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BRANCH OF THE FEDERAL STATE AUTONOMOUS EDUCATIONAL INSTITUTION OF HIGHER EDUCATION
"National Research Technological University "MISiS" in Almalyk
(NUST MISIS branch in Almalyk)
DEPARTMENT "Mathematics and natural sciences"

TRAINING AND METODOLOGY COMPLEX
BY SUBJECT

"HYDRAULICS"

(for students of the direction of education: specialty
210504 - "**05/21/04 Mining, 05/21/04-SGD-16-9.PLX Mining machines and equipment»**

Almalyk-2023

МИСиС
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Educational-methodical complex on "Hydraulics"

Developed in accordance with OS VO:

Self-established educational standard of higher education Federal State Autonomous Educational Institution of Higher Education "National Research Technological University" MISiS ", specialty 21.05.04 MINING (order dated 02.12.2020 No. 602 o.v.)

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Content

BRANCH OF THE FEDERAL STATE AUTONOMOUS EDUCATIONAL INSTITUTION OF HIGHER EDUCATION
"National Research Technological University "MISiS" in Almalyk

COLLECTION OF LECTURES
by subject

"Hydraulics"

Lecture 1

The field of study and the history of the subject "Hydraulics" Technological training for lecture No. 1.

Time - 2 hours	Number of students: 20-30 people
Form of the lesson	Introduction, visual lecture
Lesson Plan	one.Field of study and history of the subject ,,Hydraulics” 2. Basic concepts and definitions. 3. The role and application of hydraulics in modern, mechanical engineering and agriculture. 4. Physical properties of liquids. 5. Hydrostatic pressure and its properties. 6. Newton's law for friction in liquids. Viscosity. 7. Ideal and real gases 8. Saturated vapor pressure of a liquid 9. The concept of cavitation. 10. Models of ideal and real gases
Purpose of the lesson*:* To acquaint students with the content of the subject: “Hydraulics”; with basic concepts and definitions, with the physical properties of liquids	
Tasks of the teacher: - • introduce the concept and essence of hydrostatics; • talk about the subject, methods and problems of hydrostatics; • briefly characterize the basic concepts of liquid.	*Learning outcomes:* The student must learn: -What does the subject “Hydraulics” study; -What is the role and application of hydraulics in modern engineering; - Liquid properties; - Hydrostatic pressure and fluid viscosity
Teaching methods and techniques	Lecture - visualization, techniques: blitz survey, focusing questions, "think - work in pairs - share", "Cluster" technique.
Means of education	Laser projector, visual materials, information support.
Forms of study	Collective, frontal work, work in pairs.
Conditions of education	An audience adapted to work with TCO.

Technological map of the lecture (1st lesson)

	Activity	
	teacher	**students**
Stage 1. Introduction (10 min.)	1.1.Informs the topic, purpose, planned results of the training session and the plan for its implementation.	1.1. Listen, write.
Stage 2. Basic (60 min.)	2.1.In order to update students' knowledge, asks focusing questions: - What is a liquid? What are the types of liquid? Where are liquids used? Work in pairs to answer questions. Conducting a quiz. 2.3. Consistently presents the material of the lecture on the issues of the plan, uses visual materials Focuses on the key points of the topic, offers to write them down.	2.1. Listen. They take turns answering the questions. Listen to the correct answer. 2.3.Discuss schema content and tables, visual al materials ly, clarify ask questions. write down main.
3 stage. Closing (10 min.)	3.1.Conducting a quiz. Makes a final conclusion. Gives assignments for independent work. 3.2 Cluster the word "Liquid". Set ratings.	3.1. Reply to question. 3.2. are listening, write down

1.1Field of study and history of the subject "Hydraulics"

Hydraulics called applied technical science, which studies the laws of equilibrium and motion of dropping liquids and considers the application of these laws to the solution of specific technical problems. Another science, hydromechanics, is also studying the laws of equilibrium and movement of fluids, in which only strictly mathematical methods are used, which make it possible to obtain general theoretical solutions to various problems related to the balance and movement of fluids. For a long time, hydromechanics considered predominantly an inviscid (ideal) fluid, i.e. some conditional fluid with absolute particle mobility, which is considered to be absolutely incompressible, not possessing viscosity - not resisting shear stress. Recently, hydromechanics has also begun to solve the problems of the motion of real fluids, and therefore the role of experiment in hydromechanics has increased significantly. Thus, two sciences are engaged in the study of the laws of equilibrium and motion of liquids: hydraulics (technical mechanics of liquids) and hydromechanics.

Brief history of the course. Water has always played an important role in human life. Even during the primitive communal system, people used rivers and lakes as means of communication, and in the ancient world, water was used for a variety of purposes. Many thousands of years ago, quite large hydraulic structures were built in Central Asia, China, Egypt, Assyria, Babylon, Rome and Greece. Then the first ships were created.

With the development of productive forces, water began to be widely used for artificial irrigation of fields, water supply, as a source of energy, and for many other purposes. This led to the construction of canals, water pipes, water engines. The greatest experience in matters of hydraulics was accumulated during the construction of water pipelines.

Of the most significant works of the ancient world on hydraulics, only one has survived to this day - Archimedes' treatise "On Floating Bodies", written approximately 250 years BC. The well-known law of Archimedes, which determines the forces of pressure of a liquid on the surface of a body immersed in it, has reached our days in complete integrity. In the XIV century, the famous scientist Leonardo da Vinci (1452-1519) wrote a study "On the movement and measurement of water", which, however, was published only in the XX century.

The subsequent major works in the field of hydraulics belong to Galileo (1564-1642), Toricelli (1608-1647), Pascal (1623-1662) and Isaac Newton (1642-1726). Toricelli formulated the law of fluid flow from holes. Pascal owns the law on the transfer of pressure inside a fluid (Pascal's law), and Newton hypothesized about internal friction in a fluid and established the law of dynamic similarity of moving flows, which is currently widely used in modeling theory in hydraulic laboratory studies.

M.V. Lomonosov, in his classic work “Discourses on the Solidity and Fluid of a Body”, having discovered the law of conservation of matter and motion, created a theoretical basis for the further development of hydrodynamics, i.e. section of hydraulics, which deals with the laws of motion of fluids.

In the outstanding work "Hydrodynamics", published in 1738. Academician Bernoulli received a well-known equation that establishes the relationship between pressure, speed and depth. It is the basic equation of hydrodynamics.

Academician Euler in his work "General Principles of Fluid Motion" (1755) derived differential equations for the equilibrium and motion of fluids, giving a more general solution to this problem. From Euler's differential equations, Bernoulli's equation can easily be obtained.

The French scientist Chezi is known for his work in the field of uniform fluid motion. His formula for the average fluid velocity is currently the main one in the calculation of channels, natural channels and pipes. Venturi's work is mainly devoted to the study of fluid flow through holes and nozzles (Venturi nozzles, Venturi water meter), and Weisbach's work is mainly devoted to the study of local and path pressure losses in pipes. The results of Bazin's extensive studies, who studied the outflow of liquid through weirs, as well as the uniform movement of the liquid, are still used today (Bazan's formula for weirs with a thin wall).

We should especially note the work of the English physicist Osborne Reynolds, who for the first time (in 1883), on the basis of his suppressed visual experiments, showed the existence of two modes of motion of real fluids - laminar and turbulent.

Professor Petrov published in 1882. research "Hydrodynamic theory of friction in the presence of a lubricating fluid", which brought him world fame.

Zhukovsky, at the end of the 19th century, solved the problem of hydraulic shock in pipes (in 1898), thereby initiating the study of one of the most important problems in hydraulics. In 1906 Zhukovsky, together with Chaplygin, published the work "On the friction of the lubricating layer between the spike and the bearing." In it, an exact mathematical solution of Petrov's problem was given. In the same year, Zhukovsky developed the theory of wing lift. Based on this theory, it became possible to calculate the wings of aircraft, as well as the blades of the impellers of hydraulic turbines, centrifugal and propeller pumps. Thus, the most important problem of aerodynamics and hydrodynamics was solved.

1.2. Basic concepts and definitions.

liquid bodies,or liquids are called physical bodies that easily change their shape under the influence of the most insignificant forces. Unlike solids, liquids are characterized by a very high mobility of their particles and therefore have the property of fluidity and the ability to take the shape of the vessel in which they are poured.

Distinguish liquids*drip*and gaseous. Droplets are liquids found in nature and used in technology: water, oil, gasoline, etc. All dropping liquids show great resistance to volume change and are difficult to compress. When pressure and temperature change, their volume changes very slightly. Gaseous - liquids (gases) change their volume under the influence of these factors to a large extent. In hydraulics, dropping liquids are usually studied.

Dropping liquids practically do not show noticeable resistance to tensile forces. The cohesive forces that exist between the molecules of these liquids appear only on their surface in the form of the so-called surface tension forces, where the well-known resistance of the liquid to rupture is revealed. This explains, for example, the existence of a thin film of a soap bubble, the formation of a drop kept from falling, etc. The forces of resistance to rupture in a liquid are negligible. Thus, a force is sufficient to break water, about ten million times less than the force required to break steel (iron). Therefore, when solving ordinary problems in hydraulics, it is considered that there are no tensile forces in the fluid.

Along with this, it should be emphasized that dropping liquids provide significant resistance to shear forces, which manifests itself during the movement of a liquid in the form of forces during the movement of a liquid - one of the main tasks of hydraulics.

In hydraulics, a liquid is considered as a collection of material points (particles) in a limited volume. The sizes of these particles are assumed to be infinitely small, but they are in no way comparable with the sizes of the many times smaller molecules that actually make up the liquid. Physically similar particles represent, as it were, some fairly large set of them. It is assumed that the liquid fills the volume under consideration completely, without any voids and, thus, is a continuous medium - a continuum.

There are solid surfaces that limit the volume of a liquid (for example, the walls and bottom of vessels containing a liquid), and free surfaces along which a liquid borders on other liquids or gases (for example, the contact surface of a liquid with air in an open vessel).

The forces acting on a limited volume of fluid in hydraulics are usually divided into internal and external. Internal - these are the forces of interaction between individual particles of the volume of liquid under consideration. External forces are divided into surface forces applied to surfaces limiting the volume of a liquid (for example, forces acting on a free surface, reaction forces of the walls and bottom of vessels), and on mass, or volumetric, continuously distributed throughout the volume of a liquid (for example, gravity, inertial forces).

In hydraulics, both body and surface forces are usually considered in the form of unit forces: body forces are related to a unit of mass, and surface forces are related to a unit of area. A unit body force is numerically equal to the corresponding acceleration. A unit surface force is the stress of this force and, in the general case, is decomposed into components: normal stress (it is called hydromechanical pressure) and tangential stress.

To facilitate and simplify a number of theoretical conclusions and studies in hydraulics, the concept of an ideal, or perfect, fluid is sometimes used, which has absolute incompressibility, a complete absence of thermal expansion and does not resist tensile and shear forces. Of course, an ideal fluid is a fictitious fluid, and does not exist in reality. All real liquids are characterized to some extent by all of the properties listed above. However, as noted above, the compressibility, thermal expansion, and tensile strength of real liquids are negligible and are usually not taken into account. Thus, the main and, in essence, the only feature that distinguishes a real liquid from an ideal one is the presence of shear resistance forces in the first, determined by a special property of the liquid - viscosity.

It should be noted that in addition to the concept of an ideal fluid generally accepted in hydraulics, the concept of an ideal compressible fluid is also used in hydromechanics. Compressibility, however, manifests itself and becomes perceptible only at very high fluid velocities close to the speed of sound. Therefore, in hydraulics dealing with speeds that are much lower, the compressibility factor is usually not taken into account (the exception is water hammer) and they operate with the concept of an ideal incompressible fluid, omitting the word "incompressible".

It should be noted that the basic laws of hydraulics are widely used in the theory of vane pumps and hydraulic turbines. So,

for example, the Bernoulli equation for the relative motion of a fluid is used in the analysis of the nature of the movement of flows in the area of the impellers of these hydraulic machines. It also serves to investigate the phenomenon of cavitation in vane pumps and hydraulic turbines, allowing you to set the suction height or limit the speed of the impellers. The reactive interaction of the jet and the vessel explains the hydraulic scheme of the operation of bladed machines.

The theory of hydrodynamic similarity as applied to hydraulic vane machines is necessary to solve many complex issues related to the creation of new machines and the improvement of existing designs. The theory of water hammer is widely used in the design of pipelines and safety devices used to combat water hammer, as well as in the design of hydraulic rams used to combat water hammer, as well as in the design of hydraulic rams.

Hydraulic presses, hydraulic accumulators, hydraulic jacks and similar devices are designed based on the law of pressure transfer within a fluid. The theory of hydraulic drive is based on the same law, which operates on the volumetric principle and serves to regulate the operation of modern machine tools. Calculation of the stability of pontoons, floats of seaplanes and other floating facilities, as well as float devices in carburetors is carried out in accordance with the theory of floating bodies. The pressure force of gasoline acting on the walls of the gas tank of the aircraft during its movement, the force of pressure of the liquid on the walls of tanks during the movement of the train, etc. are determined from the equations of relative rest of the fluid.

1.3. Physical properties of liquids.

Definition of liquid. *Liquid*-This is a physical body that easily changes its shape under the influence of any force of any magnitude. A liquid differs from a solid body in that it has a high mobility of particles (fluidity) and takes the form of a vessel in which it is located.

There are two types of liquids: drip and gaseous.

To dripliquids include, for example, water, oil, oil, mercury, etc. Dropping liquid is characterized by very low compressibility and low resistance to tensile forces.

Gaseous liquids include all gases under normal conditions, which are characterized by high compressibility and lack of resistance to tensile forces.

In hydraulics, it is customary to combine liquids, gases and vapors under a single name - liquids. This is explained by the fact that the laws of motion of liquids and gases (vapours) are practically the same if their speeds are much lower than the speed of sound. Therefore, in the future, liquids will be called all substances that have fluidity when the smallest shear forces are applied to them.

The general laws of equilibrium and motion of liquids are usually expressed in the form of differential equations obtained on the basis of considering a liquid as a continuous homogeneous medium. At the same time, they neglect the fact that an elementary volume, or a particle of a liquid, is a collection of molecules located at certain distances from one another. Such an assumption is possible, since the particle sizes are always much larger than the mean free path length of the molecules.

When deriving the basic laws in hydraulics, the concept of a hypothetical ideal fluid is introduced, which, unlike a real (viscous) fluid, is absolutely incompressible under pressure, does not change density with temperature changes, and does not have viscosity.

Real liquids are divided into drop and elastic (gases or vapors).

dripliquids are practically incompressible and have a very small coefficient of volumetric expansion. The volume of elastic liquids varies greatly with changes in temperature or pressure.

There are the following main properties of liquids:

Density. The mass of a unit volume of liquid, i.e. the ratio of the mass m to its volume V is called the density and is denoted by ρ ;

$$\rho = \frac{m}{v} \quad (1\text{-}1)$$

where: m is the mass of the liquid;
V is the volume of liquid.
The unit of density is a kilogram per cubic meter (kg/m3), which corresponds to the density of such a homogeneous substance, one cubic meter of which has a mass of one kilogram.
In hydraulics, the concept of relative density is also widely used, which is the ratio of the density of the liquid under consideration to the density of water at t = + 3.98°C and atmospheric pressure. Relative density is denoted by d.
Therefore, the relative density of water d is the ratio of the density of water at a given temperature to the highest density of water corresponding to t = + 3.98 °C. Then the dependence of the relative density of water on temperature at atmospheric pressure is characterized by the data given in Table. one.

Table 1.

t0C	d	t0C	D	t0C	d	t0C	d
0	0.99987	ten	0.99750	thirty	0.99576	70	0.97794
3	0.99999	fifteen	0.99915	40	0.99235	80	0.97194
3.98	1.00000	twenty	0.99826	fifty	0.98820	90	0.96556
5	0.99999	25	0.99712	60	0.98338	100	0.95865

Specific gravity -is the weight of a unit volume of liquid, which is denoted by γ ,those.:

$$\gamma = \frac{G}{V} \quad (1\text{-}2)$$

Where: G - weight; V - liquid volume
Table 2 shows the specific gravity of some liquids.

Table 2.

Name liquids	Specific gravity (kg/m3)	t0C	Name liquids	Specific The weight (kg/m3)	t 0C
Pure fresh water	1000	four	Petrol	700-750	fifteen
Normal marine water	1020- 1030	four	ordinary Solar oil	880 - 890	fifteen
Light oil	860 - 880		Lubricating oils	890 - 920	fifteen
Oil average	880-900	fifteen	fuel oil	890-940	fifteen
Heavy oil	920 930	fifteen	Tar	930-950	fifteen
Kerosene	790-820	fifteen	Alcohol anhydrous	790 - 800	fifteen
Aviation gasoline	650	fifteen	Glycerol	1260	0
		fifteen	Mercury	13600	0

Compressibilitycharacterized by the volumetric compression ratio β_v ,which is a relative change in volume with a change in pressure by 1 Pa:

$$\beta_v = \frac{(V_1 - V_2)}{(W_1(p_2 - p_1))}, (1\text{-}3)$$

where: V is the initial volume; W2 ~ final volume; P1 and P2 - initial and final pressure.
Surface tension (capillarity) - this is a property of a liquid, which is due to the forces of mutual attraction that arise between the particles of the surface layer and cause its stressed state. Under the action of these forces, the surface of the liquid turns out to be, as it were, covered with a uniformly stretched thin film, which tends to give the volume of the liquid a shape with the smallest surface.

Surface tension forces exert additional pressure on the liquid, normal to its surface. This pressure is measured in newtons per square meter (N/m2) and can be determined using Laplace's formula:

$$p = \sigma\left[\frac{1}{r_1} + \frac{1}{r_2}\right] \quad (1\text{-}4)$$

where: p - coefficient of surface tension;
*r1*and r2 are the radii of curvature of the curves obtained by crossing the liquid surface by any two mutually perpendicular planes drawn through the normal to this surface at some point.

Average values for some liquids at the interface with air are as follows:
Water .... 0.073 Oil 0.025
Alcohol........... 0.0225 Glycerin 0.065
Benzene .... 0.029 Mercury 0.490
In general, as the temperature rises, the surface tension of liquids decreases.
Surface tension is especially strong in tubes of very small diameter (capillary), where, due to the action of additional pressure caused by this tension, the position of the surface changes compared to its normal level (capillarity).
For capillary tubes, formula (1-4) takes the form:

$$p = \frac{2\sigma}{r} \quad (1\text{-}5)$$

where r is the tube radius.
Two cases of level change are possible: raising, if the liquid wets the walls (for example, water), and lowering, if the liquid does not wet the walls (mercury).
For water at t = 200C, the height of the capillary rise (in mm) in a glass tube is determined by the formula:

$$h = \frac{29{,}8}{d}$$

where: d is the internal diameter of the tube.
For mercury under the same conditions, the drop in level (in mm):

$$h = \frac{10{,}15}{d}$$

Thermal expansion characterized by the coefficient of thermal expansion of liquids, expressing the relative increase in volume with an increase in temperature by 1 ° C:

$$\beta_t = \frac{(V_1 - V_2)}{(W_1 \Delta t)},$$

where: Δt— change in temperature.
The coefficient of thermal expansion for water increases with increasing pressure, but for most other dropping liquids, this coefficient decreases with increasing pressure. Table 3. shows data on the values of the coefficient of thermal expansion for water.

Table.3.

Pressure am	At temperature t,0C				
	4-10	10-20	40-50	60-70	90-100
one	0.000014	0.000150	0.000 422	0.000556	0.000719
100	0.000043	0.000165	0.000 422	0.000548	-
500	0.000 149	0.000236	0.000 429	0.000523	0.000523

The coefficients of thermal expansion for dropping liquids are much higher than their coefficients of volumetric compression, however, they are also very small.

1.4. Newton's law for friction in liquids. Viscosity.

VISCOSITY is the property of a fluid to resist shear shear forces. This property cannot be detected when the liquid is at rest, because it manifests itself only when it moves.

To clarify the physical essence of the concept of viscosity, consider the following scheme. Let there be two parallel platesBUTand B (Fig. 1.1). The space between them contains liquid. Let the lower plate be stationary, the upper one move forward with some constant speed ϑ *one*.

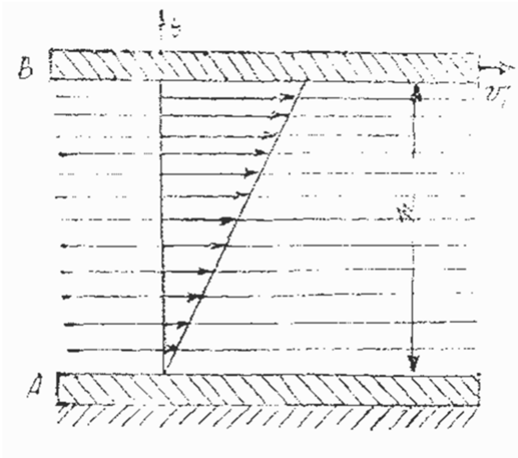


Fig.1.1

At the same time, as experience shows, the layers of liquid adjacentsticking directly to the plates will have the same velocities with them, i.e. the layer adjacent to the upper plate B will move at a speed ϑ one, and adjacent to the lower plate A, will be at rest. The intermediate layers will slide one over the other at a speed proportional to their distance from the bottom plate. If the distance between the plates is denoted by n, then the speed ϑ atliquid layer at a distance y from this plate will be equal to

$$\vartheta_y = \vartheta_1 \frac{y}{n} .$$

Even Newton suggested (subsequently confirmed by experience) that the resistance forces arising from such sliding of the layers are proportional to the area of contact of the layers and the speed of sliding. Then, taking the contact area equal to unity, we can write:

$$\tau = \mu \text{ (dv/dy)(1-6)}$$

where: τ - resistance force per unit area, or friction stress: μ - coefficient of proportionality, depending on the type of liquid, or the dynamic viscosity of the liquid.

