of device № 3

Device № 3 has a transparent case (Fig. 4.1, a), tanks 1 and 2 with a dampening wall 3 for dampening the liquid disturbance resulting from jets falling and air bubbles floating up. Channels 4 and 5 having the same section link the tanks. The end of channel 4 is provided with a slot 6 and the opposite end of channel 5 is provided with a grid 7 (a partition with a lot of holes). The device is filled with water containing microscopic particles of aluminium for visualizing the flows (current). The water level in tank 2 is measured by the scale 8.

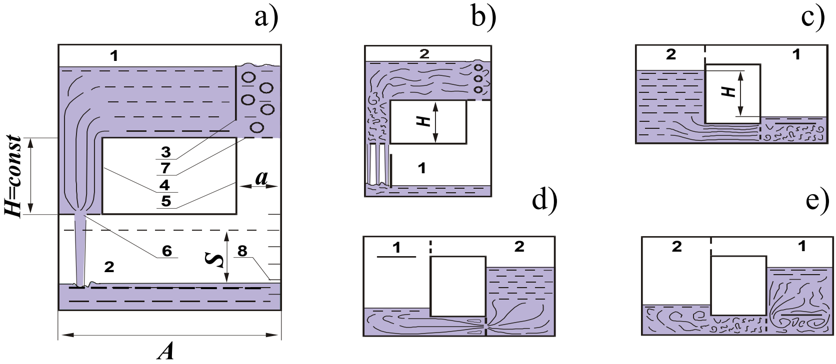


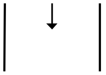
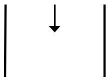
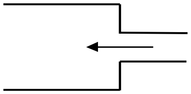
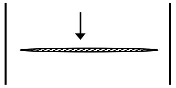
Fig. 4.1. The scheme of device № 3:
1, 2 - tanks; 3 - partitions; 4, 5 - experimental channels; 6 - a slot; 7 – a grid; 8 - level gauge scale

The device operates as follows. Within the device (Fig. 4.1, a, b) the water entering through the left channel in the lower tank displaces (expels) air in the form of air bubbles to the upper tank. So, pressures at the entrance to the channel (at the bottom of the upper tank) and above the liquid in the lower tank are equaled and the outflow (discharge) occurs under the action of steady head *H*, created by a liquid column in the left channel. In this way, the settled movement of liquid (with consumption constant in time) is provided. It should be noted that in channel 4 there establishes a laminar regime due to low current speed (rate) because of high resistance to a slot 6. In turn, low hydraulic resistance of grid 7 provides the presence of turbulent flow in channel 5 at the expense of high speeds (rates) (Fig. 4.1, b). The consumption can be reduced by tilting the device from oneself. In cases shown in Fig.4.1, c, d, e in channels 4 and 5 there arises unsteady (under changeable (variable) head and consumption) flow of liquid due to direct connection of air cavities of the tanks. This allows observing the change in flow components in the process of decreasing their speed to zero.

4.3. The work order

1. Create in channel 4 a laminar regime mode of the liquid flow. For this purpose, with tank 1 filled with water, put the device with its tank 2 on the desktop (Fig. 4.1, a). Observe the flow components.
2. Turn the device in the vertical plane 180^0 clockwise (Fig. 4.1, b). Observe a turbulent mode of flow in a channel 5.
3. With tank 2 filled with water, place the device in such a way that channel 5 (with a grid) occupied lower horizontal position (Fig. 4.1, c). Observe the process of transition from a turbulent mode of flow to the laminar one in the channel. Pay attention to the fact that the grid causes turbulization of flow behind it.
4. With tank 2 filled with water, place the device so that canal 4 (with a slot) occupied a lower horizontal position (fig.4.1, d). Observe the flow components in tank 2 at an unexpected narrowing and expanding in the channel behind the slot and at the flow leaving the channel for tank 1. Consider circulation zones, transit jet and connection of velocities with the channel section areas.
5. With tank 1 filled with water, observe the flow components at the flow around the partition 3 (Fig. 4.1, e).
6. Draw the flow components for cases stated in Tab. 4.1.

Table 4.1

Laminar regime	Turbulent regime	Flow expansion	Flow around the partition
			

WORK 5. DEFINITION OF FLOW REGIME

The work purpose: mastering of the computation method of flow components determination.

5.1. General information

Criteria of the flow regime is the *Reynold's number*

$$Re = Vd / \nu, \tag{4.1}$$

where V is mean speed of the flow;

d - inner diameter of a tube (channel);

ν - kinematic coefficient of the liquid viscosity.