Thus, viscosity is a physical property of a fluid that characterizes its resistance to slip or shear.

1.5 Ideal and real gases.

Boyle-Mariotte law, Gay-Lussac law

Insert the piston into the tube, the opposite end of which is sealed. By moving the piston, we reduce the volume of gas in the tube. At the same time, the gas pressure increases: if you do not hold the piston, the gas raises the piston to its previous height and occupies the original volume.

By pushing the piston out of the tube, we increase the volume of gas, while its pressure decreases, since under the influence of atmospheric pressure the piston returns to its previous position as soon as we release it.

Precise experiments allowed the English scientist Robert Boyle (1627-1691) and the French scientist Edme Mariotte (1620-1684) to establish the following pattern, which is called the Boyle-Mariotte law: at a constant temperature, the pressure of a constant gas mass is inversely proportional to the gas volume.

Gaseous liquids, in comparison with droplets, have a much lower density, which is subject to large changes depending on pressure and temperature.

For perfect (ideal gases) obeying the laws of Boyle-Mariotte and Gay-Lussac, there is the following relationship between pressure p, density ρ and temperature t:

$$\frac{p}{\rho} = Rt \quad (1\text{-}7)$$

known as the equation of state of ideal gases, where R is the specific gas constant, it is equal to the work of expansion of 1 kg of gas when it is heated by 1 K at constant pressure. The gas constant is measured in joules per kilogram and kelvin [J/(kg K)].

Density (at t = 0°C, p = 101325 Pa) and gas constant are given in Table. .four.

Table 4

Gas	$\rho, кг/м^3$	R J/(kg K)	Gas	ρ, kg/m3	R J/(kg TO)
Air	1.293	287.0	Argon	I.783	208.2
Oxygen	1.429	259.8	Helium	0.179	2078.0
Nitrogen	1.251	296.8	Methane	0.717	518.8
Hydrogen	0.090	4124.0	Ethylene	1.251	296.6
Carbon dioxide	1.977	188.0	Ammonia	0.771	488.3

Real gases do not obey the equation of state (1-7). The deviations of their properties from this equation increase with increasing pressure and decreasing temperature, and at high pressures they are taken into account by introducing correction factors for compressibility, which are established empirically.

The saturation vapor pressure of a liquid, or vapor pressure, is the pressure at which the vapors of the liquid are in equilibrium with the liquid and the number of molecules passing from liquid to vapor is equal to the number of molecules making the reverse transition.

The saturated vapor pressure of various liquids largely depends on temperature and, as a rule, increases with its increase (Table 5.).

Table 5

Saturated vapor pressure (Pa)

Liquid	Liquid temperature t, °C											
	0	5	ten	twenty	thirty	40	fifty	60	70	80	90	100
Water	613	872	1225	2332	4214	7350	1234	1989	3 1 16	4733	7007	
Easy	3430	-		7840		1372	eight	four	four	four	0	-
oil						0	_	3724	_	8526	—	
Petrol	646	-	7938	1068	1656			0		0		
Clayey solution	eight		1764	one	2	2253	3 194				-	-
				3136	5390	eight	eight	-	-	-	-	
						8320	1372	-		-		

Saturated vapor pressure can be defined in the same way as the pressure corresponding to the boiling point of a liquid at a given temperature. Therefore, for example, if the liquid is in any vessel (reservoir, pipeline), the absolute pressure $p_{абс}$, which is equal to the pressure of saturated vapors r.p. (rabs = r.p.), the liquid will boil, and the vessel will be filled with its vapors.

1.6. The concept of cavitation.

cavitation (from the Latin word "cavitas" - cavity) is the formation of cavities in a moving liquid filled with steam or air (gas). Cavitation occurs when the pressure in some places of the flow decreases so much that it becomes less than the saturation pressure, i.e. pressure corresponding to the evaporation of a liquid at a given temperature.

The phenomenon of cavitation can be observed, for example, in siphon pipelines, where its appearance is determined by the geometric configuration and the principle of operation of the pipeline itself, the main part of which is under pressure less than atmospheric; cavitation can also occur in the operation of high-speed hydraulic turbines, centrifugal pumps and propellers. In these cases, the cause of cavitation is the occurrence of high local velocities, leading to a decrease in pressure. If, in this case, the pressure value is less than the vapor pressure, a rapid evaporation of the liquid begins in the corresponding places of the flow, the liquid begins to boil, and cavitation cavities are formed in it, consisting of bubbles filled with vapor. If then, with further movement of the flow, the pressure in it rises, steam condenses, usually accompanied by a sharp crack, and the cavitation cavities close. The occurrence of cavitation is greatly facilitated by the presence of air bubbles in the liquid, as well as dissolved gases.
At the same time, as a result of instantaneous, rapidly alternating processes of compression of individual bubbles, very large local impulsive pressures arise here (several hundreds and even thousands of atmospheres), leading to very short and intense impacts that destroy the metal, first chipping its grains from the surface, and then rapidly spreading and deep. These purely mechanical, impact actions are often accompanied by chemical actions on the metal of oxygen-enriched air released from the liquid, and in some cases also by electrolytic actions. As a result of all these phenomena, especially if cavitation lasts for a long time, the metal corrodes, separate pieces fall out of it, and it takes on a spongy structure to a great depth.
In order to prevent cavitation, blades and blades are designed in the form of slightly curved profiles with rounded inlet and outlet edges and special, corrosion-resistant materials are used for their manufacture (for example, steels with the addition of chromium and nickel) with carefully, if possible, treated surfaces.

1.7. hydrostatic pressure.

Forces acting on a fluid When a fluid is at rest, viscous forces appear in it. Consequently, real fluids at rest will be characterized by properties very close to those of an ideal fluid. Therefore, all problems of hydrostatics, considered using the concept of an ideal fluid, are solved with great accuracy.
A fluid at rest is subject to the action of two categories of external forces: mass and surface. Mass forces are proportional to the mass of the liquid - the forces of gravity, as well as the forces of inertia, the latter act,
for example, in the case when the liquid is in relative rest, being placed, for example, in a moving tank, etc. Surface forces are the forces acting on the surface of the studied volumes of liquid, for example, the pressure forces of a piston on the surface of a liquid. As a result of the action of external forces, stresses arise inside the liquid, measured in kilograms per square meter (kg / m2), etc.
The compressive stress that occurs inside a fluid at rest is called hydrostatic pressure or hydrostatic pressure stress.
Let us establish the main provisions related to the concept of hydrostatic pressure. Consider a certain volume of a liquid body in equilibrium (Fig. 1.3). Let us divide this volume of liquid into two parts by the plane AB. The liquid contained in part 1 of the volume under study will act on part 2 along the interface plane AB. Let us denote the area of the interface plane through ω (Fig. 1.3), mentally discarding the right side 1. Then, to maintain the balance of the remaining left side, we will replace the impact on it of the discarded right side by the force P, called the force of hydrostatic pressure acting on the area ω .

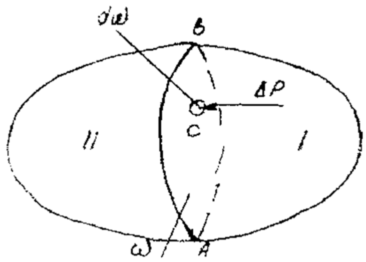


Fig.1.2.

Dividing the hydrostatic pressure force P by the area ω ,we get the average hydrostatic pressure:

$$p_{cp} = \frac{p}{\omega} \text{ (1-8)}$$

Take an arbitrary point C on the plane AB and select a small area near it dω (Fig. 1.2). There will be some force on this site ΔR.If we decrease area dω so that it tends to zero, then we get the limit of the ratio of force to the site, called the hydrostatic pressure at a given point C:

$$p = \lim_{d\omega \to 0} \left(\frac{\Delta P}{d\omega} \right) \text{ (1-9)}$$

test questions:

1. What does the subject "Hydraulics" study?
2. The history of the subject "Hydraulics"?
3. What is the role and application of hydraulics in modern engineering and agriculture?
4. Determination of pressure?
5. Forces acting on the fluid?
6. What is the specific gravity and specific volume of a liquid?
7. What is the density of a liquid?
8. Thermal expansion?
9. Fluid compressibility?
10. The viscosity of the liquid?
11. Give the formulation of the Boyle-Mariotte law
12. .The concept of cavitation
13. Dissolution of gases in liquids.
14. What is the ideal liquid?
15. Explain real liquid.
16. Boyle's Law - Mariotte.
17. Gay–Lussac law
18. .Explain the Claiperon equation

Key words Keywords: hydromechanics, hydraulic machines, forces acting on a liquid, basic physical properties of a liquid, density, viscosity, surface tension. Properties of hydrostatic pressure, ideal and real gases, Boyle-Mariotte law, equation of state of ideal gases, saturated vapor pressure, hydrostatic pressure, forces acting on a liquid, dropping liquids, piston, real gases do not obey the equation of state of ideal gases, gas mass is inversely proportional volume of gas $p = \lim_{d\omega \to 0} \left(\frac{\Delta P}{d\omega} \right)$.

Lecture 2

Hydrostatics

Technological learning for lecture #2

Time - 2 hours	Number of students: 20-30 people
Form of the lesson	Introduction, visual lecture
Lesson Plan	1. Forces acting on a liquid. 2.Hydrostatics: a) the basic properties of a fluid at rest. b) differential equation of fluid equilibrium (Euler equation). 3. Free liquid surface. 4. Basic equation of hydrostatics. 5. The concept of a piezometer, piezometric height and vacuum. 6. Devices and methods for measuring pressure. 7. The movement of the tank with liquid vertically with constant acceleration. 8. Horizontal movement of the liquid tank with constant acceleration. 9. Rotation of a cylindrical vessel with liquid at a constant angular velocity.
Purpose of the lesson: To acquaint students with the basic properties of a fluid at rest, with instruments that measure pressure, and with the basic equations of hydrostatics.	
Tasks of the teacher: • familiarizeinstruments and methods for measuring pressure; • teach how to write a differential equationfluid balance; • briefly describe the main conceptsfree liquid surface.	Learning outcomes: The student must learn: - the main properties of a liquid at rest; - differential equation of liquid equilibrium - Euler differential equation; - free surface of the liquid, the basic equation of hydrostatics; - the concept of a piezometer, piezometric height and vacuum, instruments and methods for measuring pressure
Means of education	Laser projector, visual materials, information support.
Forms of study	Collective, frontal work, work in pairs. graphorganizers
Conditions of education	An audience adapted to work with TCO.

stages, time	Activity	
	teacher	**students**
Stage 1. Introduction (10 min.)	1.1.Informs the topic, purpose, planned results of the training session and the plan for its implementation.	1.1. Listen, write.
Stage 2. Basic (60 min.)	2.1.In order to update students' knowledge, asks focusing questions: – What is pressure? -Fluid at rest? – Differential equilibrium equation? Work in pairs to answer questions. Conducting a quiz. 2.3. Consistently presents the material of the lecture on the issues of the plan, uses visual materials. Shows the devicepiezometer and explains its operation. Focuses on the key points of the topic, offers to write them down	2.1. Listen. They take turns answering the questions. Listen to the correct answer. 2.3.Discuss the content of the schemes and tables, visual materials, clarify ask questions. Write down the main things.
3 stage. Closing (10 min.)	3.1.Conducting a quiz. Makes a final conclusion. Gives assignments for independent work. 3.2 Cluster the word "Liquid". Set ratings.	3.1. Reply to question. 3.2. Listen, write.

2.1 Basic properties of the liquid, at rest

Consider the equilibrium of a liquid. To do this, in the space of the investigated liquid, we choose the system of coordinate axes*x, y, z*centered at point O and fix an arbitrary point A with coordinates x, y, z (Fig. 2.1). Then, near point A, we select an infinitely small parallelepiped 1-2-3-4-5-6-7-8 with infinitely small sides dx, dy, dz so that point A is in the center of this parallelepiped. The hydrostatic pressure arising at point A under the action of external forces will be denoted by p. The selected parallelepiped, which is under the action of external forces, will be in equilibrium if the sum of the projections of all acting forces on any of the coordinate axes is equal to 0.

Let us establish the external forces acting on the liquid parallelepiped under study. The external forces here are: 1) body forces proportional to the mass of the parallelepiped; 2) the hydrostatic pressure forces acting on the faces of the parallelepiped from the side of the surrounding fluid are expressed by Euler's differential equilibrium equations.

Let us denote by X, Y and Z the projections of all mass forces (gravity and inertia forces), related to a unit of mass, onto the coordinate axes x, y, z. Then the projection of the body forces dQx on the x axis will be equal to:

$$dQ_x = Xdm,$$

$$dm = dxdydz\rho.$$

Consequently,

$$dQ_x = Xdxdydz\,\rho.$$

In a similar way, the projections of body forces on the x, y and z axes are determined:

$$dQ_y = Xdxdydz\ \ \rho \text{ and } dQ_z = Zdxdydz\rho$$

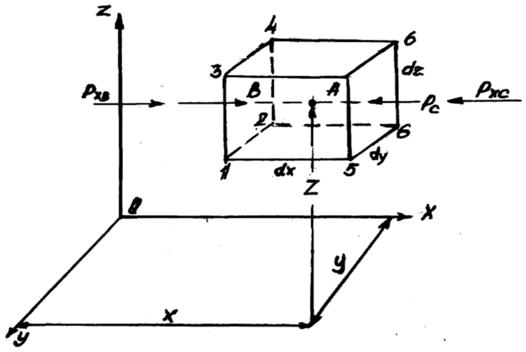
We proceed to the establishment of the hydrostatic pressure forces acting on the face of the parallelepiped. Consider the forces acting on the vertical faces 1-2-3-4 and 5-6-7-8. According to the first property of hydrostatic pressure, these forces act normally to the indicated areas, i.e. directed along the x-axis. Let us draw a horizontal line BC through point A, which will intersect the face of the parallelepiped 1-2-3-4 at point B, and the face 5-6-7-8 at point C. We will denote the hydrostatic pressure at point B as p, and at point C - via rs. Since in a liquid medium the hydrostatic pressure changes continuously according to a linear law, the hydrostatic pressures at points B and C will be expressed as:

$$p_B = p - \frac{dx}{2}\frac{\partial p}{\partial x}$$

and

$$p_C = p + \frac{dx}{2}\frac{\partial p}{\partial x},$$

where is the partial derivative $\frac{\partial p}{\partial x}$ called the hydrostatic pressure gradient.



Rice. 2.1.

Sites 1-2-3-4 and 5-6-7-8 are infinitesimal, so the hydrostatic pressures at points B and C can be considered as the average hydrostatic pressures for these sites. Therefore, it is possible to establish the magnitude of the hydrostatic pressure forces on the considered sites PxB and PxC (Fig. 2.1):

$$P_{xB} = (пл.1-2-3-4)p_B = dydz\left(p - \frac{\partial p}{\partial x}dx\right);$$
$$P_{xC} = (пл.5-6-7-8)p_C = dydz\left(p - \frac{\partial p}{\partial x}dx\right) \quad (2.1)$$

Let us compose the equilibrium equation of the liquid parallelepiped under study 1-2-3-4-5-6-7-8 with respect to the x-axis. Projecting on the x-axis all external forces acting on the box, we obtain:

$$P_{xB} - P_{xC} + dQ_x = 0 \ (2.2)$$

Here the hydrostatic pressure forces*RxB*and PxC, being normal to faces 1-2-3-4 and 5-6-7-8, are projected onto the x-axis in full size. The projections of all other hydrostatic pressure forces acting on other faces will be equal to zero, and therefore will not be included in equation (2.2). Equation (2.2) can be rewritten as follows:

$$dydz\left(p - \frac{1}{2}\frac{\partial p}{\partial x}dx\right) - dydz\left(p + \frac{1}{2}\frac{\partial p}{\partial x}dx\right) + Xdxdydz\rho = 0.$$

After simple transformations, we get:

$$-\frac{\partial p}{\partial x}dxdydz + Xdxdydz\,\rho = 0.$$

Finally:

$$-\frac{\partial p}{\partial x} + \rho X = 0. \ (2.3)$$

In a similar way, one can compose the equilibrium equations with respect to the y and z axes:

$$-\frac{\partial p}{\partial x} + \rho Y = 0. \ (2.3/)$$

$$-\frac{\partial p}{\partial x} + \rho Z = 0. \text{ (2.3//)}$$

Equations (2.3), (2.3$^{/}$) and (2.3//) are differential equations for fluid equilibrium (Euler):

$$\left.\begin{aligned} -\frac{\partial p}{\partial x} + \rho X = 0. \\ -\frac{\partial p}{\partial y} + \rho Y = 0. \\ -\frac{\partial p}{\partial z} + \rho Z = 0. \end{aligned}\right\} \text{(2.4)}$$

For further study, we will transform the system of differential equations (2.4). Multiplying each of the equations (2.4) by dx, dy and dz, respectively, we get:

$$\left.\begin{aligned} -\frac{\partial p}{\partial x} dx + \rho X dx = 0. \\ -\frac{\partial p}{\partial y} dy + \rho Y dy = 0. \\ -\frac{\partial p}{\partial z} dz + \rho Z dz = 0. \end{aligned}\right\} \text{(2.4/)}$$

Let's add this system of equations:

$$\frac{\partial p}{\partial x} dx + \frac{\partial p}{\partial y} dy + \frac{\partial p}{\partial z} dz = \rho(Xdx + Ydy + Zdz) \text{ (2.5)}$$

Since the hydrostatic pressure is only a function of the coordinates of the point$x = f(x, y, z)$,then the left side of the equation is the total pressure differential:

$$dp = \frac{\partial p}{\partial x} dx + \frac{\partial p}{\partial y} dy + \frac{\partial p}{\partial z} dz \text{ (2.6)}$$

$$dp = \rho(Xdx + Ydy + Zdz). \text{ (2.7)}$$

Since the density of the liquid we are considering ρ is constant, equation (2.7) can only make sense if the right side of this equation is also a total differential. To do this, it is necessary that there is such a function U \u003d f (x, y, z), the partial derivatives of which with respect to x, y and z would be equal:

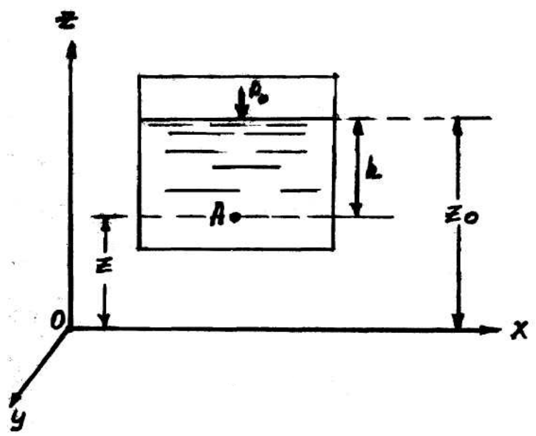
$$\frac{\partial U}{\partial x} = X; \frac{\partial U}{\partial y} = Y; \frac{\partial U}{\partial z} = Z. \text{ (2.8)}$$

Such a function is called potential, or force, and the forces that are expressed by this function are called potential forces.

Therefore, a liquid can be in equilibrium only when the system of mass forces acting on it has a potential. From mechanics, many forces are known that have potential, the most important of which are the forces of gravity and the forces of inertia.

2.3 Free liquid surface.

Let us consider the most important for practice case of equilibrium of a liquid under pressure.action, only gravity.



Rice. 2.2

Assume that the liquid is in a closed vessel, as shown in Fig. 2.2. We will also assume that the known pressure p0, which is different from atmospheric pressure, acts on the surface of the liquid. Then the projections of body forces (in this case, gravity forces) on the Ox, Oy axes will be equal to zero:

$$X = \frac{\partial U}{\partial x} = 0 \text{ and } Y = \frac{\partial U}{\partial y} = 0.$$

The projection of the force of gravity on the z-axis, related to a unit of mass, will be equal to:

$$Z = \frac{\partial U}{\partial z} = -g,$$

since the z-axis has a direction opposite to the direction of gravity. Substituting into the Euler equations we have:

$$dp = \rho\left(\frac{\partial U}{\partial x}dx + \frac{\partial U}{\partial y}dy + \frac{\partial U}{\partial z}dz\right)$$

or

$$dp = \rho dU \quad (2.9)$$

Those. the differential equation for the case under consideration will take the following form:

$$dp = -\rho g dz = -\gamma dz \qquad (2.10)$$

$$\frac{dp}{\gamma} + dz = 0 \quad (2.10/)$$

The resulting equation (2.10/) is a differential equation for the equilibrium of a fluid under the action of gravity alone.

As a result of integrating equation (2.10/), we have:

$$z + \frac{p}{\gamma} = C \,(2.11)$$

We know the boundary conditions on the liquid surface: at$z=z0$pressure p=p0.