In engineering practice the regime is determined by comparison of the Reynold's number Re with its *critical value* Re_k, corresponding to a change (replacement) in regimes of the liquid flow. For uniform liquid flows in tubes (channels) of round cross-section Re_k is taken as equal to 2300. The regime is considered laminar at $Re < Re_k$ and turbulent at $Re \geq Re_k$.

From the equation (4.1) it follows that Reynold's numbers are small and, consequently, a laminar regime, at low velocities of flow in channels of small cross-section (in soil pores, capillaries) or at the flow of liquids with high viscosity (oil and bitumen).

A turbulent regime in nature and engineering occurs more often. Its regularities underline water flow in rivers, streams, canals, water supply and sewerage systems, as well as flow of petrol and kerosene and other low-viscous liquids in tubes.

5.2. The work order

1. Develop in channel 4 a liquid flow (Fig. 4.1, a) by an arbitrary tilt of device № 3 from yourself.
2. Measure the time t of the water level displacement in the tank at some distance S and take the readings of the thermometer T in the device № 1.

3. Computate Reynold's number by the order indicated in Tab. 5.1.

4. Turn the device upside down (fig. 4.1, b) and perform operations according to points 2 and 3.

5. Compare the obtained values of Reynold's numbers with each other and then, on the basis of comparison with the critical value, make a conclusion about the flow regime.

Table 5.1

№	Names of values	Symbols, formulas	Test	
			1	2
1.	Change in water level in the tank (reservoir), cm	S		
2.	Time of watching the level, s	t		
3.	Water temperature, °C	T		
4.	Kinematic coefficient of water viscosity, cm^2/s	$\nu = 17.9/(1000 + 34T+0.22T^2)$		
5.	Volume of water filling the tank (reservoir) for the time t, cm^3	$W = A\,B\,S$		
6.	Water consumption, cm^3/s	$Q = W/t$		
7.	Average flow (speed) velocity in the channel, cm/s	$V = Q/\omega$		
8.	Reynold's number	$Re = Vd/\nu$		
9.	Name of a flow regime	$Re\ (<, >)\ Re_k = 2300$		

A =... cm; B =... cm; d =... cm; ω =... cm^2

Note. The tank cross-section sizes (A, B), hydraulic diameter d and cross-section area ω of the experimental tubes (channels) are indicated on the body of device № 3.

WORK 6. ILLUSTRATION OF BERNOULLI'S EQUATION

The work purpose: Experimental confirming of D. Bernoulli's equation, i.e., decrease (reduction) in mechanical energy along the flow and transformation of potential energy into kinetic and backwards (connection between pressure and velocity (speed).

6.1. General information

D. Bernoulli's equation expresses the law of energy conservation and for the two cross-sections of real liquid flow in its simplified form is written as follows:

$$P_1/(\rho g) + V_1^2/(2g) = P_2/(\rho g) + V_2^2/(2g) + h_f,$$

where P is pressure;

V is average flow rate in section;

ρ is liquid density;

g is acceleration of free fall;

h_f is summary pressure losses on resisting hydraulic friction forces between sections 1-1 and 2-2; index numbers "1" and "2" indicate the section number to which the value refers.

The equation components express *energies* per unit of gravity which are called *liquid heads* in hydraulics: $P/(\rho g)=H_p$ - *piezometric head* (potential energy), $V^2/(2g)=H_k$ – *velocity head* (kinetic energy), $P/(\rho g)+V^2/(2g)=H$ - *full head* (complete mechanical energy of a liquid), h_f - *head loss* (loss of mechanical energy due to its transformation into thermal energy). Such energies are measured in length units, as J/N = Nm/N = m.

From the equation, it follows that when there is no flow thermoexchange (heat transference) with the environment, *the complete specific energy* (including the thermal one) *is invariable along the flow*, that is why, a change in one kind of energy results in the opposite in sign change the other kind of energy. Such is the *energetic* meaning of a Bernoulli's equation. For instance, when the flow expands, velocity (rate) V and, consequently, kinetic energy $V^2/(2g)$ decrease, which, in virtue of balance conservation, causes an increase in potential energy $P/(\rho g)$. In other words, a decrease in the flow rate V along the flow results in an increase in pressure P, and visa versa.

6.2. Description of device № 4

Device № 4 contains vessels 1 and 2 connected by experimental channels of variable 3 and constant 4 cross-sections (Fig. 6.1). The channels are connected by uniformly placed piezometers *I-V* necessary for measuring piezometric heads in typical cross-sections. The device is filled with coloured water. One of the vessels contains a scale 5 for measuring water level.