Consequently,

$$z_0 + \frac{p_0}{\gamma} = C \quad (2.12)$$

We substitute the resulting expression for the integration constant into dependence (2.12)

$$z + \frac{p}{\gamma} = z_0 + \frac{p_0}{\gamma},$$

or finally:

$$p = p_0 + \gamma(z_0 - z) \,(2.13)$$

2.4 Basic equation of hydrostatics.

From equation (2.14)

$$\left.\begin{aligned} -\frac{\partial p}{\partial x} + \rho X = 0. \\ -\frac{\partial p}{\partial y} + \rho Y = 0. \\ -\frac{\partial p}{\partial z} + \rho Z = 0. \end{aligned}\right\} \quad (2.14)$$

it follows that the pressure in a fluid at rest changes only vertically (along the z axis, Fig. 2.3), remaining the same at all points of any horizontal plane, since the change in pressure along the x and y axes is zero. Due to the fact that in this system of equations the partial derivatives $\frac{\partial p}{\partial x} u \frac{\partial p}{\partial \gamma}$ equal to zero, partial derivative $\frac{\partial p}{\partial z}$ can be replaced by $\frac{dp}{dz}$ and hence:

$$-\rho g - \frac{dp}{dz} = 0$$

From here

$$- dp - \rho g dz = 0 \quad (2.15)$$

Dividing the left and right sides of the last expression by $\rho g$and changing signs, we represent this equation in the form:

$$dz + d\frac{1}{\rho g}dp = 0$$

For an incompressible homogeneous fluid, the density is constant and, therefore,

$$dz + d\left(\frac{p}{\rho g}\right) = 0$$

or $d\left(z + \frac{p}{\rho g}\right) = 0$

whence after integration we get

$$z + \frac{p}{\rho g} = const \quad (2.16)$$

For two arbitrary horizontal planes 1 and 2, equation (2.16) is expressed in the form:

$$z + \frac{p_1}{\rho g} = z_0 + \frac{p_2}{\rho g}, \quad (2.17)$$

Equation (2.16) or (2.17) is***basic equation hydrostatics***. In equation (2.17): z1 and z2 are the heights of two points inside a homogeneous fluid at rest above an arbitrarily chosen horizontal reference plane (comparison plane), and p1 and p2 are hydrostatic pressures at these points.

Consider, for example,two particles of a liquid, one of which is located at point 7 inside the liquid volume (Fig. 2.3) at a height z from an arbitrarily chosen comparison plane 0-0, and the other is located at point 2 on the liquid surface at a height z0 from the same plane. Let p and po be the pressures at points 1 and 2, respectively. With these notations, according to equation (2.17):

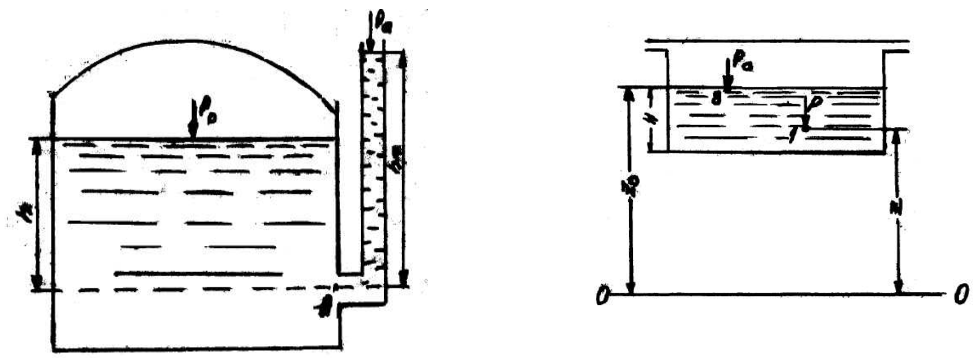
$$z + \frac{p}{\rho g} = z_0 + \frac{p_0}{\rho g}, \quad (2.17.a)$$

Or

$$\frac{p - p_0}{\rho g} = z_0 - z, \quad (2.17.b)$$

2.5 The concept of a piezometer, piezometric height and vacuum

Consider a closed vessel*L*filled with liquid, on the surface of which the pressure p0 acts, which exceeds the atmospheric pressure patm (Fig. 2.3)



Rice. 2.3.

Suppose that at some point A, located at a depth h, a hole is made, to which a tube 2 is connected, open from above, i.e. communicating with the atmosphere. Since the pressure on the surface of the liquid p0 is greater than atmospheric pressure, the liquid in the tube 2 rises to a certain height h0, which in hydraulics is called the piezometric height, and the tube itself, in which the liquid rises, is a piezometric, or piezometer. The piezometric height hp is determined from the dependence for the hydrostatic pressure at point A in accordance with the equation:

$$p_{абс} = p_{ат} + \gamma h_p, \ (2.19)$$

The pressure rabs at point A can be determined in another way. In fact, the area of the point a is under the pressure of the liquid column in the vessel and the pressure p0 acting on the surface of the liquid in the vessel.

Then:

$$p_{абс} = p_0 + \gamma h,$$

In the liquid, which in this case is at rest, the pressures in the region of point A, both from the side of the piezometer and from the side of the vessel, are equal to each other, which allows us to write the equation:

$$p_{ат} + \gamma h_p = p_0 + \gamma h,$$

From this equality we obtain the second expression for hp

$$h_p = \frac{p_0 - p_{ат}}{\gamma} + h. \ (2.20)$$

Therefore, the piezometric height corresponds to the magnitude of the overpressure at point A.

Let us now turn to dependence (2.20), which determines the piezometric height. Let us assume that the vessel in which the piezometer is installed is open. Then the pressure on the surface of the liquid in it will be equal to atmospheric

(p0 = ratm), and dependence (2.20) gets a simple expression:

$$h_p = h \ (2.20/)$$

Thus, in this case, the piezometric height will be equal to the depth of immersion of the point in the liquid.

In practice, one often encounters areas where rarefaction or vacuum occurs, i.e. where pressures are less than atmospheric. Vacuum is the difference between atmospheric and absolute pressure, which characterizes the lack of pressure to the ambient atmospheric pressure. Many cases of vacuum formation can be cited. For example, a vacuum is created in the suction pipe of a pump. The formation of vacuum in the suction pipe of a piston pump occurs as a result of the movement of the piston, and in a centrifugal pump - as a result of the rotation of the impeller. The vacuum that occurs in the nozzles increases their throughput, etc.

Let us dwell on the study of the question of the formation of a vacuum, the methods of its measurement and its limiting value. On fig. 2.5 shows a tank filled with liquid, on the surface of which the pressure p0 is less than atmospheric pressure (for example, part of the air is pumped out of the tank by a vacuum pump). At point K at a depth h, a curved U-shaped tube is attached to the tank, with which you can measure the pressure at this point (such a tube is called an inverse piezometer, or vacuum gauge).

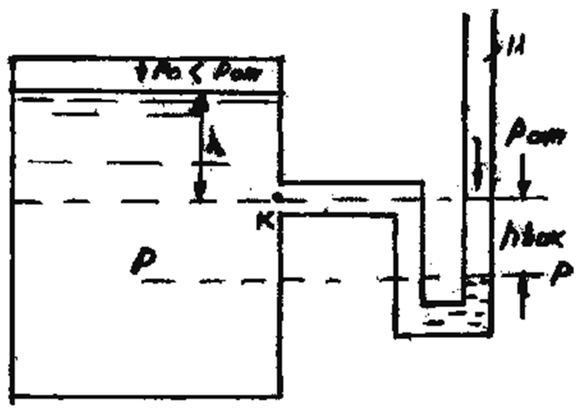


Fig.2.5

Since the pressure acting on the surface of the liquid in the tank p0 is less than atmospheric pressure, the liquid level in the tube will decrease compared to the position of the point K by the value hvac, as shown in Fig. 2.5. Let us determine the height hvac, called the vacuum height. To do this, we first set the pressure in the plane passing through the liquid level in the tube (Figure 2.5, line A-A).

$$p_{p3} = p_0 + \gamma h + \gamma h_{вак},$$

on the side of the tube, it will be:

$$p_{mp} = p_{am}$$

Let the pressure p on the surface of the liquid in the vessel be greater than atmospheric pressure. Then the liquid in the piezometer tube rises above the liquid level in the vessel to a certain height hp. The hydrostatic pressure at point A of the liquid taken at the base of the piezometric tube at a depth h from the free surface of the liquid in the vessel is determined by the basic equation of hydrostatics

$$p_A = p_{am} + \gamma(h_n + h)$$

and hence

$$h_n + h = \frac{p_A - p_{am}}{\gamma}$$

On the other hand, we also have:

$$p_A = p + \gamma h$$

Thus, we find:

$$p = p_{am} + \gamma h_n$$

From this it can be seen that the height of the rise of the liquid in the piezometric tube, the so-called piezometric height, characterizes the excess pressure in the vessel and can serve as a measure of the day for determining its magnitude. The measurement of pressure by the height of a liquid column is very convenient and is often used in engineering. It is useful to remember that a pressure equal to 1 kg / cm2 (technical atmosphere) corresponds to the weight of a column of water with a base 1 cm2 high:

$$h_{п.в.} = \frac{p}{\gamma_B} = \frac{1}{0{,}001} = 1000 см = 10 м$$

or the weight of a column of mercury high

$$h_{n.pm} = \frac{p}{\gamma_{pm}} = \frac{1}{0{,}0136} = 73{,}5 см = 735 мм$$

The physical atmosphere (1.033 kg / cm2) is determined by the mercury column in760 mm. Therefore, for example, if the pressure in the vessel is 2.5 atm or, which is the same, 2.5 kg/cm2, it can be defined in the same way as the pressure equal to25 mwater or 183.75 cm of mercury.

The piezometer is a very sensitive and accurate device, but it is only suitable for measuring low pressures (not more than 0.5 atm); at high pressures, the piezometer tube turns out to be excessively long, which complicates measurements. In these cases, so-called liquid manometers are used, in which the pressure is balanced not by the same liquid as the liquid in the vessel, as is the case in a piezometer, but by a liquid of a larger specific gravity; usually this liquid is mercury. Since the specific gravity of mercury is 1.36 times greater than the specific gravity of water, when measuring the same pressures, the mercury manometer tube is much shorter than the piezometric tube and the device itself is more compact.

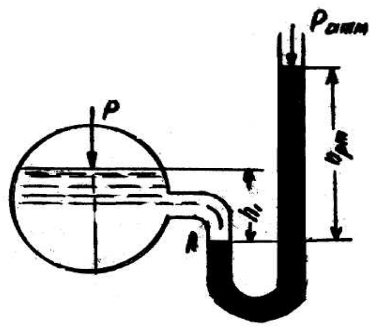


Fig.2.6.

A mercury manometer (Fig. 2.6) is usually a U-shaped glass tube, curvedbut which is filled with mercury. Under the action of pressure in the vessel, the level of mercury in the left knee of the manometer decreases, and in the right it rises. In this case, the value of hydrostatic pressure at point A, taken on the surface of mercury in the left knee, by analogy with the previous one, is determined as follows:

$$p_A = p + \gamma_1 h_1 = p_{am} + \gamma_{pm} h_{pm}$$

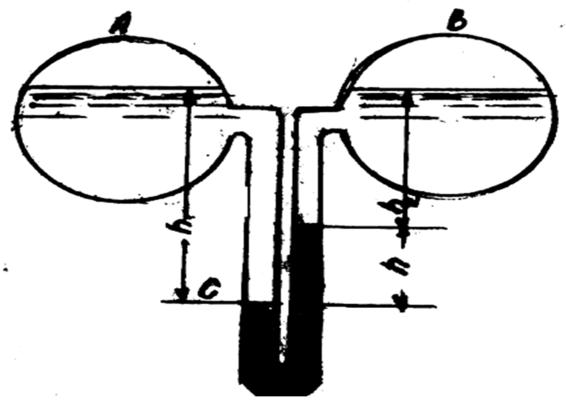
where γ1 and γrt are the specific gravity of the liquid in the vessel and mercury. From here:

$$p_{am} = p + \gamma_{pm} h_{pm} - \gamma_1 h_1$$

To measure high pressures, a piston pressure gauge is used, which is a reversed hydraulic press.
This manometer (Fig. 2.7) consists of a tube A, through which the measured pressure p is transmitted to the piston B, ending in a wide metal plate C. Under it there is a rubber plate D, which is in contact with water filling the short elbow of the manometer E. The lower part of this elbow and open tube G is filled with mercury.
If we denote: f is the area of the piston, F is the area of the plate, h is the height of mercury in the manometric tube, then (this follows from the equilibrium equation) we will have:

$$p = \frac{F}{f} \gamma_{pm} h \ .$$

From this equation it can be seen that a piston pressure gauge with a relatively low height of the mercury column makes it possible to measure very high pressures.
In cases where it is necessary to measure not the pressure in the vessel, but the pressure difference in two vessels or at two points of the liquid in the same vessel, differential pressure gauges are used. A differential pressure gauge connected to two vessels A and B is shown in Fig. 2.7.



Rice. 2.7

Here, for the pressure p at the level of the mercury surface in the left knee, we have:

$$p = p_A + \gamma_1 h_1 = p_B + \gamma_1 h_2 + \gamma_{pm} h$$

where:

$$p_A - p_B = \gamma_1 (h_2 - h_1) + \gamma_{pm} h$$

or, since $h_2 - h_1 = -h$,

$p_A - p_B = (\gamma_{pm} - \gamma_1) h.$

Thus, the pressure difference is determined by the level difference in the two knees of the differential pressure gauge.
Micromanometers are used to improve the accuracy of measurements, as well as when measuring pressures that are insignificant in magnitude. One of the designs of the micromanometer is shown in Fig. 2.8. It consists of a reservoir A connected to a vessel in which the pressure is measured and a manometric tube B, the angle of inclination of which to the horizon α can be changed.

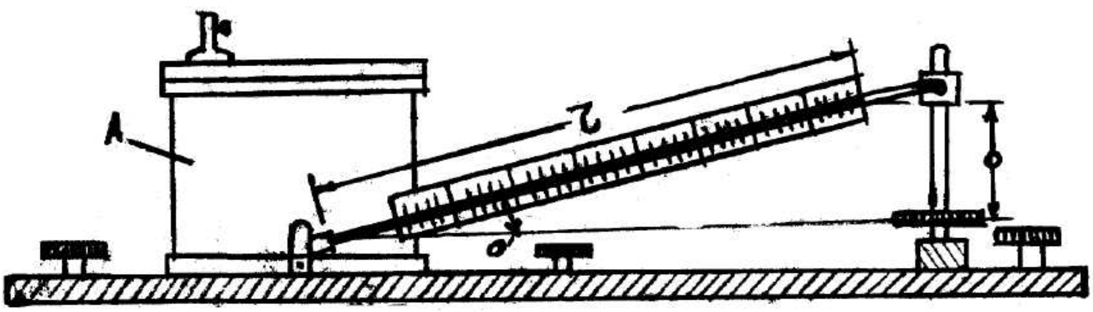


Fig.2.8

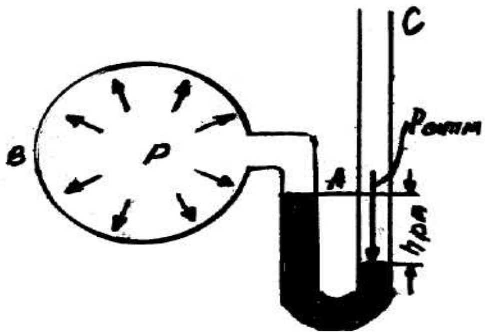
Pressure near the base of the tube; measured by a micromanometer, is determined by the expression: $p = \gamma l \sin\alpha$. Compared to a conventional manometer, such a micromanometer has a much greater sensitivity, since it allows, instead of a small height h, to read the length l, the greater, the smaller the angle α .

If the measured pressure is less than atmospheric pressure, i.e. there is a vacuum in the vessel, instruments used to measure pressure are called vacuum gauges. Usually, however, vacuum gauges do not measure pressure directly, but vacuum, i.e. lack of pressure to atmospheric. In principle, they are no different from mercury manometers and also represent a curved tube filled with mercury (Fig. 2.9), one end of which - A - is connected to space B, where pressure is measured, and the other end - C - is open. Let, for example, the pressure of a gas in vessel B be measured; in this case we get:

$$p_{am} = p + \gamma_{pm} h_{pm},$$

where:

$$p = p_{am} - \gamma_{pn} h_{pn}$$



Rice. 2.9

Height:

$$h_{pm} = \frac{p - p_{am}}{\gamma_{pm}},$$

corresponding to the vacuum in the vessel (rvac = pat - p), is usually called the vacuum height and denoted by hvac. This shows that the magnitude of the vacuum can also be measured by the height of the liquid column. So, for example, if the reading of a mercury vacuum gauge hrt =50 cm, then the vacuum

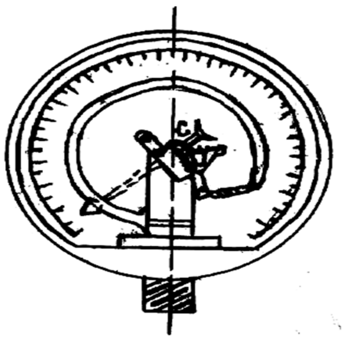
$$p_{вак} = \gamma_{pm} h_{pm} = 0{,}0136 \cdot 50 = 0{,}68 кГ/см^2.$$

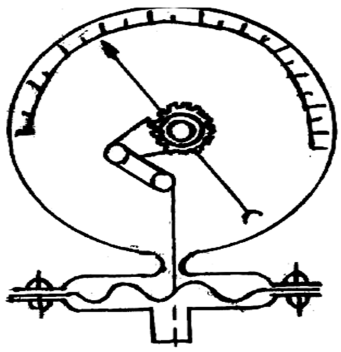
Manometers and vacuum gauges are not always necessarily filled with mercury. In some cases, depending on the purpose and working conditions, other liquids can be used for this purpose. In this case, however, it should be borne in mind that volatile liquids (alcohol, ether) cannot be used to fill vacuum gauges, since under reduced pressure they will evaporate intensively and may boil.

The use of the considered liquid-type devices, including mercury ones, is limited to the region of relatively low pressures; they are mainly used in laboratory practice, where they are used very widely due to their simplicity and high measurement accuracy. In cases where it is necessary to measure high pressures, devices of the second type are used - mechanical ones, of which the spring pressure gauge, schematically shown in Fig. 2.8, is most widely used in practice.

It consists of a hollow thin-walled curved tube A, one end of which is sealed.

This end is connected with a chain.B with gear C; the second - open - end of the tube communicates with the vessel in which pressure measurements are made. Fluid enters tube A through this end. Under the action of pressure, the spring is partially straightened and, by means of a gear mechanism, sets in motion an arrow, by the deviation of which the pressure value is judged. Such pressure gauges are usually equipped with a graduated scale showing the pressure in atmospheres, and are sometimes equipped with recorders.





Rice. 2.10. Rice. 2.11.

There are also so-called membrane manometers, in which the liquid exerts pressure on a thin metal plate or a plate of rubberized matter (membrane). The resulting deformation of the membrane is transmitted by means of a system of levers to an arrow indicating the amount of pressure. A diagram of such a pressure gauge is shown in Fig. 2.11.

Test questions:

1. List the main properties of a fluid at rest.
2. Compose a differential equation for the equilibrium of a liquid (Euler equation). Give examples.
3. What is called the free surface of a liquid?
4. The equation of the surface of equal pressure for a vessel filled with liquid vertical movement. Give examples.
5. Distribution of pressure in a vessel filled with liquid during its movement in a horizontal direction. Equation for surfaces of equal pressure.
7. Derive the basic equation of hydrostatics?
8. What pressures are called absolute gauge and vacuum gauge?
9. What do you know about the piezometer, piezometric height and vacuum?
10. Explain the principle of operation of a U-shaped mercury manometer.
11. The principle of operation of the micromanometer and vacuum gauge.
12. Instruments and methods for measuring pressure?

Key words:hydrostatics, basic properties of a fluid at rest, differential equilibrium equation of a fluid, free surface of a fluid, basic equation of hydrostatics, the concept of a piezometer, piezometric height and vacuum, instruments and methods for measuring pressure.

Lecture 3

Laws of hydrostatics and their application in engineering.

Technological learning for lecture #3

Time - 2 hours	Number of students: 20-30 people
Form of the lesson	Information lecture, joint study and use of a graphic organizer table "Z. Z. U."
Lesson Plan	1. Laws of hydrostatics and their application in technology a) Pascal's law 2.Hydrostatic machines 3.pressure on flat walls. Plots of hydrostatic pressure. Law of Archimedes.
***Purpose of the lesson*:**to acquaint students with the laws of hydrostatics and their application in technology, recall the laws of Archimedes and Pascal, explain the principle of operation of hydrostatic machines.	
Tasks of the teacher: • familiarizationkinematics and fluid dynamics; • introducemain hydraulic flow elements; • briefly describeEuler's equation for the motion of an ideal fluid.	*Learning outcomes:* The student must learn: -aboutPascal's law - hydrostatic machines -flat wall pressure; -;Plots of hydrostatic pressure.
Teaching methods and techniques	Lecture, "learning together"; techniques: Insert, blitz-survey, presentation, graphic organizer: C/X/U table
Means of education	Laser projector, information support, markers, adhesive tape, sheets of A32 paper
Forms of study	Frontal, individual work, work in groups
Conditions of education	Audience adapted to work in groups, having the conditions for the use of TCO / information technology

Technological map of the lecture (3rd lesson)

stages, time	Activity	
	teacher	**students**
Stage 1. Introduction (10 min.)	1.1.Informs the topic, purpose, planned results of the training session and the plan for its implementation.	1.1. Listen, write.
Stage 2. Basic (60 min.)	2.1.In order to update students' knowledge, asks focusing questions: - Work in pairs to answer questions. Conducting a quiz. 2.3. Consistently presents the material of the lecture on the issues of the plan, uses visual materials. Shows the devicepiezometer and explains its operation. Focuses on the key points of the topic, offers to write them down	2.1. Listen. They take turns answering the questions. Listen to the correct answer. 2.3.Discuss schema content and tables, visual materials, clarify, ask questions. write down main.

3.1 Pascal's law.

Let us place a piston on the free surface of the liquid in equilibrium in the tank (Fig. 3.1) and apply the force Po to it. as a result of which pressure p0 arises on the liquid from the side of the piston.According to the basic equation of hydrostatics:

p - ro + pgh,

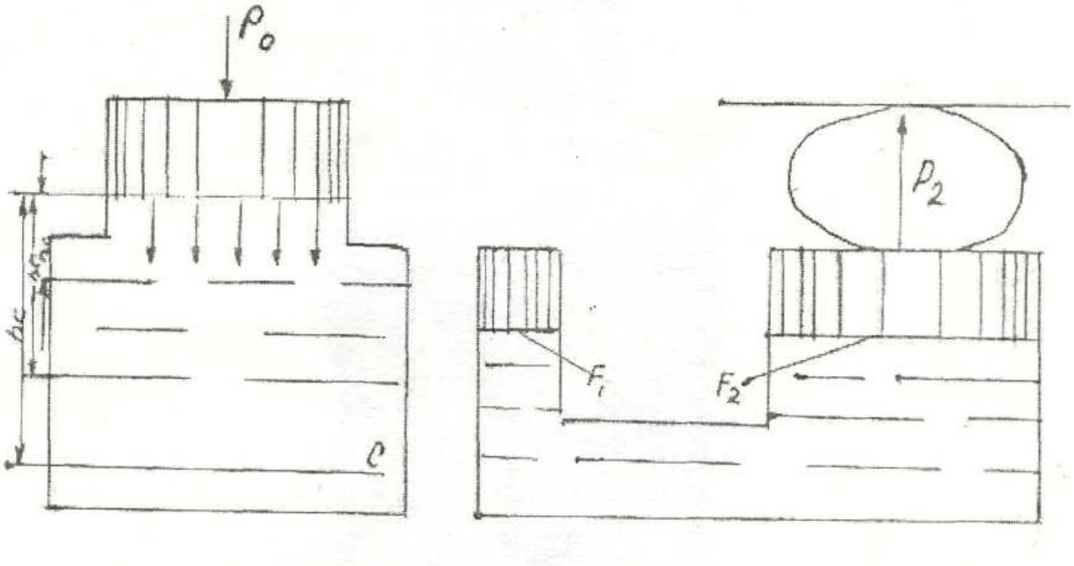
absolute pressures at arbitrarily chosen points of the liquid A, B, C will be respectively equal:

$p_A = p_0 + \rho g h_A.$

$p_B = p_0 + \rho g h_B$

$p_c = p_0 + \rho g h_C$

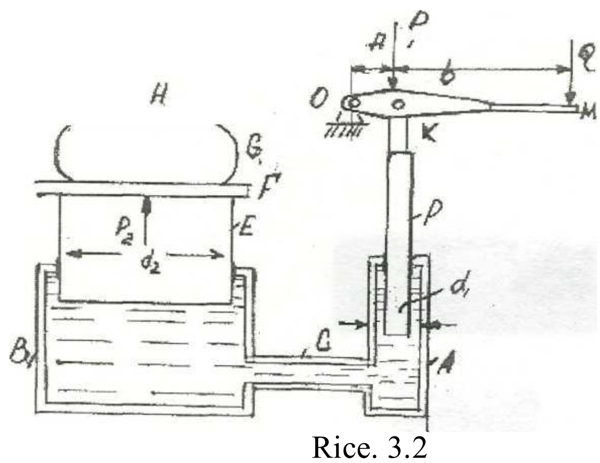
From the analysis of the equations obtained, it can be seen that the absolute pressures at the points of the liquid located at different depths will be different, however, the external pressure on the liquid enclosed in a closed vessel is transmitted to all its particles without change. This is the essence of Pascal's law.



Rice. 3.1

3.2. Hydrostatic machines

Consider the principle of operation and the main schemes of the most common hydrostatic machines. **Hydraulic Press**it is used to obtain large compressive forces, which is necessary, for example, for the deformation of metals during pressure treatment (pressing, forging, stamping), when testing various materials, compacting loose materials, briquetting, etc.



. Rice. 3.2

Schematic diagram of a hydraulic press.

The schematic diagram of the press is shown in fig. 3.2. It consists of two cylinders A and B (small and large diameter), interconnected by a tube C. In a small cylinderDre has a piston (dived) D connected to the OKM lever. Having a fixed hinged support at point O, and in painpiston (plunger) E, constitutingone piece with the table (platform) F, on which the pressed body G is placed.

The lever is operated manually or bywith the help of a special engine. In this case, the piston D receives a downward movement and exerts pressure on the fluid below it, which is transmitted to the piston E and forces it, together with the table, to move up until the body G comes into contact with the fixed plate H. After that, with continued work press, and hence the further lifting of the table, in fact, the pressing process begins and the body G is subjected to compression.
If the device in question is not for pressing, but only for lifting the load, i.e. represents the so-called hydraulic lift, the fixed plate turns out to be superfluous and is excluded from the design.

In addition to the main parts indicated, the hydraulic press is always also equipped (not shown in the diagram) with suction and discharge valves that regulate the operation of the press and protect it from bursting when the pressure rises excessively.

Let's establish the basic relationships that determine the work of the press. Let the force acting on the end M of the OKM lever be Q. and the lever arms, respectively, are OK = a, KM = b. Then, consideringequilibrium of the lever and making the equation of moments about its center of rotation O:
Q(a+b) = P1a
easy to find strength

$$P1=\frac{Q\left(a+b\right)}{a},$$

transmitted to the piston D of the small cylinder and creating additional hydrostatic pressure in the liquid:

$$P=\frac{P_1}{\frac{\pi d_1^2}{4}}.$$

This pressure is transferred to the piston E of the large cylinder, as a result of which the total pressure force on this piston, due to the force Q, will be equal to:

$$P_2=p\frac{\pi d_2^2}{4}=Q\left(\frac{d_2}{d_1}\right)^2\frac{a+b}{a}$$

where d1 and d2 are the diameters of the cylinders, respectively small and large. It can be seen from the last expression that the force P2 can be obtained arbitrarily large by choosing the appropriate dimensions of the cylinders and arms of the driving lever. Real strength P_2', transmitted to the table and carrying out the pressing process, turns out to be somewhat less than the force P2, due to the inevitable energy losses to overcome friction in the moving parts of the press and fluid leaks through various non-densities and gaps, which is taken into account by introducing the efficiency of the press into the last formula η

$$P_2'=Q\left(\frac{d_2}{d_1}\right)^2\frac{a+b}{a}\eta.$$

In modern hydraulic presses, very large forces are developed (up to 25,000 tons). In these designs, the small cylinder is usually made in the form of a high-pressure piston pump that supplies the working fluid (water or oil) to the large cylinder (the press itself), often with the inclusion of a special device - a hydraulic accumulator that equalizes the operation of the pump.

Hydraulic accumulator. As the name itself indicates, the hydraulic accumulator is used for accumulation, i.e. accumulation, collection of energy. It is used in practice in cases where it is necessary to perform short-term work that requires significant mechanical effort, for example, when lifting heavy loads, opening and closing gates of locks, etc.
Hydraulic accumulators are currently most widely used during the operation of hydraulic presses, representing here installations that accumulate liquid during the idling period of the press and give it away during the working stroke, when the performance of the pumps is insufficient.
The hydraulic accumulator (Fig. 3.3) consists of cylinder A, in which plunger B is placed, connected with its upper part to platform C, which carries a heavy load. To the accumulator through pipe D

tothe pump pumps liquid (water, oil), which lifts up the plunger with the load; when the upper end position is reached, the pump switches off automatically.

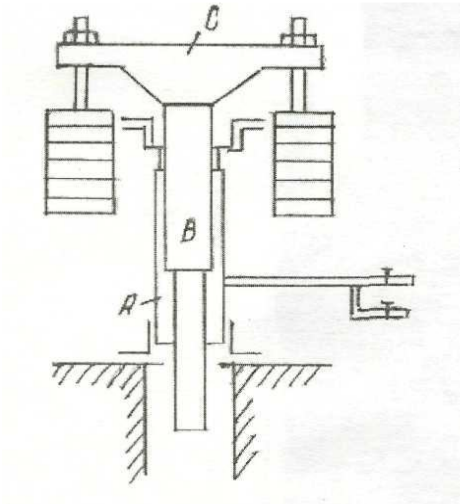


Figure 3.3

Let us denote the weight of the plunger with the load through G, and its full lift height through H. Then the energy stored by the accumulator at the full lift of the plunger will be equal to G, and the hydrostatic pressure created by it in the liquid:

$$p = \frac{G}{F}$$

where F is the cross-sectional areaplunger.

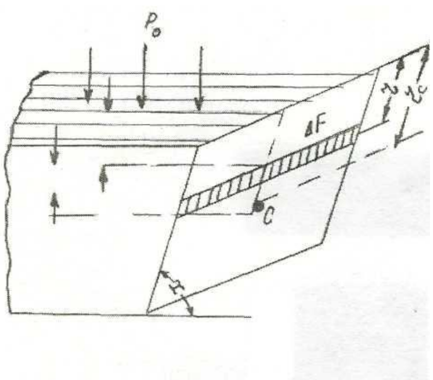
Under this constant pressure, the liquid in the accumulator is supplied through pipe E to hydraulic machines - tools, such as press pumps, thereby ensuring their operation with a constant load. The total work done by the battery is given by the equation

$$A = pFH\eta .$$

The hydrostatic pressure created by the accumulator is the greater, the smaller the cross-sectional area of the plunger.

3.3. Fluid pressure on flat walls and curved surfaces

Fluid pressure on flat walls Assume that there is a flat wall of area F, inclined to the horizon at some angle α (Fig. 3.4). Let us divide it in height into a number of elementary horizontal (very narrow) strips AF and determine the pressure on one of these strips. Hydrostatic pressure at any point on the axis of the strip is given by:



$$R = \sum \Delta R = \sum (p_0 + \gamma h)\Delta F = p_0 \sum \Delta F + \gamma \sum h\Delta F$$

Fig.3.4

Sum $\sum \Delta F = F$, and the sum $\sum h\Delta F$ Fcan be represented as:

$\sum h\Delta F$ F=$\sum l \sin \alpha \Delta F$ F=sin $\alpha \sum l\Delta$ F,

where: L is the distance to the strips from the water surface, measured in the plane of the wall.

But the sum $\sum / \Delta F$ there is a statisticarea F relative to the line of intersection alongsurface of the water with the plane of the wall (this line is called the water's edge) and is equal to:

$\sum lF = Fl$

where lc is the distance (inwall velocities) to the center of the tietins of this area. Consequently,

$$\sum h\Delta F = FLc \sin \alpha = Fhc$$

where hc = lc sinα -immersion depth of the center of gravity of the wall.

Thus, we get:

$$R = p0\ F + \gamma\ hcF = (p0 + yhc)F$$

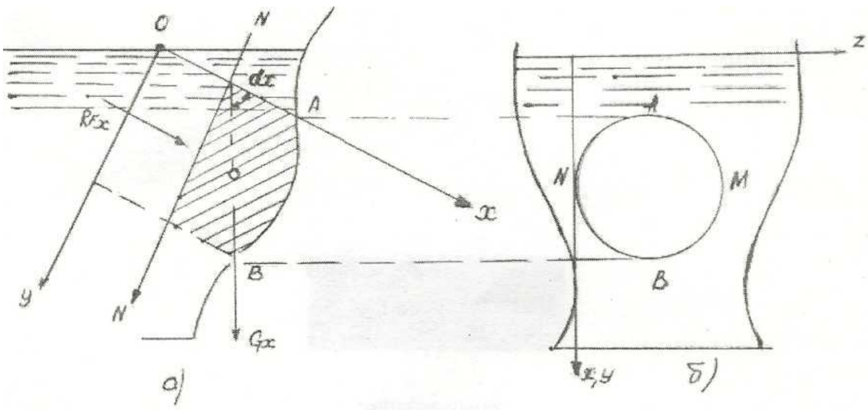
Noticing that the value in parentheses is the hydrostatic pressure at the center of gravity of the wall, and denoting it as pc, we finally obtain:

$$R = pcF$$

Consequently, the pressure of a liquid on a flat wall is equal to the product of the wetted area of the wall and the hydrostatic pressure at its center of gravity.

Fluid pressure on curved surfaces.

Let's take a vessel of arbitrary shape and select on its wall some curvilinear surface S bounded by the FMBN contour (Fig. 3.5). We will look for the components of the total pressure on this surface along the coordinate axes, choosing, for example, the origin of coordinates on the free surface of the liquid, as well as arranging the axes as shown in Fig. 3.5. In this case, we confine ourselves to the definition of only one component



Rice. 3.5.

rx,parallel to the x-axis, since the other components can be found in exactly the same way.

Let us find the projection of the surface S onto some plane NN normal to the x-axis and located between this surface and the coordinate plane zOy. Note that the indicated projection plane NN, as well as the direction of the x-axis itself, can be chosen in various ways.

The following forces act on the fluid compartment enclosed in the volume between the surface S, the plane NN and the surface of the projecting cylinder, the generatrix of which is parallel to the x axis:

1) the weight of the allocated liquid volume Gx;
2) force RF - liquid pressure on the projection of the surface S onto the plane NN;
3) pressure forces on the lateral surface of the specified volume; their projection on the x-axis is zero;
four) reaction force$R$from the side of the surface S, equal in magnitude, but opposite in direction, to the desired fluid pressure force.

Projecting these forces onto the x-axis, we have:

$\sum X = RFx + Gx \cos \alpha_x - Rx = 0,$

whence for the projection of the reaction force we obtain the following expression:

Rx= RFx$\underline{+\ Gx\cos\alpha_x = 0}$(3-1)

Similar expressions are found in the same way for the projections of the reaction force on other coordinate axes:

Ry = RFy+ Gy cos α_y=0

Rx= RFx+ Gxcos α_x=0(3-2)

where $\alpha_x, \alpha_y, \alpha_z$ —angles between the direction of the line of action of gravity and the coordinate axes x, y, z.

So, we get the following general theorem on pressure on a curved surface: "the projection onto a given x-axis of the pressure force on a curvedlinear surface S is equal to the sum of the projections onto this axis of the weight of the liquidbone located between the surface S, projecting the surfaceof the master cylinder and the projection plane normal to the x-axis, and the fluid pressure force on the projection of the surface S onto the same projection plane ".

3.4. Plots of hydrostatic pressure.

hydrostatic changeswhich pressures on the fluid-bounding surface are depicted very clearly using graphs, or diagrams, of pressure. In this case, the pressure, which increases with the depth of immersion of the point of its application according to a linear law, is plotted on a certain scale in the form of segments normal to the surface.

Assume that it is required to plot the absolute pressure on the vertical wall AB of a vessel filled with liquid

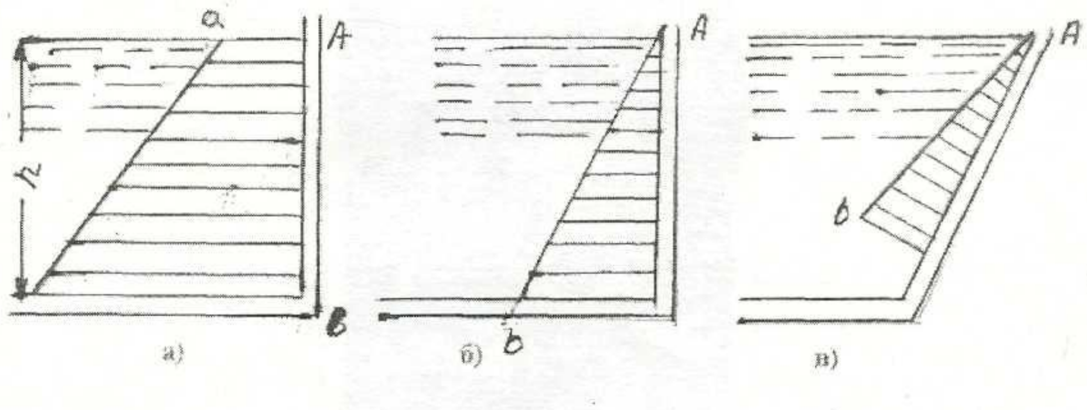


Fig.3.6

specific gravity γ up to level h (Fig. 3.6, a) the pressure on the free surface of the liquid is equal to atmospheric pressure. Change in hydrostatic pressure along the height of the wall. In this case, it is determined by the equation:

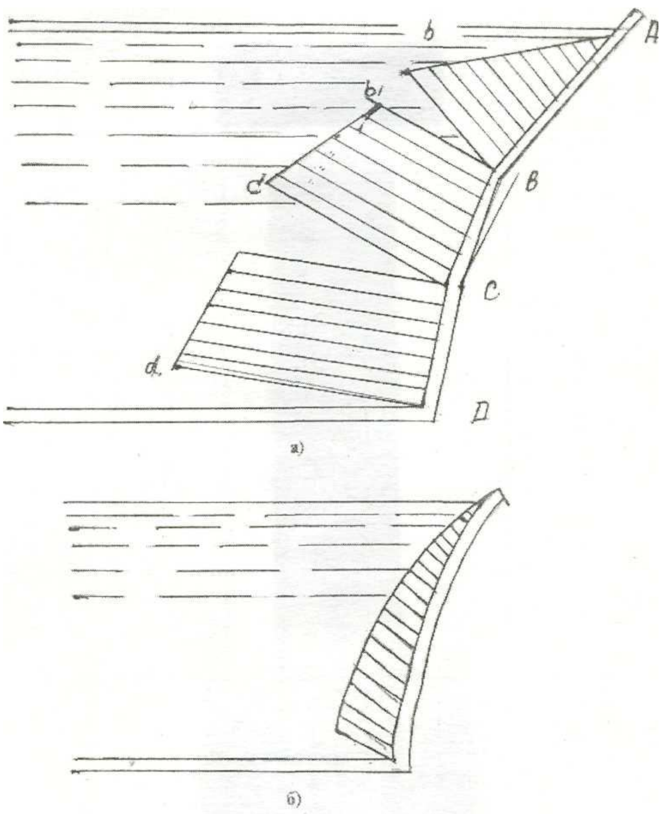
$$p = p_{amm} + \gamma h,$$

representing the equation of a straight line. Therefore, to build a pressure diagram, it is necessary to plot from point A on the free surface of the liquid (h \u003d 0) segment aA, corresponding on the scale of construction to atmospheric pressure, and from point B at the bottom of the vessel - segment bB, depicting the pressure at this point $p = p_{amм} + \gamma h$, and connect the ends of these segments with a straight line ab. The resulting figure - a trapezoid AabB - and will be a hydrostatic pressure diagram. The diagram of the excess gauge pressure p - yh for the same wall is obviously represented by a right-angled triangle AbB (Fig. 3.6. b).

In the case of a vessel with an inclined wall making a certain angle with the horizontal plane α , the diagram of excess hydrostatic pressure is also a right-angled triangle AbB (Fig. 3.6, c), in which the segments depicting pressures are inclined to the horizon at an angle of 90 ° - α .

If the wall consists of a number of separate flat faces inclined at different angles to the horizon, and is depicted in the drawing (Fig. 3.7. a) as some broken line ABCD, the hydrostatic pressure diagram can be constructed using the same methods as for a conventional flat wall . To do this, first, from the point B, normal to the face AB, we plot the segment Bb, representing the hydrostatic pressure at this point. Then we connect points A and b with a straight line and get a diagram of pressure on the indicated face in the form of a right triangle AbB. Next, let's move on to plotting the pressure diagram on the BC face. Let us set aside from points B and C of this face, normal to it, segments corresponding to

hydrostatic pressures - from point B, segment Bb equal to Bb, and from point C, segment Cc. As a result, we obtain the trapezoid Bb'Cc, which is a diagram of the pressure on the face.
We note the same case when the wall has a curvilinear shape. The hydrostatic pressure at individual points of such a wall is also depicted by straight line segments normal to the wall at the corresponding points, while the pressure plot will in this case be a curvilinear triangle (Fig. 3.7. b).



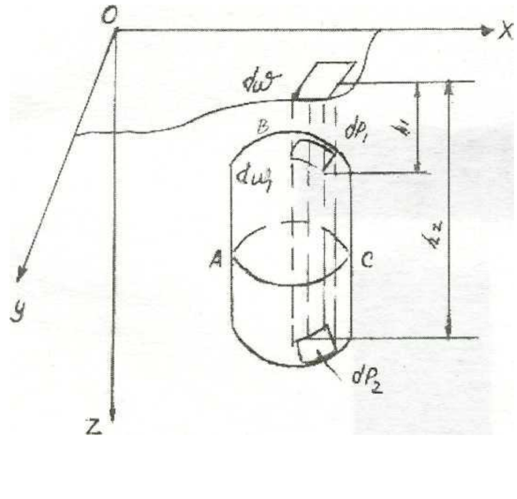
Rice. 3.7.

3.5. Law of Archimedes.

The law of Archimedes, discovered by him in 250 BC, characterizes the buoyancy of a body immersed in a liquid. Fortheoretical derivation of the law of Archimedes, consider the pressure of a liquid on a body immersed in it. For simplicity, let us assume that the surface of the body has no kinks and, therefore, from anyumbrella straight peintersects only at two points (Fig. 3.8).
We cut the body with vertical planes parallel to the coordinate planes yOz and xOz, on elementary prisms with platforms $d\omega_1$ and $d\omega_2$, on the vertical axis will be equal to:

$$dP_{1=} = p_1 d\omega_1 \cos(dP_1 z) = p_1 d\omega = \gamma h_1 d\omega$$

$$dP_{2=} = -p_2 d\omega_2 \cos(dP_2, z) = -p_2 d\omega = -\gamma h_2 d\omega \text{ (3-1)}$$



Rice.3.8

where: p_1 AND p_2—gauge pressures in the centers of gravity of the platforms $d\omega_1$ and $d\omega_2$;

h_1 and h_2 – immersion depths of the centers of gravity of the platforms $d\omega_1$ and $d\omega_2$.

Integrating equations (3-1) and summing them to determine the resulting force of vertical pressure on the body, we obtain:

$$P=\int p_1 d\omega - \int p_2 d\omega = \gamma(\int h_1 d\omega - \int h_2 d\omega) = \gamma\,(W1\text{-}W2) = \gamma\, W \qquad (3\text{-}1,a)$$

where: W1 and W2 are the volumes of prisms that have the projection of the body on the coordinate plane xOy as the upper base, the upper and lower ones as the lower basebody surface ABCD,W is the volume of the body.