At the device turning upside down, due to the constancy of outflow head H_0 in time, the established water movement in a low channel is provided. At this time the other channel transports the air expelled by the liquid from a lower to an upper vessel.

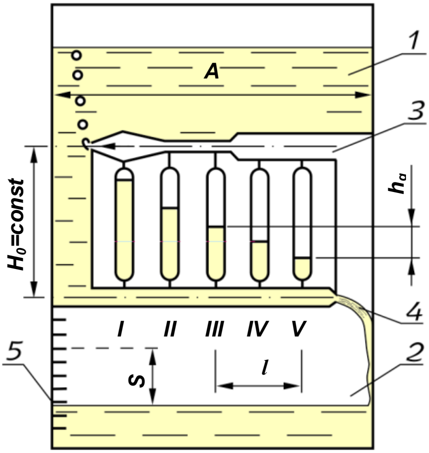


Fig. 6.1. Scheme of device № 4:
1,2 are vessels;
3,4 are experimental channels of variable and constant sections;
5 – a uniformed scale;
I-V – piezometers

6.3. The work order

1. When tank 2 is filled with water (Fig. 6.1), turn the device upside down to get a flow in the channel of a variable section 3.
2. Take the readings of piezometers $H_P=P/(\rho g)$ on a lower part of water meniscus in them.
3. Measure time t of the level movement in the vessel at an arbitrarily given value S.
4. Determine the water consumption Q in the channel according to A and B sizes of the tank cross-section, level movement S and time t. Then determine velocity (kinetic-energy) head H_k and full head H in the channel sections following the order in table 6.1.

Table 6.1

№	Values, names	Symbols, formulas	Channel sections					
			I	II	III	IV	V	VI
1.	Channel section area, cm	ω						
2.	Average velocity, cm/s	$V = Q/\omega$						
3.	Piezometric head, cm	$H_P=P/(\rho g)$						
4.	Velocity head, cm	$H_k=V^2/(2g)$						
5.	Full head, cm	$H= P/(\rho g)+V^2/(2g)$						

A =... cm; B =... cm; S =... cm; t =... s; $Q = ABS / t$ =... cm^3/s

5. Draw in scale a channel with piezometers (Fig. 6.2). By connecting the liquid levels in piezometers with the center of output section *VI*, obtain *piezometric line* 1, indicating a change in potential energy (pressure) along the flow. To obtain *head line* 2 (a line of full mechanical energy), lay off the channel axis full heads H and connect the obtained points.

6. Analyze the change in the full mechanical *H*, potential *P/(ρg)* and kinetic $V^2/(2g)$ energies of the liquid along the flow; find out how these changes correspond to Bernoulli's equation.

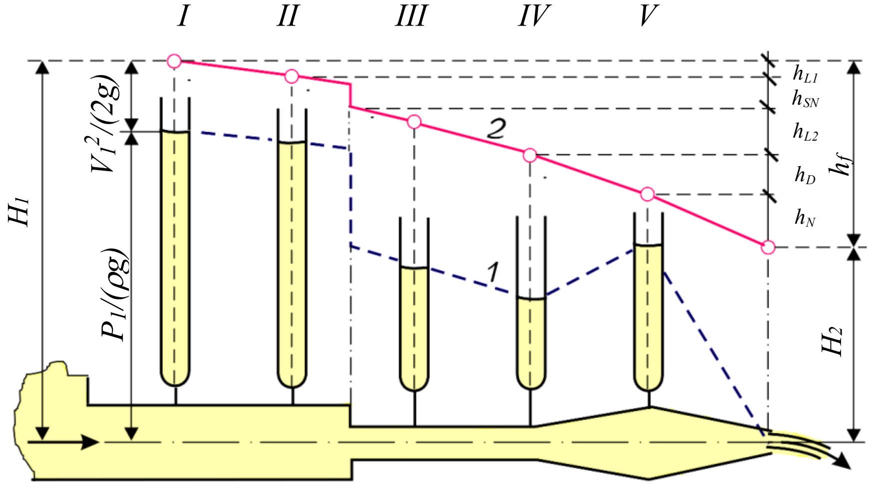


Fig. 6.2. Illustration of Bernoulli's equation:
1, 2 are piezometric and head lines; H_1, H_2 are full heads (mechanical energies) at the channel entrance and exit; h_f, h_{L1}, h_{L2}, h_{SN}, h_D, h_N are head losses: total through the length of sections 1 and 2, on unexpected narrowing, as well as smooth expansion and reduction (constriction, contraction).

WORK 7. DETERMINATION OF LOCAL HEAD LOSSES

The work purpose. To determine experimentally the head losses due to overcoming local resistance and compare them with those calculated by engineering formulas.

7.1. General Information

Local head (energy) *losses* of a liquid occur on short segments of a pipeline with flow obstructions, known as local resistors (e.g., sudden (sharp, unexpected) expansion or reduction of pipes, valves, gate valves, valve disks, pipe bends). In such places, there form circulation zones, where liquid rotation requires a part of the head mechanical energy, called local head losses. Their value is experimentally determined by a difference in liquid full heads before and after a local resistor.

In engineering calculations for definition of local pressure losses will be used the formula

$$h_M = \xi V^2/(2g),$$

where z - the factor of local resistance (is selected under the reference book);

V - half speed of a flow behind local resistance.

7.2. The work order

1. Transfer values of section areas and velocities from Table 6.1 to Table 7.1.
2. Determine experimental values of local losses h_M (h_{SN}, h_D) from the chart (see Fig. 6.2).
3. Find out the designed values of local losses, compare them with the experimental ones and explain the differences.

Table 7.1

№ o/o	Values, names	Symbols, formulas	Resistance			
			Reduction		Expansion	
			1(II)	2(III)	1(IV)	2(V)
1	2	3	4	5	6	7
1.	Section areas, см^2	ω				
2.	Average velocities behind resistance, cm/s	V_2				
3.	Experimental values of local losses, cm	$h_M \, (h_{SN}, h_D)$			-----------	
4.	Coefficients of local resistors	$\zeta_{SN}=0.5(1-\omega_2/\omega_1)$ $\zeta_{SD}=(\omega_2/\omega_1 - 1)^2$	----------			
5.	Designed values of local losses, cm	$h_M = \zeta \, V_2^2/(2g)$				

Nice: ζ_{SN}, ζ_{SD} - coefficients for sudden reduction and expansion.

WORK 8. DETERMINATION OF HEAD LOSSES ALONG THE LENGTH

The work purpose. Mastering experimental and designed methods of determining friction head losses along the length.

8.1. General Information

Head losses along the length are caused by braking action of the walls resulting in viscous friction between a liquid particles and jets along the pipeline. They are determined by the equation:

$$h_L=\lambda(l/d)\ V^2/(2g),$$

where λ is a hydraulic friction factor;

l, d are the channel length and inside diameter, respectively;

V is average velocity.

In the experiments the head losses along the length are determined by difference in the readings of piezometers fixed at the ends of an experimental segment of the channel, as the velocity head does not change along the way.

8.2. The work order

1. With vessel 1 filled with water put the device № 4 with its vessel 2 on the desktop (Fig. 6.1).
2. Take the readings of piezometers I through V, measure time t of the level change in the tank at an arbitrarily given value S and inside temperature T.
3. Draw a piezometric line according to piezometers readings. On this line separate a segment with a constant/permanent fall/grade (as a rule, segment *III-V*), corresponding to a uniform flow. Determine its length l and *experimental* value of losses h_d according to boundary piezometers readings (Fig. 6.1.).
4. Commutates Reynolds's number and *the designed* value of the head losses h^*_d by the order indicated in Table 8.1 and a rel-

ative difference in experimental and designed values of head losses. Explain the difference.

Table 8.1

№	Names of values	Symbols, formulas	Meanings of values
1	2	3	4
1.	Piezometer readings, cm	$P_1/(\rho g),\dots,\ P_5/(\rho g)$	
2.	Length of the segment with a uniform flow, cm	l	
3.	Experimental value of head losses along the length, cm	$h_L = P_3/(\rho g) - P_5/(\rho g)$	
4.	Kinematic coefficient of water viscosity, cm^2/s	$\nu = 17.9/(1000+34T+0.22T^2)$	
5.	Reynold's number	$Re = Vd/\nu$	
6.	Friction coefficient at		
	$Re < 2300$	$\lambda = 64/Re$	
	$2300 < Re < 10d/\Delta$	$\lambda = 0.316/Re^{0.25}$	
	$Re > 10d/\Delta$	$\lambda = 0.11(68/Re+\Delta/d)^{0.25}$	
7.	Computated value of head losses along the length, cm	$h^*_L = \lambda(l/d)\ V^2/(2g)$	
8.	Relative difference in experimental and computated values of head losses	$\delta_h = (h_L - h^*_L)/h_L$	

d =... cm; ω =... cm^2; A =... cm; B =... cm; T =... °C; S =... cm; t =... s; $Q = ABS/t$ =... cm^3/s; $V = Q/\omega$ =... cm/s.

Note. Absolute roughness of channel walls is to be accepted equal to $\Delta = 0.001$ mm.