The sums of the projections of the pressure forces on the x and y axes must be equal to zero,because the liquid is at rest, and the pressure does not depend on the orientation of the areas, but only on their depth.

Equation (3-1a) shows that the resulting pressure forceliquid on a body immersed in it (Archimedean force) is equal to the weight of the liquid in the volume of the body immersed in it and is directed vertically from bottom to top.

Swimming of bodies in a liquid. Body buoyancy.

If the weight of a body G immersed in a liquid is less than the Archimedean force, i.e. less than the fluid pressure force on it, or P=$\gamma\, W > G$.body floats. If P < G, the body sinks. When P=G=$\gamma\, W$ the body does not sink and does not float, being at rest at any point in the water space.

Therefore, when P > G , then only part of the body is immersed in the liquid, which characterizes its buoyancy. In this case, the Archimedean force Pn is equal to the weight of the liquid in the volume of the part of the body immersed in it $\xi\, W$,where ξ -coefficient that determines the part of the body immersed in the liquid (ξ<1)or Pn=$\gamma\, W\, \xi = G$.

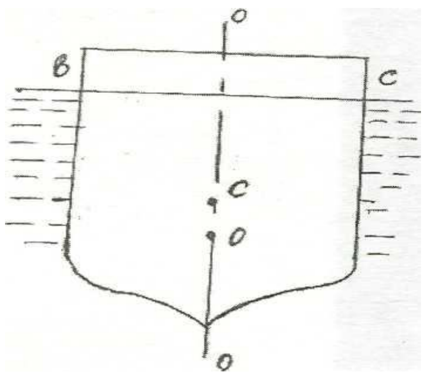


Fig.3.9.

The weight of a liquid in the volume of the part of the body immersed in it $\gamma\, W\, \xi$ called displacement (or Archimedean force). Accordingly, the center of pressure during swimming, i.e. the point of application of the Archimedean force is called the center of the waterdisplacement.When the ship is rolling, the center of pressure changes its position, because. in this case, one part of the vessel is immersed in water, and the opposite, on the contrary, comes out ofwater, as if drying up; this changes the shape of the underwater part of the vessel and, consequentlyconsequently, the position of the center of pressure. Displacement determines the poppythe maximum immersion of the vessel in water and its carrying capacity.

The line of intersection of the free surface of the reservoir with the side surface of the vessel at its maximum load is called the waterline of the explosive, and the plane within the vessel, bounded by the waterline, is called the navigation plane (Fig. 3.9). The vertical axis of symmetry O-O, normal to the navigation plane and necessarily passing through the center of gravity C of the floating body or ship, is called the navigation axis. The center of gravity of a dry-cargo vessel (not a tanker) does not change its position during rolling. For tankers with a free surface of the filled liquid, the center of gravity moves when rolling.

Test questions:

1. Explain the principle of hydraulic presses.
2. Explain the application of the laws of hydrostatics in engineering.
3. Write the equation for a surface of equal pressure?
4. Explain the pressure diagram.
5. Formulate the law of Archimedes.
6. Formulate Pascal's law.
7. Application of the law of Archimedes in technology.

Key words: The laws of hydrostatics and their application in technology, Pascal's law, hydrostatic machines, fluid pressure on flat and curved surfaces,hydrostatic pressure diagrams, Archimedes' law;theories of swimming bodies; movement of the reservoir with liquid; movement of a reservoir with liquid, rotation of a cylindrical vessel with liquid.

Lecture 4

Learning technology for lecture No. 4.

Time - 2 hours	Number of students: 20-30 people
Form of the lesson	Information lecture, joint study and use of a graphic organizer table "Z. Z. U."
Lesson Plan	Kinematics and fluid dynamics. Classification of motions, local fluid velocity. Streamline and its direction. Main tasks of hydrodynamics 3. Basic hydraulic flow elements. 4. The equation of continuity (continuity) of the flow. 5. Euler's equation for the motion of an ideal fluid.
Purpose of the lesson: To acquaint students with the kinematics and fluid dynamics, with the main problems of hydrodynamics, with the main hydraulic elements of the flow, with the equation of continuity (continuity) of the flow.	
Tasks of the teacher: • familiarizationkinematics and fluid dynamics; • introducemain hydraulic flow elements; • briefly describeEuler's equation for the motion of an ideal fluid.	*Learning outcomes:* The student must learn: -kinematics and fluid dynamics; - problems of hydrodynamics streamline and its direction; - Euler differential equation; -basic hydraulic flow elements;
Teaching methods and techniques	Lecture, "learning together"; techniques: Insert, blitz-survey, presentation, graphic organizer: C/X/U table
Means of education	Laser projector, information support, markers, adhesive tape, sheets of A32 paper
Forms of study	Frontal, individual work, work in groups
Conditions of education	An audience adapted to work in groups, having the conditions for the use of TCO and information technology

Technological map of the lecture (4th lesson)

stages, time	Activity	
	teacher	**students**
Stage 1. Introduction to educational occupation (2 min.)	1.1. Informs the topic and plan of the lecture (displays it on the screen), recalls the main questions, introduces the planned learning outcomes of the lesson and the work schedule.	1.1. Listen, write down.
Stage 2. Updating knowledge (17 min.)	2.1. Displays the Z/X/Y table and commentary on working with it (Appendix 2). Gives the task to draw a table in workbooks and fill in column 2 in accordance with the lecture plan. 2.2. Invites students, using the marks they made in the margins of the text while reading it, to answer the questions: (one) What do they already know? (i.e. they can tell on their own) (2) What remains unlearned, not understood? (3) What additionalinformation?, in accordance with this, fill in the 3rd and 4th columns of the table, putting down the numbers of key concepts (Appendix 3). 2.3. Conducting a quiz. At the same time, youlistens to just a few answers and reports that the work will be continued in mini-groups.	2.1. Redraw the table Z / X / Y, enter the questions of the lecture plan in the 2nd column of the table. 2.2. Fill in the 3rd and 4th columns of the table. 2.3 Read out the results.
Stage 3. Informational (55 min.)	3.1. Divides students into 4 mini-groups on an arbitrary basis and gives exercise: (one) analyze individual information in columns 4 of table З/X/У on a fragment of the topic, in accordance with the number of the group: 1 group - on 1 question, 2 group - on 2 questions, etc.; (2) summarize the unlearned in 1-2 questions; (3) jointly prepare answers using any available sources (textbook,lecture text); (four) prepare for the presentation of the results of the work - arrange the answers on the presentation sheets in the form of a table Z / X / Y according to thismu question of the topic. Announces the start of work in groups. 3.2. Organizes the process of presentation, discussion. 3.3. After each group's response: (one) asks a question to determine the level digestibility of the entire audience: “What did we learn?”, (2) conducting a quiz. 3.4. Summarizes the results of the trainingday ness, proposes to fill in the 5th column of the individual table Z / X / Y.	3.1 Work in groups: - each member of the group reads out the key concepts from the 4th column of their individual tables; - the group leader organizes the formulation process andwriting questions 4 columns; - collectively discuss and find and write down the answer in column 5 of the summary table tsy Z / X / Y; - Prepare a response on the presentation sheet. 3.2. Presentation of the results of the work: group leaders - attach a sheet to the board (Format not less than A-32) with complete table Z / X / Y for your question and comment yut her; answer questions; substantiate their opinion. 3.3. They answer questions. 3.4. Fill (up to 2 min) 5 column of individual tab persons Z/X/U.
Stage 4. Final (5 min.)	4.1. Summing up, summarizing the resultsyou, evaluates the performances of leaders, encourages active participants. 4.2. Gives assignments for self-studyra bots: write a cluster "Fluid movement".	Listen, write.

Annex 1 (4.1)

Rules for working with the insert technique

1. Read the text.
2. Organize the information received by putting notes in the margins with a pencil:

V-corresponds to the existing knowledge (information) about ...;
-(minus) - contradicts the existing knowledge about ...;
+(plus) - is new information;
? - incomprehensible / requiring clarification / addition information.

Appendix 2(4.1)

Rules for working with the use of equipment Z / X / Y
1. Read the text using the Insert technique.
2. Individually systematize the information received - "spread" into the columns of the table according to the notes made in the text.
Table Z / X / Y (I know / I want to know / I learned (a))

No.	Topic question	I know	I want to know	found out
one	2	3	four	5
one				
2				
3				
four				

Annex 3 (4.1)Key Concepts

one	Kinematics of fluid motion
2	Fluid Dynamics
3	Problems of hydrodynamics
four	Streamline
5	Direction of the streamline
6	Hydraulic flow elements
7	The fluidization of an ideal fluid
eight	Euler equation
9	Continuity equation
ten	Clearance definition
eleven	Local fluid velocity

4.1 Kinematics and fluid dynamics.

Classification of motions, local fluid velocity.

Trafficfluid is determined by the velocities of particles at individual points in the fluid flow, the pressures that occur at different depths, depths, as well as the general shape of the flow. In this case, the depth of the fluid flow, velocity, acceleration and pressure at the points of the flow depend on the position of the points, determined by the coordinates x, y, z. Therefore, these quantities are functions of the coordinates. In addition, the quantities characterizing the movement of a fluid can also change in time, being also a function of time t. In this regard, two types of motion are distinguished: steady and unsteady.

steady motion This type of movement is calledwhere velocities, accelerations, pressures do not change over time, but depend only on the position in the fluid flow of the point under consideration, being a function of the coordinates:

$$u = f(x, y, z); p = fl(x, y, z); h = f2(x, y, z).$$

Here and is the velocity of the fluid; p - hydrodynamic pressure at the considered point; h is the depth of the flow.

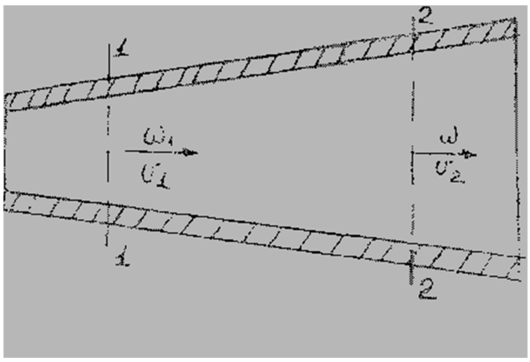
unsteady motion This type of movement is called in which all of the above components are a function of not only coordinates, but also time:

$$u = f(x, y, z, t): p = f1(x, y, z, t)\ h = f2(x, y, z, t).$$

Let us illustrate the above types of fluid motion onan example of fluid leaking out of a tank. Assume that there is a valve in the tank to release water. The water supply to the tank is carried out by a water pipe equipped with a valve. If at the same timeopen the outlet valve and the valve in the pipe and adjust their position so that the amount of outflowing water is equal to the amount of incoming water, then we will observe a steady movement in the tank. Indeed, the depth of water in the tank H will be constant, not changing over time; therefore, at any point in the liquid, the hydrodynamic pressure p, the immersion depth h of the point under consideration, and the velocity will also not change with time. We close the valve of the water pipe, and leave the outlet cock open. The tank will empty. In this case, we will observe the unsteady movement of the fluid. In fact, the depth of water in the reservoir H decreases over time. In this regard, the depth h of immersion of the considered point in the liquid, pressure and speed decrease.current growth at this point. As a result, there will come a moment when the reservoir is empty and all motion components {u, p, h) will be equal to zero.

*steady motion*divided into equal and unequaldimensional. Uniform motion is a type of steady motion in which all components of motion - speed, pressure, channel shape, depth - do not change along the length (x axis) of the flow. The cross section of the flow with uniform motion is constant along the length.

An example of uniform motion is the motion in a channelthe correct form with a constant filling depth. The movement of flow at a constant speed in a cylindrical pipe of constant cross section will also be uniform.



Rice. 4.1

Uneven movementcan be observed in a conical tube, in which the popes change along the lengthriver flow sections and hence velocities,pressure and depth.

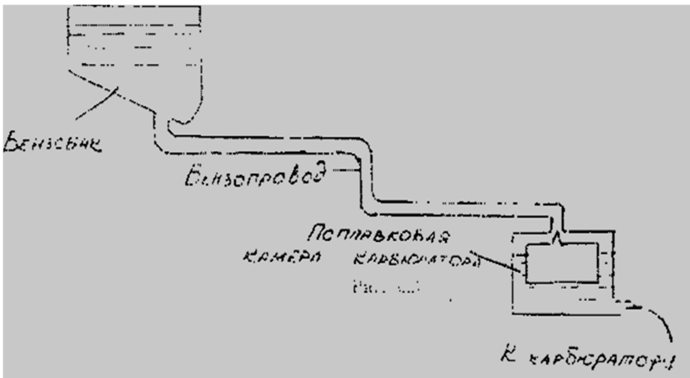
Depending on the causes and general conditions under which themovement, distinguish between pressure and non-pressure movement. Pressure movement is the movement of a fluid in a stream without free rotation.hnosti; it is usually observed in closed pipelines or other guides.raw systems. During the pressure movement, the liquid completely fills the cross section formed by the solid walls restricting the flow. The pressure movement occurs due to the presence of a pressure difference along the length of the flow, created, for example, by a water tower, a feed tank of a gravity fuel system, a pump connected to the network, etc.

. Movement when the flow is not limited on all sides by solid wallskami, but has a free surface, is called free-flow, or movementfree surface. In most cases, free beliefThe flow is in contact with the atmosphere, and therefore, during free-flow movement, the pressure on the surface of the flow is almost always equal to atmospheric pressure. The cause of non-pressure movement is the action of gravity. On fig. 4.3. shows the fuel line connecting the gas tank to the float chamber carburetor. The movement of fluid in such a gas pipeline is pressure.

Streamline and its direction.

When solving many problems of practical hydrodynamics, it is assumed that the flow of a moving fluid consists of individual elementary jets that do not change their shape (Fig.4.3.)

Thus, the flow is mentally divided into a number of elementary jets-tubes, as shown schematically in Fig. 4.2., and will be considered by us as



Rice. 4.2

set of moving elementary jets. Let's give Oprahdivision to the concept of an elementary trickle and give its properties.

Consider the flow of a fluid in steady motion(Fig. 4.3). Let's take point 1 in this flow and build a century in it.

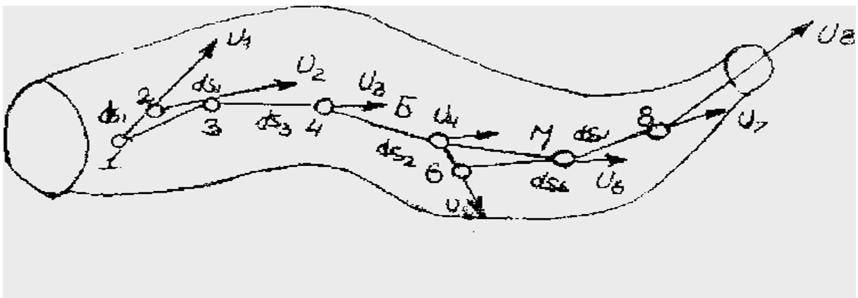


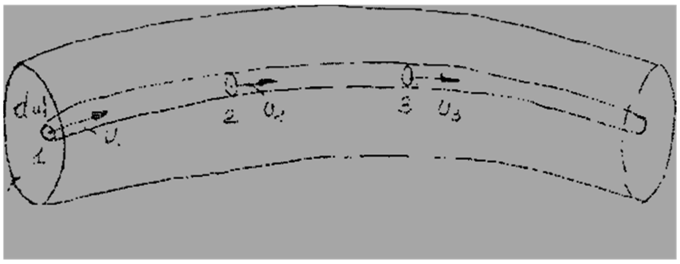
Fig.4.3.

velocity torus u1, expressing it in magnitude and direction. On this vector, we take point 2 at an infinitely small distance ds1 from point 1. At point 2, we construct a velocity vector u2, on which we take point 3 at an infinitely small distance ds2 from point 2, and so on. If we are distances between points ds1, ds2, etc. If we decrease to zero, then instead of the broken line 1-2-3-4-5-6-7-8 in the limit we get a curve starting at point 1 and called the streamline. A streamline is a line, at each point of which, at a giveninstantaneously, the velocity vector of the fluid coincides with the direction of the tangent to this line. With steady motion, the streamlines coincide with the trajectories of fluid particles. In this case, the liquid particle moves along the streamline. Therefore, in steady motion, the streamlines coincide with the trajectories of moving particles.

Let's build around a pointonea closed loop forming an infinitely small area dw, and draw streamlines through all points of the loop (Fig. 4.4.). We will get the so-called current tube. If we draw streamlines through all points of an infinitely small area dw, then we get an elementary stream filled with a "bundle" of streamlines.

Based on the foregoing, it is assumed that the elementarythe jet has the following properties:

1. The shape of an elementary stream remains unchanged over time, since the shape of the streamlines that make up the trickle does not change in the steady motion in time.



Rice. 4.4

2. The surface of an elementary stream formed by streamlines is, as it were, impenetrable for liquid particles moving in adjacent streams. Liquid particles from neighboring streams, sliding over the surface of the stream, cannot penetrate into it.
3. Due to the smallness of the cross section of an elementary jet, the velocities at all points of its cross section are the same.
4. A fluid flow consisting of elementary jets with the properties listed above is sometimes called the "jet model".fluid movement. Such a flow can, for example, be represented by fluid movement in a model consisting of a tube filled with thin glass tubes.

4.1.Basic tasks of hydrodynamics.

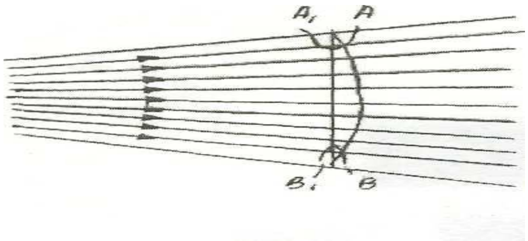
hydrodynamics called the branch of hydraulics, which studies the laws of fluid motion. The motion of a fluid is much more complex than the motion of a rigid body. If, in the case of rest, the state of the liquid was characterized by the value of only hydrostatic pressure, then the state of the liquid in motion is determined, along with the pressure, also by the velocity of liquid particles. In the general case, the values of pressure and velocity, which are different at different points in space, can also change depending on time.

In view of the large number of variables that determine the movement of a fluid, the complexity of the phenomena observed in this case, and the difficulty of mathematical research, the actual movement of a fluid is usually schematized and replaced by some conditional, simplified scheme that divides the movement into separate components. Such a scheme, underlying hydrodynamics and logically best suited to natural concepts of fluid motion, is a scheme (jet model of fluid motion), which considers a fluid flow consisting of individual elementary jets.

4.3. Basic hydraulic flow elements.

When studying fluid flows, a number of concepts are introduced that characterize flows from the hydraulic and geometric points of view. Such concepts are: the area of the active section of the flow, the wetted perimeter and the hydraulic radius.

Clear area, or, in short, the living section of the stream, is the area of the section of the stream, drawn normally to the direction of the streamlines, i.e. normal to the direction of the velocities of elementary jets; we will denote this area by F. In a number of cases, living sections, strictly speaking, are curvilinear. So, for example, when a liquid moves in a conical diverging pipe (Fig. 4.5), when the flow consists of a number of divergent elementary streams, the free section is a curved surface AB. However, if the divergence of the jets is small (the fluid motion in this case is called slow-changingmoving), then practically under the living section, usually alongtake a flat cross sectionka, normal to common onrule of liquid movementty, i.e., for example, in considerationIn the given case of a conical pipe, the section A1 B1 is normal to the axis of the pipe.



Rice. 4.5

The free section can be completely or partially limited by solid walls (in the second case, part of the free section is limited by the open surface of the liquid). If the walls restrict the flow completely, the movement of the fluid is called pressure; if the restriction is partial, the movement is called non-pressure. Non-pressure movement is characterized by a constant pressure on the free surface, usually equal to atmospheric pressure.

An example of a pressure movement is the movement of a liquid in a pipeline, for example, when flowing from a water tank; an example of non-pressure movement is the movement of fluid in open channels and rivers.

The length of the part of the perimeter of the open section, along which the flow comes into contact with the walls limiting it, is called the wetted perimeter; we will denote it through A. In the case of a pressure fluid flow, the geometric and wetted perimeters coincide in size.

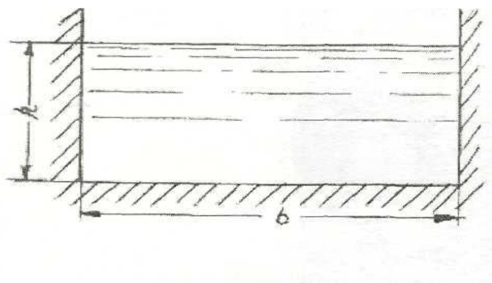


Fig.4.6.

In the case of non-pressure movement of the liquid, the wettedny perimeter will be different from the geometric one, because the line along which the liquid comes into contact with air is not included in the length of the wetted perimeter; because in the case of the channel shown in Fig. 4.6, the wetted perimeter A \u003d b + 2h, while the geometric perimeter is 2b + 2h.

The ratio of the open area to the wetted perimeter R=F/A is called the hydraulic section radius.

4.4. The equation of continuity (continuity) of the flow.

Let us establish a general relationship between the velocities in a fluid flow, for which the condition of continuity or continuity of motion is satisfied, i.e. no voids are formed that are not filled with liquid.

Let us single out (Fig. 4.9) inside the flow an elementary parallelepiped of volume dV = dxdydz, whose edges are oriented parallel to the coordinate axes. Let the component of the flow velocity along the x axis at the points lying on the left side of the parallelepiped with area dS = dydz equal to wx. Then, according to the equation Vsec \u003d wxS, through this face, the mass of liquid will enter the parallelepiped along the x axis per unit time ρ *wxdydz*,and for a period of time dτ -mass of liquid:

$$Mx = \rho\, wxdy\, dz\, d\tau$$

where ρ-liquid density on the left side of the parallelepiped. On the opposite (right) side of the parallelepiped, the velocity and density of the fluid may differ from the corresponding values on the left side and will be equal to $\left(w_x + \frac{\partial w_x}{\partial x} dx\right) u \left(\rho + \frac{\partial p}{\partial x} dx\right)$.Then through the right side of the parallelepiped in the same time $d\tau$ mass of liquid will come out:

$$M_{x+dx} = \left(\rho w_x + \frac{\partial(pw_x)}{\partial x}\right) dydzd\tau$$

Fluid mass increment in a parallelepiped along the x-axis:

$$dMx = M_x - M_{x+dx} = \left(-\frac{\partial(pw_x)}{\partial x}\right) dxdydzd\tau$$

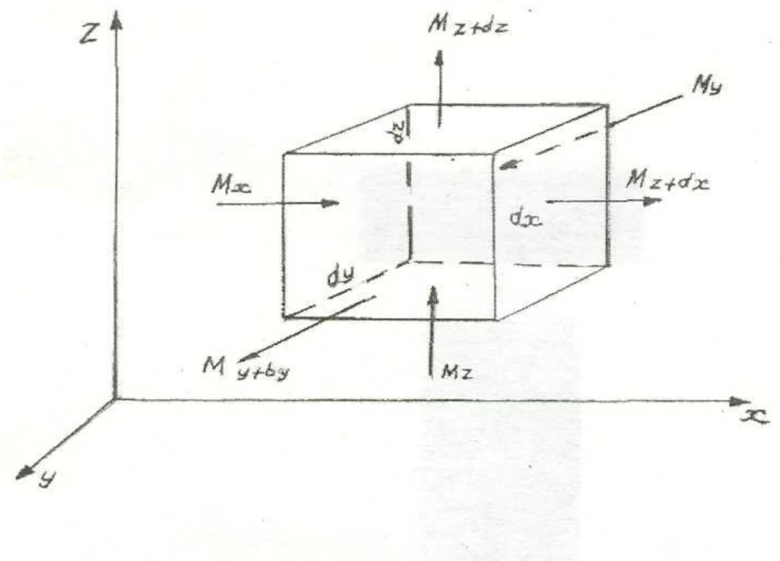
If the velocity components along the y and z axes are wy,. and wz - respectively, then the mass increments in the elementary volume along these axes:

$$dM_z = \left(-\frac{\partial(pw_z)}{\partial z}\right) dzdydxd\tau$$

$$dM_y = \left(-\frac{\partial(pw_y)}{\partial y}\right) dydzdxd\tau$$

The total accumulation of fluid mass in the parallelepiped over time dτ is equal to the sum of its increments along all coordinate axes:

$$\text{dM} = \left[\frac{\partial(pw_x)}{\partial x} + \frac{\partial(pw_y)}{\partial y} + \frac{\partial(pw_z)}{\partial z}\right] dxdydzd\tau.$$



Rice. 4.9.
To the derivation of the differential equation of continuity of the flow.

At the same time, a change in mass in a volume of a parallelepiped completely filled with liquid is possible only due to a change in density in this volume. That's why:

$$dM = \frac{\partial p}{\partial \tau} dxdydz\,d\tau$$

Equating both expressions dM, abbreviating by (-dxdydz) and transposing $\frac{\partial p}{\partial \tau}$ to the left side of the equation, we finally get:

$$\frac{\partial p}{\partial \tau}+\frac{\partial (pw_x)}{\partial x}+\frac{\partial (pw_y)}{\partial y}+\frac{\partial (wz)}{\partial z}=0$$

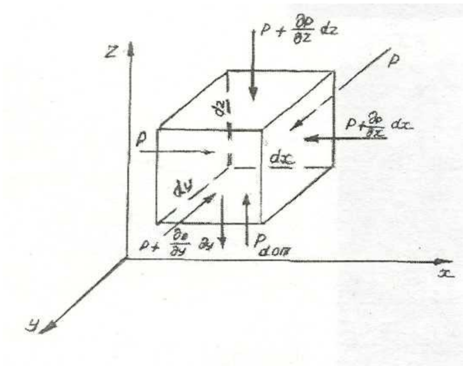
This equation is a differential equation *flow continuity for unsteady motion of a compressible liquids.*

4.5 Euler's equation for the motion of an ideal fluid.

Consider a steady flow of an ideal fluid moving without friction. Let us single out in the flow an elementary parallelepiped of volume dV= dxdydz, oriented relative to the coordinate axes.

The projections on the coordinate axes of the forces of gravity and pressure acting on the parallelepiped are, respectively:

$$-\frac{\partial p}{\partial x}dxdydz\ ,-\frac{\partial p}{\partial x}dxdydz,\ -(pg+\frac{\partial p}{\partial z})\,dxdydz$$



Rice. 4.10.

To the derivation of differential equations of equilibriumEuler.

The mass of liquid in the volume of the parallelepiped: dm = ρ *dxdydz*

According to the basic principle of dynamics, the sum of the projections of forces,*acting on a moving elementthe mental volume of liquid is equal tothe product of the mass of the fluid and its acceleration.*

If the fluid is moving at a speed w, then its acceleration is $\frac{\partial w}{\partial \tau}$, aacceleration projection on coordinate axes:

$$\frac{\partial w_x}{\partial \tau};\frac{\partial w_y}{\partial \tau};\frac{\partial w_z}{\partial \tau},$$

where wx, wy, wz-velocity components along the x, y and z axes.

According to the basic principle of dynamics:

$$\rho\, dxdydz\, \frac{\partial w_x}{\partial \tau} = -\frac{\partial p}{\partial x} dxdydz$$

$$\rho\, dxdydz\, \frac{\partial w_y}{\partial \tau} = -\frac{\partial p}{\partial x}\,\mathrm{dxdydz}$$

$$\rho\, dxdydzdz \frac{\partial w_z}{\partial \tau} = -(-pg - \frac{\partial p}{\partial z})\, dxdydz$$

or after reduction:

$$\rho\, \frac{\partial w_x}{\partial \tau} = -\frac{\partial p}{\partial x};\frac{\partial w_y}{\partial \tau} = -\frac{\partial p}{\partial x};\frac{\partial w_z}{\partial \tau} = -(-pg - \frac{\partial p}{\partial z}),\quad (4\text{-}1)$$

;

where, according to the equation

$$\frac{du}{d\tau} = \frac{\partial u}{\partial x}w_x + \frac{\partial u}{\partial y}w_y + \frac{\partial u}{\partial z}w_z$$

Substantial derivatives of the corresponding components

speeds are:
$$\left.\begin{aligned} \frac{dw_x}{d} &= \frac{\partial w_x}{\partial x}w_x + \frac{\partial w_x}{\partial y}w_y + \frac{\partial w_x}{\partial z} \\ \frac{dw_y}{d\tau} &= \frac{\partial w_y}{\partial x}w_x + \frac{\partial w_y}{\partial y}w_y + \frac{\partial w_y}{\partial z}w_y \\ \frac{dw}{d\tau} &= \frac{\partial w_z}{\partial x}w_x + \frac{\partial w_z}{\partial y}w_y + \frac{\partial w_z}{\partial z}w_z \end{aligned}\right\}\quad (4\text{-}2)$$

The system of equations (4-1), taking into account expressions (4-2), is the differential equations of motion of an ideal Euler fluid for a steady flow.

With unsteady motion, the fluid velocity changes not only when a flow particle moves from one point in space to another, but also over time at each point. Therefore, according to the equation $\frac{du}{d\tau} = \frac{\partial u}{\partial \tau} + \frac{\partial u}{\partial x}w_x + \frac{\partial u}{\partial y}w_y + \frac{\partial u}{\partial z}w_z$ acceleration components in equation (4-1), expressed by substantive derivatives for unsteady conditions, have the form:

$$\left.\begin{aligned}
\frac{dw_x}{d} &= \frac{\partial w_x}{\partial \tau} + \frac{\partial w_x}{\partial x} w_x + \frac{\partial w_x}{\partial y} w_y + \frac{\partial w_x}{\partial z} \\
\frac{dw_y}{d\tau} &= \frac{\partial w_y}{\partial \tau} + \frac{\partial w_y}{\partial x} w_x + \frac{\partial w_y}{\partial y} w_y + \frac{\partial w_y}{\partial z} w_y \\
\frac{dw}{d\tau} &= \frac{\partial w_z}{\partial \tau} + \frac{\partial w_z}{\partial x} w_x + \frac{\partial w_z}{\partial y} w_y + \frac{\partial w_z}{\partial z} w_z
\end{aligned}\right\} \text{(four-2a)}$$

The system of equations (4-1), taking into account the expressions (4-2, a) is the differential equations of motion of an ideal Euler fluid for an unsteady flow.

Test questions:

1. List the main hydraulic elements of the flow.
2. Give definitions: streamline of an elementary stream and liquid flow.
3. Definition of a living section.
4. Explain the fluid flow and the average fluid velocity.
5. Formulate the continuity equation.

Key words:kinematics and fluid dynamics, main problems of hydrodynamics streamline and its direction, basic hydraulic elements of the flow, Euler equation for the motion of an ideal fluid.

Translated from Russian to English - www.onlinedoctranslator.com

Lecture 5
Regularities of motion of real liquids
Learning technology for lecture No. 5

Time - 2 hours	Number of students: 20-30 people
Form of the lesson	Introduction, visual lecture
Lesson Plan	1. Patterns of motion of real fluids a) Bernoulli's equation for an elementary stream of a real liquid. b) Bernoulli's equation for the flow of a real fluid 2. Geometric and physical meaning of the Bernoulli equation. 3. The concept of hydraulic and piezometric slopes. 4. The Navier-Stokes equation for the motion of a real fluid. 5. Methods and instruments for measuring fluid velocities and flow rates.
Purpose of the lesson: to acquaint students with the laws of movement of real liquids, with methods and instruments for measuring the velocities and flow rates of a liquid, with a tubular water meter, with a water meter washer (diaphragm), with a Prandtl tube; teach how to write the Bernoulli equation for an elementary stream, as well as the Bernoulli equation for the flow of a real liquid.	
Tasks of the teacher: • familiarizewith real fluid properties; • introduce the Navier-Stokes equation for the motion of a real fluid; • acquaint withBernoulli's equation for a real fluid. • acquaintmethods and instruments for measuring fluid velocities and flow rates.	*Learning outcomes:* The student must learn: -with the properties of a real liquid; -Navier-Stokes equations for real fluid motion; -Bernoulli's equation for real fluid flow; -hydraulic and piezometric slopes; -volumetric method of measurement; -weight measurement method, Pitot tube;
Means of education	Laser projector, visual materials, information support.
Forms of study	Collective, frontal work, work in pairs. graphorganizers
Conditions of education	An audience adapted to work with TCO.

Technological map of the lecture (5th lesson)

stages, time	Activity	
	teacher	students
Stage 1. Introduction (10 min.)	1.1.Informs the topic, purpose, planned results of the training session and the plan for its implementation.	1.1. Listen, write.
Stage 2. Basic (60 min.)	2.1.In order to update students' knowledge, asks focusing questions: What is a real liquid? -What is an elementary stream? – Differential equilibrium equation? Work in pairs to answer questions. Conducting a quiz. 2.3. Consistently presents the material of the lecture on the issues of the plan, uses visual materials. Shows gauges gauge washerandpitot tubeexplains their work. Focuses on the key points of the topic, offers to write them down	2.1. Listen. They take turns answering the questions. Listen to the correct answer. 2.3.Discuss schema content and tables, visual materials, clarify, ask questions. write down main.
3 stage. Closing (10 min.)	3.1.Conducting a quiz. Makes a final conclusion. Gives assignments for independent work. 3.2 Compose a cluster on the word "Real liquid". Set ratings.	3.1. Reply to question. 3.2. Listen, write.

5.1. Bernoulli's equation for an elementary stream of a real liquidbones.

If, instead of an ideal fluid, we consider a real fluid (in which tangential stresses arise during motion), then the Bernoulli equation will have to change significantly. While in the first case the total energy of the liquid, or head H, remains constant along the length of the stream, when a real liquid moves, this energy will decrease in the direction of movement. The reason for this is the cost of energy to overcome the resistance to motion, due to internal friction in a viscous fluid. Therefore, for a stream of real liquid, the head H1 in section 1:

$$H_1 = z_1 + \frac{p_1}{\gamma} + \frac{v_1^2}{2g}$$

will always be greater than the pressure H2 in the section 2 following it at a certain distance:

$$H_2 = z_2 + \frac{p_2}{\gamma} + \frac{v_2^2}{2g}$$

by the magnitude of the indicated energy losses, and the Bernoulli equation, due to thistakes the form:

$$z_1 + \frac{p_1}{\gamma} + \frac{v_1^2}{2g} = z_2 + \frac{p_2}{\gamma} + \frac{v_2^2}{2g} + h_{1-2} \quad (5.1)$$

Just as the three terms on the left side of this equation and the first three terms on the right side of it are the corresponding total energies of the fluid in sections 1 and 2, so is the quantity h_{1-2} is a measure of the energy lost by a unit weight of a fluid to overcome resistance when it moves between the indicated sections. This loss of fluid specific energy is called the head loss between sections 1 and 2. Since, in the case of a real liquid, the total head along the trickle is not constant, but decreases in the direction of motion, its values along the length of the trickle are displayed in black.umbrella line, as in the previousin the other case, but in somehowl bb (Fig. 5.1); in private servicetea trickle of constant cross section, the pressure along the length of the trickle will be proportional to the distance from the initial section and the changetotal head is shown as an inclined straight line.

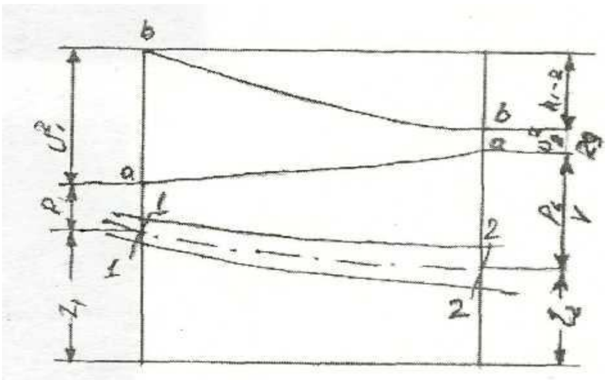


Figure 5.1

To characterize the relative change in the total head per unit length of the jet, the concept of the so-called hydraulic slope is introduced. Analytically, the hydraulic slope is the derivative of the pressure loss with respect to the corresponding distance measured from the initial section along the axis of the stream:

$$i = \frac{dh_{1-2}}{dL} \quad (5-2)$$

The hydraulic slope has no dimension, it is an abstract, immeasurable quantity.

The average value of the hydraulic slope in the section of an elementary trickle between sections 1 and 2 is determined as the value of the head loss per unit length of the trickle:

$$i_{cp} = \frac{h_{1-2}}{L_{1-2}} = \frac{\left(z_1 + \frac{p_1}{\gamma} + \frac{v_1^2}{2g}\right) - \left(z_2 + \frac{p_2}{\gamma} + \frac{v_2^2}{2g}\right)}{L_{1-2}} \quad (5\text{-}2)$$

where L1-2 is the distance between sections 1-2.

5.2. Bernoulli equation for real fluid flow.

Based on equation (5.1)

$$z_1+\frac{p_1}{\gamma}+\frac{v_1^2}{2g}=z_2+\frac{p_2}{\gamma}+\frac{v_2^2}{2g}+h_{1-2}\,(5\text{-}3)$$

multiply all the terms of this equation by γq (weight flow rate):

$$\gamma q\,\frac{v_2^2}{2g}+\gamma q\,(z_2+\frac{p_2}{\gamma})+\gamma q\;h_{1-2}=\gamma q\,\frac{v_1^2}{2g}+\gamma q\;(\;z_1+\frac{p_1}{\gamma}\;)$$

Similar expressions can be made for all individual streams. Summing them up, we get:

$$\Sigma\;\gamma q\,\frac{v_2^2}{2g}+\Sigma\;\gamma q\,(z_2+\frac{p_2}{\gamma})+\Sigma\;\gamma q\;h_{1-2}=\Sigma\,\gamma q\,\frac{v_1^2}{2g}+\Sigma\;\gamma q\;(\;z_1+\frac{p_1}{\gamma}\;)(5\text{-}4)$$

Let's consider each of the terms of this equation separately. Expressions:

$$\Sigma\;\gamma q\,\frac{v_2^2}{2g}=\frac{\gamma}{2g}\Sigma q v_2^2$$

$$\Sigma\,\gamma q\,\frac{v_1^2}{2g}=\frac{\gamma}{2g}\Sigma q v_1^2$$

represent the values of the kinetic energy (live force) of the mass of fluid flowing per unit time through the cross sections of the duct 2 and 1.

For practical purposes, it turns out to be convenient to replace these expressions in terms of the kinetic energy of the flow, calculated from the average velocity vcp for the entire flow, i.e. present in the form:

$$\gamma Q\frac{v_{cp2}^{\;2}}{2g}\quad\gamma Q\frac{v_{cp2}^{\;2}}{2g}$$

However

$$\frac{\gamma}{2g}\Sigma q v^2\neq\gamma Q\frac{v_{cp2}^{\;2}}{2g}.$$

This is explained by the fact that the value $\Sigma q v^2$ is the arithmetic sum of the products of the costs of individual elementary jets q and the squares of their actual velocities v2. while Qv2cp is the product of the total flow rate (Q $=\Sigma\, q$)by the square of the average flow velocity v2cp, which is the arithmetic mean of v to the first power (vcp $=\frac{\Sigma v}{n}$, where n is the number of jets). Therefore, in order to ensure that the replacement does not introduce changes into the value of the kinetic energy of the flow, the expression $\gamma Q\frac{v_{cp}^{\;2}}{2g}$ some correction factor must be introduced, called the Coriolis coefficient and denoted by α .Thus, the Coriolis coefficient is the ratio of the actual kinetic energy of the fluid flowing through the cross section of the flow per unit time to the kinetic energy that would occur at the same flow rate if all particles of the fluid had the same velocities equal to the average velocity, i.e. e.:

$$\alpha = \frac{\Sigma q v^2}{Q \cdot v^2{}_{cp}}$$

Taking into account the fact that q = vΔF and Q = vcpF, the last expression can also be represented in the following form:

$$\alpha = \frac{\Sigma v^2 \Delta F}{v^2{}_{cp} F}$$

Usually the Coriolis coefficient is determined empirically. It depends on the degree of uneven distribution of velocities in the cross section of the flow and is always greater than one; for the so-called laminar flow in a cylindrical tube α =1. And for the so-called turbulent regime α =1.045 $\div$ 1.10.

Let us now consider the expression of the second term of equation (5-4), which is the potential energy of the flow.

With slowly changing motion, which is mainly considered in hydraulics, the pressure distribution in the living sections of the flow obeys the basic law of hydrostatics. Therefore, we can assume that the value of z$\frac{p}{\gamma}$ at all points, the cross section of such a flow will be the same and, therefore,

$$\Sigma\ \gamma q \left(z + \frac{p}{\gamma} \right) = \gamma \left(z + \frac{p}{\gamma} \right) \Sigma\ q = \gamma Q \left(z + \frac{p}{\gamma} \right)$$

The third term of equation (5-4), expressing the sum of the work of the resistance forces, can be represented (meaning by h_{1-2} averaged head loss) in the form:

$$\Sigma\ \gamma\ h_{1-2} q = \gamma\ h_{1-2} \mathrm{Q}$$

Substituting the obtained expressions into equation (5-4), we will have:

$$\gamma \mathrm{Q} \frac{\alpha_2 v_{cp2}^2}{2g} + \gamma Q \left(z_2 + \frac{p_2}{\gamma} \right) + \gamma\ h_{1-2} \mathrm{Q} = \gamma \mathrm{Q} \frac{\alpha_1 v_{cp1}^2}{2g} + \gamma Q \left(z_1 + \frac{p_1}{\gamma} \right)$$

or after reduction by γ Qand rearrangement of terms:

$$\left(z_1 + \frac{p_1}{\gamma} \right) + \alpha_1 \frac{v_{cp1}^2}{2g} = \left(z_2 + \frac{p_2}{\gamma} \right) + \alpha_2 \frac{v_{cp2}^2}{2g} + h_{1-2} \quad (6\text{-}5)$$

In practical calculations, the coefficient α often neglected and considered equal to unity, thereby assuming that the weight of the stream, as it were, moves with the same average speed. Let us omit the indices "cp" at vcp, implying everywhere that we are talking about the average values of this quantity. Then the form of writing the Bernoulli equation for the whole flow becomes identical to its writing for an elementary trickle:

$$\left(z_1 + \frac{p_1}{\gamma} \right) + \frac{v_{cp1}^2}{2g} = \left(z_2 + \frac{p_2}{\gamma} \right) + \frac{v_{cp2}^2}{2g} + h_{1-2} \quad (5\text{-}6)$$

In this form, the Bernoulli equation is usually used in solving practical problems for flows of a homogeneous incompressible fluid with steady motion occurring under the action of one gravity force.

5.3. Methods and instruments for measuring fluid velocities and flow rates.

The simplest and at the same time accurate methods for measuring fluid flow are volumetric and gravimetric methods.

With the volumetric method of measurement, the liquid flowing in the stream under study (for example, in a pipe) enters a special, carefully calibrated vessel (the so-called measuring tank), the filling time of which is accurately recorded by a stopwatch. If the volume of the measuring tank is V,and the measured filling time is T, the volume flow will be equal to:

$$Q=V/T$$

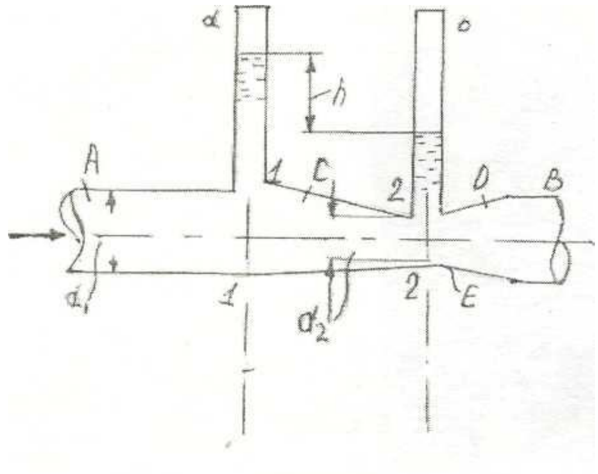
In the weight method, by weighing on the scales, the weight Gv of the entire liquid that entered the measuring tank during the time T is found, the weight flow is determined:

$$G=\frac{G_v}{T}$$

and from it, knowing the specific gravity of the liquid γ ,calculate the volume flow:

$$Q=\frac{G}{\gamma}$$

However, volumetric or gravimetric methods are suitable only for relatively small liquid flow rates, because otherwise, the dimensions of the merniks turn out to be cumbersome and measurements are difficult; moreover, it is impossible to measure the flow rate in an arbitrary section using these methods. For example, a long pipeline or channel without violating the integrity of the latter. Therefore, with the exception of cases of measuring relatively small flow rates of liquids in short pipes and channels, volumetric or weight methods, as a rule, are not used, but in practice they use special devices that are preliminarily calibrated by volume or weight. One of these maininstrumentation is a tubular water meter, or Venturi water meter. The great advantage of this water meter is the simplicity of design and the absence of any moving parts in it.



Tubular water meters can be horizontal and verticking; consider ina meter with a horizontal axis, shown in fig. 5.2. It consists of two cylinderstubes A and B, connectedwith the help of conical sections (pipes) C and D with a cylindrical insert E of a smaller diameter. in sectionpiezometric tubes a and b are connected to the water meters 1 and 2, the difference in liquid levels h of which shows the pressure difference in these sections.

Compiling the Bernoulli equation for sections 1 and 2, we obtain, neglecting very small losses over a small length between these sections,

$$\frac{\rho_1}{\gamma}+\frac{v_1^2}{2g}=\frac{\rho_2}{\gamma}+\frac{v_2^2}{2g}$$

where

$$\frac{\rho_1}{\gamma}-\frac{\rho_2}{\gamma}=\frac{v_2^2}{2g}-\frac{v_1^2}{2g}.$$

But

$$\frac{\rho_1}{\gamma}-\frac{\rho_2}{\gamma}=h,$$

Consequently,

$$h=\frac{v_2^2}{2g}-\frac{v_1^2}{2g}.$$

On the other hand, from the equation of constant flow we have

$$vlFl=v2F2$$

Let's express from here through v1 through v2:

$$v_1=v_2\frac{F_2}{F_1},$$

and substituting this value into the previous equation

$$h=\frac{v_2^2}{2g}\left[1-\left(\frac{F_2}{F_1}\right)^2\right]$$

we determine the average speed in section 2:

$$v_2=\sqrt{\frac{2gh}{1-\left(\frac{F_2}{F_1}\right)^2}}.$$

Then the desired flow rate will be equal to:

$$Q = v_2 F_2 = F_2 \sqrt{\frac{2gh}{1-\left(\frac{F_2}{F_1}\right)^2}}.$$

In fact, due to the uneven distribution of velocities in the cross sections of the flow, as well as due to the inevitable pressure losses between the considered sections, the actual flow rate of the liquid will differ somewhat from that calculated by this formula, which is taken into account by introducing a correction factor m into it. Taking into account this circumstance:

$$Q = mF2 \sqrt{\frac{2gh}{1-\left(\frac{F_2}{F_1}\right)^2}}.$$

The value of the coefficient for each given water meter is established empirically on the basis of a number of preliminary measurements of flow rates at various fluid flow rates; this is the calibration of the water meter.
In the practical determination of flow, the formula is usually used:

$$Q = c\sqrt{h},$$

where coefficient

$$c = mF2 \sqrt{\frac{2g}{1-\left(\frac{F_2}{F_1}\right)^2}}$$

is called the constant of the water meter and has a well-defined value for a given water meter.
In most cases, the pressure difference in sections 1 and 2 of a tubular water meter is measured using a differential pressure gauge, usually mercury. Then, as follows from the description of the differential pressure gauge,

$$\frac{p_1 - p_2}{\gamma} = \left(\frac{\gamma_1}{\gamma} - 1\right) h_1$$

and therefore in the formulas obtained above, instead of h, it is necessary to introduce the quantity

$$\left(\frac{\gamma_1}{\gamma} - 1\right) h_1,$$

where γ_1 -specific gravity of mercury;
h1 is the difference between the levels of mercury in both knees of the differential pressure gauge.
In this case, to determine the flow rate, respectively, we obtain the following formula:

$$Q=mF2\sqrt{\frac{2g\left(\frac{\gamma_1}{\gamma}-1\right)}{1-\left(\frac{F_2}{F_1}\right)^2}}.$$

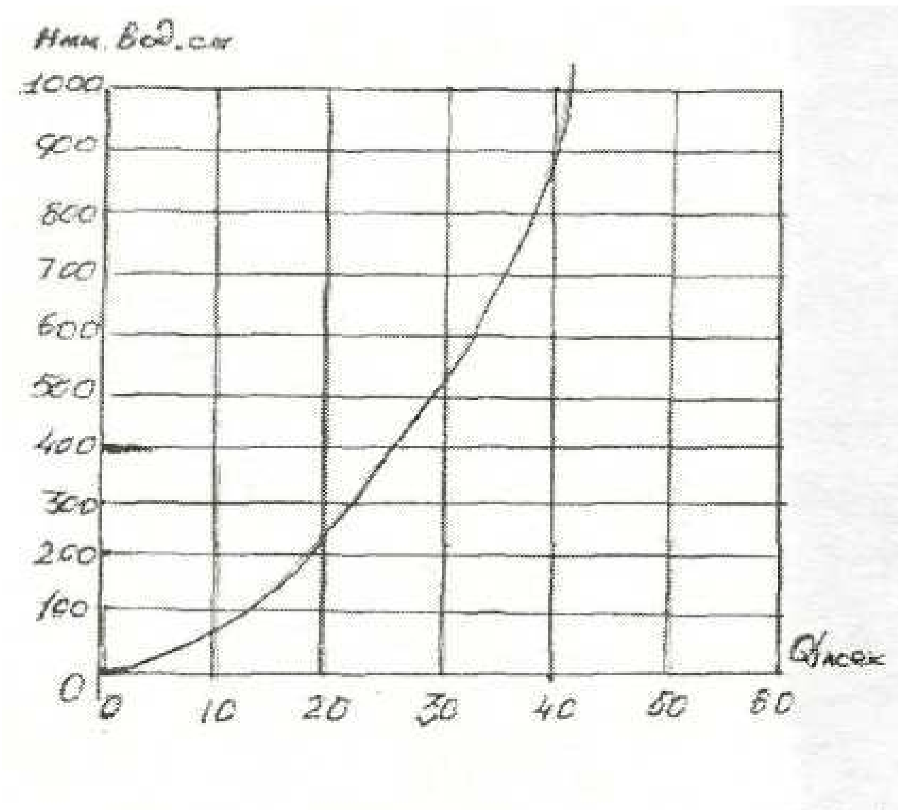
As well as

$$Q=c1\sqrt{h_1},$$

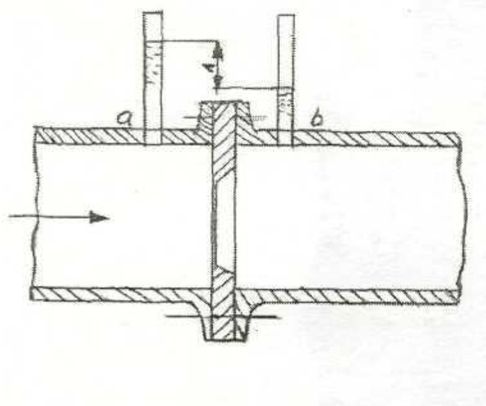
where is the water meter constant

$$c1=mF2\sqrt{\frac{2g\left(\frac{\gamma_1}{\gamma}-1\right)}{1-\left(\frac{F_2}{F_1}\right)^2}}$$

Rice. 5.3.



In practice, instead of calculatingliquid consumption formulasbones are often determined from so-called calibration curves, obtained empirically and giving for of this water meter, a direct relationship betweenpressure gauge reading H measured flow ratesliquid Q. One of these curves is shown in Figure 5.3.



Rice. 5.4

Another common flow measurement device is the orifice (or orifice), usually youfilled in the form of a flat ring with a round holein the center, installed between the flanges of the pipelinewater (Fig. 5.4). Opening edgesThe nozzles most often have sharp entry edges at an angle of 45°, or they are rounded according to the shape of the liquid jet flowing into the hole (nozzle). Two piezometers a and b or a differential pressure gauge are used to measure the differential pressure before and after the orifice.

The flow rate is determined by the measured level difference in the piezometer tubes using a formula similar to that of a water meter

$$Q=c\sqrt{h}.$$

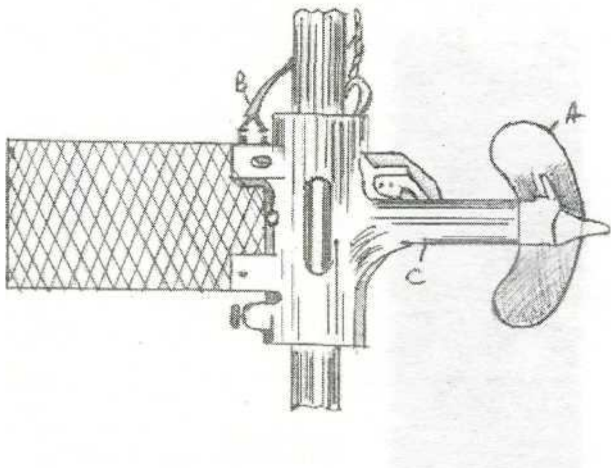
The value of the coefficient c is determined empirically for each type of diaphragm separately.

Flow rates can also be calculated as a result of measurements of fluid flow rates and flow cross sections. One of the widely used instruments used for this purpose is the hydrometric meter. It has received the widest application for measurements in natural flows (rivers) and open channels.

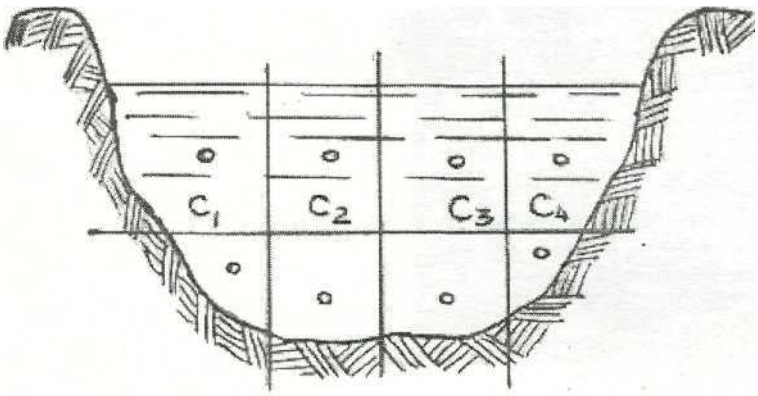
The spinner (Fig. 5.5) consists of an impeller A, which is a wheel with helical blades mounted on a horizontal shaft C. Being installed in the stream, the impeller rotates under the action of the flowing liquid, and the number of its revolutions is directly proportional to the flow velocity. Wires B are led upward from the turntable, leading to an electric bell that gives a signal at each closing of the electrical circuit, which is carried out after a certain number of revolutions by a special contact mechanism placed in chamber C, or to a special counter that automatically records the number of revolutions and time.

To determine the flow rate of a liquid, they proceed as follows: they draw a living section of the flow on a scale (Fig. 5.6) and divide it into a number of elementary sections $\Delta F_1, \Delta F_2$ ... .., then the speed is measured with a turntable v_1, v_2 ... in the centers of gravity of these sections c1,c2,...; elementary costs through these sections will be:

$q1 = \Delta F_1 v_1, \quad q2 = \Delta F_2; \; ....$



rice. 5.5



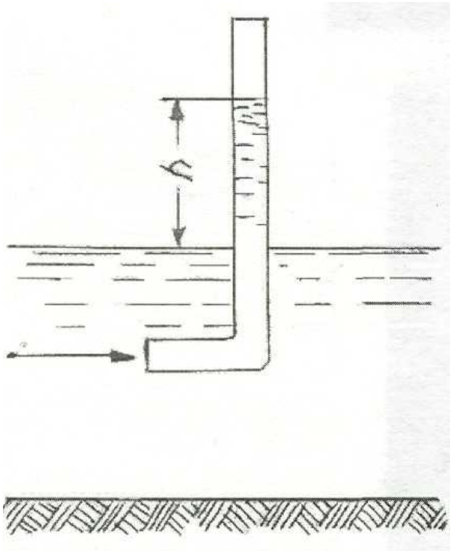


Fig.5.7

The total flow rate of the liquid is found by summing the elementary strokes over the entire section

$$Q = \sum qi, = \Delta F_1 v_1 + \Delta F_2 v2 + ...$$

A common instrument for measuring velocity at a point in a stream, used both in small open streams, mainly in laboratory practiceke, and when moving in pipes, is the Pitot tube. In simplein our form, the Pitot tube (Fig. 5.7) is a tube bent at a right anglesmall diameter, installed in the flow open bottomwith its end to meet the flow of liquid; the second, upper, end of the tube is removed from the flowout.

If such a tube is installed in an open flow, for example, in a channel where the pressure on the free surface of the liquid is equal to atmospheric pressure, then, as follows from the previous one, the height h of the liquid in the tube aboveflow surface is the magnitude of the velocity $\frac{v^2}{2g}$ pressure at the point of installation of the pipe. In this way,

$$h = \frac{v^2}{2g}$$

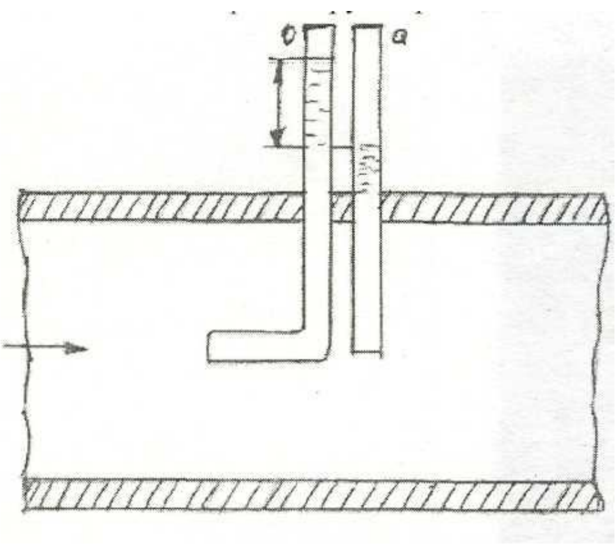
where is the velocity of the fluid:

$$v = \sqrt{2gh}.$$

The actual value of the velocity, due to the inevitable loss of pressure in the tube itself and some disturbance of the flow caused by the introduction of a foreign body into it, turns out to be somewhat larger and is determined by the formula

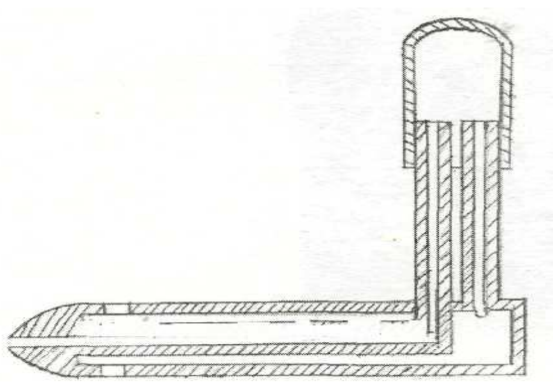
$$v = a\sqrt{2gh},$$

where a is a correction factor determined empirically for each given tube.



Rice. 5.8

Prandtl tube is a further development and improvementpitot tube. It is used to measure the flow rate of fluid in pressure pipes. It consists of two tubes (Fig. 5.8), one of which is a preis a conventional piezometer showing piezometric head $\frac{p}{\gamma}$. and the other b-a $\frac{p}{\gamma}+\frac{v^2}{2g}$. The difference in liquid levels in both tubes h gives the magnitude of the velocity head $\frac{v^2}{2g}$, which determines the speed.



Rice. 5.9

In existing designs, both tubes are usually combined into one instrument, consisting in this case of two concentric tubes, the ends of which are connected to a differential pressure gauge (5.9). Central inner tubegives full pressure to the pressure gauge; external pipeska, having a cutout or holes on the side surface, transmits a piezometric pressure.To reduce fluid flow disturbances near the tube, its head is given a conveniently streamlined spherical shape. Tube dimensions can be made very small - up to0.5 mm in diameter (syringe needle), so that the speed measured by it can be taken as the speed at a given point.

The value of the fluid velocity at the installation point of the Prandtl tube is found by the formula:

$$v = a\sqrt{2gh\left(\frac{\gamma_1}{\gamma} - 1\right)}$$

where:h is the level difference in the knees of the differential pressure gauge;
γ_1 and γ_2 —the specific gravity of the test liquid and the intermediate liquid of the manometer;
a -a correction factor determined empirically and varying from 1 to 1.04, depending on the accuracy of the manufacture of the tube and its dimensions.

By placing the Prandtl tube at different points in the cross section of the flow, one can find the distribution of velocities in this section and then calculate the flow rate.

Test questions:

1. Give the Navier - Stokes equations for the motion of a real fluid.
2. Give the Bernoulli equation for an elementary trickle.
3. Give the Bernoulli equation for an elementary stream of a real liquid.
4. Explain the geometric meaning of the Bernoulli equation.
5. Explain the physical meaning of the Bernoulli equation for the flow of a real fluid.
6. Explain hydraulic and piezometric slope.
7. Methods for determining the rate of fluid flow.
8. Devices for measuring the speed and flow of liquid and the principle of their operation.

Key words: Bernoulli equation, water gauge, hydraulic slope, yBernoulli equation for real fluid flow,hydrometric meter, diaphragm,Coriolis coefficient, volumetric measurement method, weight measurement method, Pitot tube.

Lecture 6
Modes of motion of liquids and the basis of hydrodynamic similarity.
Technological map of the lecture (6th lesson)

Time - 2 hours	Number of students: 20-30 people
Form of the lesson	Information lecture, joint study and use of a graphic organizer table "Z. Z. U."
Lesson Plan	1. Modes of movement of liquids. 2. The concept of "hydrodynamic similarity", similarity criteria. 3. Distribution of velocities and flow rate of liquid at steady laminar flow. 4. Turbulent regime of fluid motion. 5. Pulsation and average flow velocity in turbulent fluid motion. .

***Purpose of the lesson**:* to acquaint students with the regimes of fluids, with the concept of "hydrodynamic similarity", similarity criterion, with pulsation and average flow velocity, with the distribution of velocities and fluid flow in a steady laminar flow.	
Tasks of the teacher: •The concept of "hydrodynamic similarity", similarity criteria; • introduceturbulent fluid flow; • briefly describepulsation and average flow velocity in turbulent fluid motion.	*Learning outcomes:* The student must learn: -"hydrodynamic similarity", similarity criteria; - Pulsation and average flow velocity in turbulent fluid flow; -lubrication theory in hydrodynamics; -critical Reynolds number;
Teaching methods and techniques	Lecture, "learning together"; techniques: Insert, blitz-survey, presentation, graphic organizer: C/X/U table
Means of education	Laser projector, information support, markers, adhesive tape, sheets of A32 paper
Forms of study	Frontal, individual work, work in groups
Conditions of education	An audience adapted to work in groups, having the conditions for the use of TCO and information technology

stages, time	**Activity**	
	teacher	**students**
Stage 1. Introduction to educational occupation (3 min.)	1.1. Informs the topic and plan of the lecture (displays it on the screen), recalls the main questions, introduces the planned learning outcomes of the lesson and the work schedule.	1.1. Listen, write down.

Stage 2. Updating knowledge (17 min.)	2.1. Displays the Z/X/Y table and commentary on working with it (Appendix 2). Gives the task to draw a table in workbooks and fill in column 2 in accordance with the lecture plan. 2.2. Invites students, using the marks they made in the margins of the text while reading it, to answer the questions: (one) What do they already know? (i.e. they can tell on their own) (2) What remains unlearned, not understood? (3) What additionalinformation?, in accordance with which, fill in the 3rd and 4th columns of the table, putting down the numbers of key concepts (Appendix 3). 2.3. Conducting a quiz. At the same time, you-listens to just a few answers and reports that the work will be continued in mini-groups.	2.1. Redraw the table Z / X / Y, enter the questions of the lecture plan in the 2nd column of the table. 2.2. Fill in the 3rd and 4th columns of the table. 2.3 Read out the results.

Stage 3. Informational (55 min.)	3.1. Divides students into 4 mini-groups on an arbitrary basis and gives the task: (one) analyze individual information in columns 4 of table 3/X/У on a fragment of the topic, in accordance with the number of the group: 1 group - on 1 question, 2 group - on 2 questions, etc.; (2) summarize the unlearned in 1-2 questions; (3) jointly prepare answers using any available sources (textbook,lecture text); (four) prepare for the presentation of the results of the work - arrange the answers on the presentation sheets in the form of a table Z / X / Y according to thismu question of the topic. Announces the start of work in groups. 3.2. Organizes the process of presentation, discussion. 3.3. After each group's response: (one) asks a question to determine the level digestibility of the entire audience: "What did we learn?", (2) conducting a quiz. 3.4. Summarizes the results of the trainingday ness, proposes to fill in the 5th column of the individual table Z / X / Y.	3.1 Work in groups: - each member of the group reads out the key concepts from the 4th column of their individual tables; - the group leader organizes the formulation process and- writing questions 4 columns; - collectively discuss and find and write down the answer in column 5 of the summary table tsy Z / X / Y; - Prepare a response on the presentation sheet. 3.2. Presentation of the results of the work: group leaders - attach a sheet to the board (Format not less than A-32) with complete table Z / X / Y for your question and comment yut her; answer questions; substantiate their opinion. 3.3. They answer questions. 3.4. Fill (up to 2 min) 5 column of individual tab persons Z/X/U.
Stage 4. Final (5 min.)	4.1. Summing up, summarizing the resultsyou, evaluates the performances of leaders, encourages active participants. 4.2. Gives assignments for self-studyra bots: write a cluster "Turbulent motion".	Listen, write.

Annex 1 (3.1)

Rules for working with the insert technique

1. Read the text.
2. Organize the information received by putting notes in the margins with a pencil:

V- corresponds to the existing knowledge (information) about ...;
-(minus) - contradicts the existing knowledge about ...;
+(plus) - is new information;
? - incomprehensible / requiring clarification / addition information.

<u>Appendix 2</u>(3.1)

Rules for working with the use of equipment Z / X / Y 1. Read the text using the Insert technique. 2. Individually systematize the information received - "spread" into the columns of the table according to the notes made in the text. Table Z / X / Y (I know / I want to know / I learned (a))				
No.	Topic question	I know	I want to know	found out
one	2	3	four	5
one				
2				
3				
four				

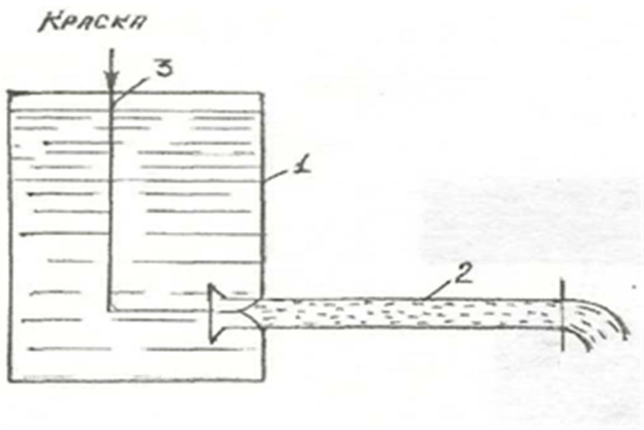
Annex 3 (3.1)Key Concepts

one	laminar motion
2	Turbulent driving mode
3	Reynolds number
four	geometric similarity
5	similarity criteria
6	Velocity distribution and fluid flow
7	Hydrodynamic similarity
eight	Velocity distribution over the cross section
9	Velocity distributions for turbulent motion
ten	Speed ripple
eleven	Equal Speed
12	Critical Reynolds number

6.1. Two modes of motion of a viscous fluid.

Different modes of fluid flow can be traced by introducing a colored stream or some other indicator into the flow.

For the first time, fluid flow regimes were studied by O. Reynolds in 1883. To vessel 1, in which a constant water level is maintained, a horizontal glass pipe 2 is attached. A thin stream of colored water (indicator) is introduced into this pipe along its axis through a capillary tube 3. At a low water velocity in pipe 2, the colored stream is drawn into a horizontal thread, which, without blurring, reaches the end of the pipe



Rice. 6.1. a.

This indicates that the particle paths are rectilinear and parallel to each other.

Such a movement in which all particles of the liquid move along parallel trajectories is called laminar.

If the speed of water in pipe 2 is increased beyond a certain limit, then the colored stream first acquires a wave-like motion, and then begins to blur, mixing with the bulk of the water. This is due to the fact that the individual particles of the liquid no longer move parallel to each other, but are mixed in the transverse direction.

A movement in which all particles of a fluid move randomly is called turbulent.

Experience shows that the transition from laminar to turbulent flow is the easier, the greater the mass velocity of the liquid pw and the diameter of the pipe d and the lower the viscosity of the liquid μ. Reynolds found that these quantities can be combined into a dimensionless complex $\omega d\rho / \mu$, the numerical value of which makes it possible to judge the regime of fluid motion. This complex is called the Reynolds criterion (Re):

$$\mathbf{Re}=\frac{\omega d\rho}{\mu} \quad (6\text{-}1)$$

The Re number is a measure of the relationship between the forces of viscosity and inertia in a moving stream. Indeed, the greater the probability of violation of the laminar flow regime and the occurrence of chaotic movement of particles, the lower the viscosity of the fluid that prevents this violation, and the greater its density, which is a measure of the inertia of particles deviated from the rectilinear motion. Therefore, at equal velocities of movement of various fluids in pipes of the same diameter, turbulence arises because lighter the denser ρ and less μ, or the lower the kinematic viscosity $\nu = \frac{\mu}{\rho}$. Accordingly, the Reynolds criterion can be written as:

$$\mathbf{Re}=\frac{\omega d\rho}{\mu} \quad (6\text{-}1, a)$$

The transition from laminar to turbulent motion is characterized by the critical ReKp value. So, when liquids move along straight smooth pipes ReKp$\approx$2320. When Re<2320, the flow is usually laminar, so this region of Re values is called the region of a stable laminar flow regime. At Re>2320, the turbulent nature of the movement is most often observed. However, at 2320< Re <10000 the flow regime is unstable turbulent or transitional (mixed). Although turbulent motion is more likely under these conditions, laminar flow can sometimes be observed at these Re values. Only at Re>10000 does the turbulent motion become stable (developed).

6.2. The concept of "hydrodynamic similarity", similarity criteria.

The modern theory of modeling hydraulic machines and hydraulic structures is based on the theory of hydrodynamic similarity. The basic law of dynamic similarity established in1686. Newton in relation to moving fluid flows can be formulated as follows.

In dynamically similar flows, the acting forces at similar points in the flows must be in the same proportions. These ratios are called Newton's numbers in hydraulics. Two flows are considered geometrically similar if between their linear dimensions L and l, areas Ω and ω, volumes W and w, the following relations are observed:

$$\frac{L}{I}=\lambda \quad \frac{\Omega}{\omega}=\lambda^2 \quad \frac{W}{w}=\lambda^3 \, (6\text{-}2)$$

where λ - linear scale of modeling, showing how many times the size of the model is reduced compared to the real one.

If the flows are geometrically and dynamically similar, then they will also be kinematically similar, i.e. condition is met:

$$\frac{T}{t} = \tau \text{ (6-3)}$$

where τ -time simulation scale.

One of the conditions for dynamic similarity is the constancy of the relationship between the densities of the liquid in moving flows:

$$\frac{\rho_1}{\rho_2} = r \text{ (6-4)}$$

where: r - density scale;

ρ_1, ρ_2 are the liquid densities of the first and second flows.

If the mass of the first stream with volume W is denoted by M, and the mass of the second stream with volume w is denoted by m, then:

$\mathrm{M} = \rho_1 W$ and $m = \rho_2 w$.

or based on (6-2) and (6-4):

$$\frac{M}{m} = \frac{\rho_1 W}{\rho_2 w} = r\lambda \text{ (6-5)}$$

If the speed of the first stream is V, and the second - v, then:

$V = \frac{L}{T}$ and $v = \frac{l}{t}$.

Consequently,

$$\frac{V}{v} = \frac{\frac{L}{T}}{\frac{l}{t}} = \frac{Lt}{lT} = \frac{\lambda}{\tau} \text{ (6-6)}$$

If the acceleration of the first flow is U, and of the second - and, then:

$$U = \frac{L}{T^2} \text{ and } u = \frac{l}{t^2}$$

or $\frac{U}{u} = \frac{\frac{L}{T^2}}{\frac{l}{t^2}} = \frac{Lt^2}{T^2 l} = \frac{\lambda}{\tau^2}$ (6-7)

Let us now turn to modeling the forces acting on moving flows. Let's write:

S=MU; s=mu,

where S and s are the forces acting on the first and second flows, M and m are the masses, $U = \frac{L}{T^2}$ and $u = \frac{l}{t^2}$ - acceleration of the first and second flows.

Then:

$$S = \frac{\rho_1 WL}{T^2} = \frac{\rho_1 WL^2}{T^2 L} = \frac{\rho_1 WV^2}{L}$$

Let us determine the ratio of forces S and s

$$\frac{S}{s} = \frac{\rho_1 WV^2 l}{L\rho_2 wv^2} = \frac{\rho_1 L^2 V^2}{\rho_2 l^2 v^2}$$

$$\frac{W}{w} = \lambda^3 = \frac{L^3}{l^3}$$

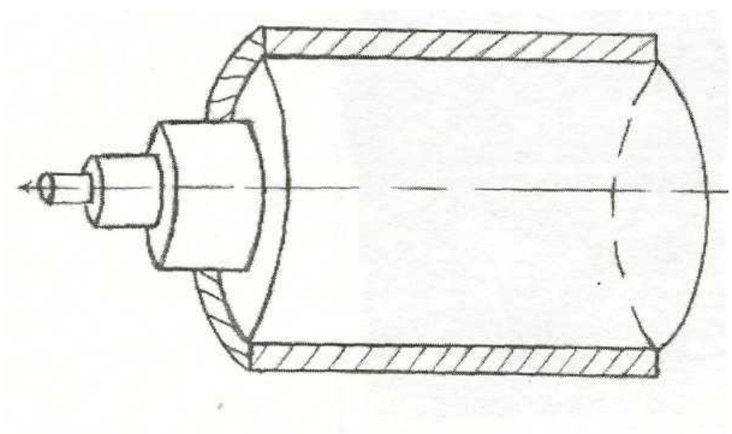
For dynamic similarity, the following condition must be met:

$$\frac{S}{s} = \frac{\rho_1 L^2 V^2}{\rho_2 l^2 v^2} = const \quad (6\text{-}8)$$

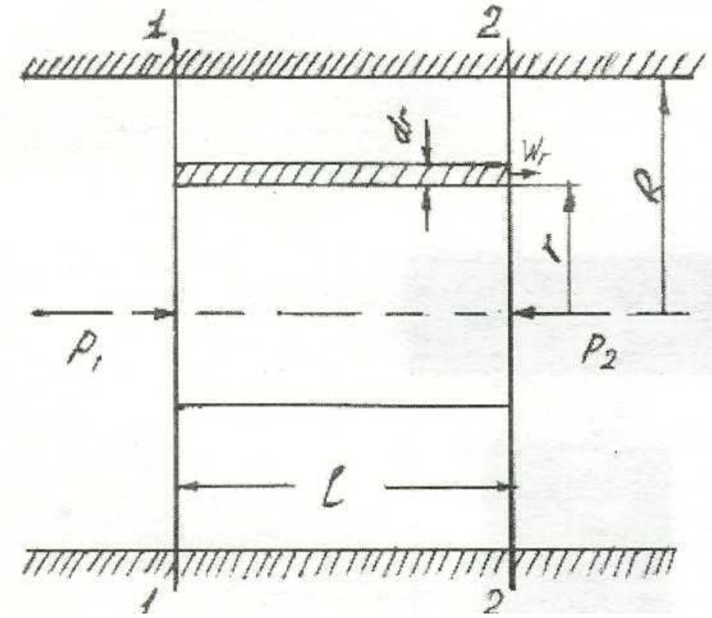
Equality (6-8) is a mathematical expression of the basic law of dynamic similarity.

6.3. Velocity distribution and fluid flow rate at steady laminar flow.

In the case of laminar motion of a viscous fluid in a straight pipe with a circular cross section, the entire fluid can be mentally divided into a number of annular layers coaxial with the pipe (Fig. 6.2, a).



Due to the action between the layers of friction forces, the layers will move at different speeds. The central cylindrical layer near the axis of the pipe has a maximum speed, but as you move away from the axis, the speed of the elementary annular layers will decrease. Directly at the wall, the liquid seems to “stick” to the wall, and its velocity vanishes here.



Let's single out a cylindrical layer with a length l and a radius r in a laminar flow moving through a pipe with a radius Re (Fig. 6.2, b).

The movement of the layer occurs under the action of the difference in pressure forces P1 and P2 on both end sides of the cylinder:

Fig.6..2 b

$$P1 - P2 = (p1 - p2)\pi r^2$$

where p1 and p2 are hydrostatic pressure in sections 1-1 and 2-2.

The movement of the cylinder is resisted by the internal friction force T, equal, according to the equation:

$$T = \mu F \frac{dw}{dn}$$

where: μ - coefficient of proportionality.

$$T = -\mu F \frac{dw_r}{dn}$$

where wr is the velocity of the fluid along the axis of the cylinder at a distance r from the axis; $F = 2\pi r l$ - the outer surface of the cylinder; μ is the viscosity of the liquid.

The minus sign indicates a decrease in velocity with increasing radius r (when r = R, the value wr = 0).

With steady motion, the difference in pressure forces P1, -P2 is spent on overcoming the friction force T, that is:

$$(p_1 - p_2)\pi r^2 = -\mu \pi r l \frac{dw}{dr},$$

whence, after reduction and separation of variables, we obtain:

$$\frac{p_1 - p_2}{2\mu l} r dr = -dw_r$$

Turning to the entire volume of liquid in the pipe, we integrate this differential equation, taking into account that the variable value of the radius on the left side of the equation varies from r to r = R, and the variable velocity on the right side - from w = wr to w = 0 (near the wall, where r = R).

$$\int_r^R \frac{p_1 - p_2}{2\mu l} r dr = -\int_{w_r}^0 dw_r$$

Then:

$$\frac{p_1 - p_2}{2\mu l} \cdot \left(\frac{R^2}{2} - \frac{r^2}{2} \right) = w_r,$$

or $w_r = \frac{p_1 - p_2}{4\mu l} \cdot \left(R^2 - r^2 \right)$(6-9)

The speed has a maximum value on the axis of the pipe, at $r = 0$:

$w_{max} = \frac{p_1 - p_2}{4\mu l} \cdot \left(R^2 \right)$(6-9a)

Comparing expressions (6-9) and (6-9a), we find:

$w_r = w_{max} \frac{R^2 - r^2}{R^2} = w_{max} (1 - \frac{r^2}{R^2})$ (6-10)

Equation (6-10) is Stokes' law, which expresses the parabolic distribution of velocities in the pipeline section during laminar motion.

To determine the fluid flow during laminar motion, consider an elementary annular section (Fig. 6.1, b) with an inner radius r and an outer radius (r + dr), whose area is dS = $2\pi rdr$. The volumetric flow rate of liquid through this section is:

$dVcek = wrdS = wr\, 2\pi\, rdr$

or taking into account equation (6-9a)

$$dV_{сек} = \frac{p_1 - p_2}{4\mu l}(R^2 - r^2)2\pi rdr$$

Integrating the last equation, we obtain the total fluid flow through the pipe:

$$V_{сек} = \frac{p_1 - p_2}{4\mu l}\int_0^R (R^2 - r^2)2\pi dr = \frac{p_1 - p_2}{4\mu l}(2\pi R^2 \int_0^R rdr - 2\pi \int_0^R r^3 dr) = \frac{p_1 - p_2}{8\mu l}\pi R^4 \quad (6\text{-}11)$$

Substituting instead of R the diameter of the pipe d = 2R and denoting (p1 - p2) =Δ R, we finally find:

$$Vcek = \frac{\pi d^4 \Delta p}{128\mu l} \quad (6\text{-}11a)$$

The equation (6-11) and (6-11a), which determines the flow rate of a liquid during its laminar movement along a round straight pipe, is called the Poisel equation.

Relationship between average speed w and maximum speed $w_{\max}$ can be obtained by matching the Vcek values from the equation:

$$Vcek = wS, \quad (6\text{-}11)$$

$$\text{Vcek} = \frac{p_1 - p_2}{4\mu l}\cdot\int_0^R (R^2 - r^2)2\pi\, rdr = \frac{p_1 - p_2}{4\mu l}\left(2\pi R^2 \int_0^R rdr - 2\pi \int_0^R r^3 dr\right) = \frac{p_1 - p_2}{8\mu l}\cdot(\pi R^4), \text{ or}$$

$$wS = \frac{p_1 - p_2}{8\mu l}\cdot(\pi R^4),$$

where

$$w = \frac{p_1 - p_2}{8\mu l}\cdot(R^2). \quad (6\text{-}12)$$

Comparing equations (6-9a) and (6-12), we find:

$$w = \frac{w_{\max}}{2}. \quad (6\text{-}13)$$

Thus, with laminar flow in a pipe, the average fluid velocity is equal to half the velocity along the axis of the pipe.

Accordingly, the parabolic law of velocity distribution over the pipe section, expressed by equation (6-13), can be represented as:

$$w_r = 2w\left(1 - \frac{r^2}{R^2}\right). \quad (6\text{-}13a)$$

6.4 Turbulent regime of fluid motion.

In industrial practice, the most common turbulent movement of fluids. During turbulent motion, due to the chaotic motion of particles, the velocities in the bulk of the flow are equalized and their distribution over the pipe section is characterized by a curve that differs in shape from the parabola in Fig. 6.3, a: the curve has a much wider peak (Fig. 6.3. b).

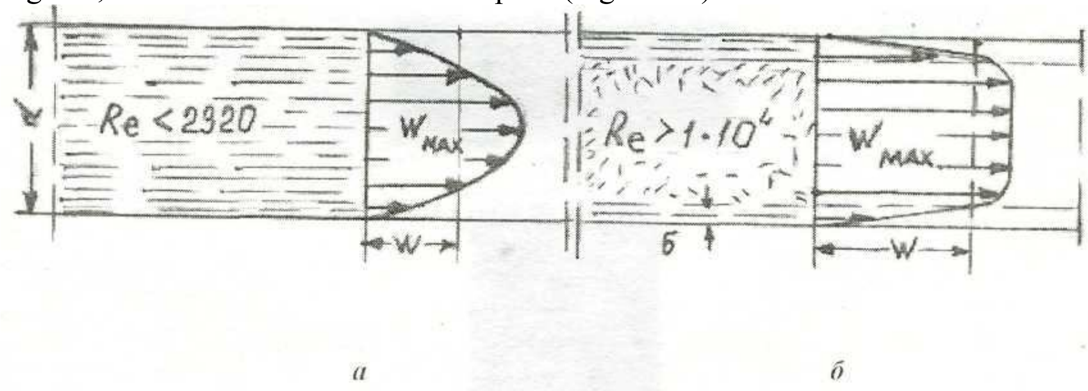


Fig.6.3.

Experience shows that the average speed w during turbulent motion is not equal to half the maximum (as for laminar motion), but is much greater than this value, moreover: w/wmax = *f* (Re). For example, at Re = 108 the value w ≈ *0.9 wmax.*

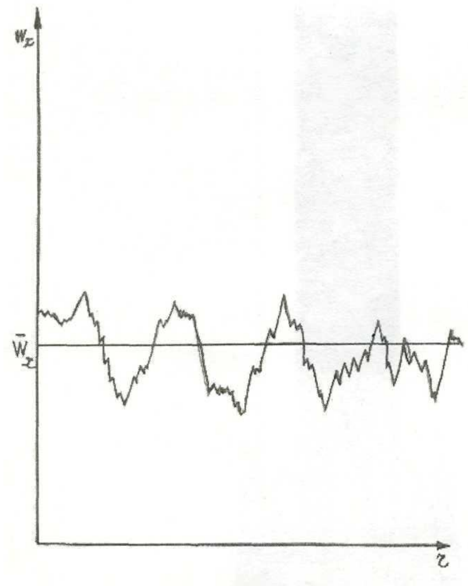
6.5 Pulsation and average flow velocity in turbulent fluid motion.

Due to the complex nature of the turbulent motion, it is not possible to strictly theoretically obtain the velocity distribution profile and the value of w/wmax. In addition, with a turbulent flow, the velocity profile (Fig. 6.3, b) expresses the distribution of not true, but time-averaged velocities.

At each point of a turbulent flow, the true velocity does not remain constant in time due to the randomness of the particle motion. Its instantaneous values experience fluctuations, or irregular pulsations, which are of a chaotic nature.

A typical picture of the change in the component of the true instantaneous speed w_x (along the flow axis) for some point depending on the time t is shown in Fig. 6.4. The true speed itself is almost impossible to measure due to the chaotic movement of particles in all directions. As can be seen from Figure 6.4, the velocities fluctuate around some time-averaged value, becoming either greater or less than it. For a given point, the time-averaged value and speed can be found from the relationship:

$$w_x = \frac{\int_0^{\tau} w_x d\tau}{\tau}.$$



Rice. 6.4

Thus, the value w_x is equal to the height of a rectangle equal to the area enclosed between the pulsation curve and the abscissa axis within the time change from 0 to τ (Fig. 6.4). The difference between the true and average speeds is called the instantaneous pulsation speed and denoted

$$w\text{-}wx = \Delta\, w. (6\text{-}15)$$

Test questions:

1. Explain laminar flow?
2. Explain turbulent motion?
3. What does the Reynolds number mean?
4. What is geometric similarity?
5. Explain similarity criteria.
6. What criteria can be met for hydrodynamic similarity two streams?
7. Velocity distribution over the cross section.
8. Give examples obeying the laws of a parabola.
9. Give the formula for the parabola law for the velocity distribution.
10. Explain the law of velocity distribution for turbulent driving mode.
11. Explain speed ripple.
12. What is the equivalent speed?

Key words:regime, flow, water level, laminar, density scale, area, fluctuation, or irregular pulsations, of the entire cross section of the pipeline.

Translated from Russian to English - www.onlinedoctranslator.com

Lecture 7

Head loss during fluid movement

Learning technology for lecture No. 7

Time - 2 hours	Number of students: 20-30 people
Form of the lesson	Introduction, visual lecture
Lesson Plan	1. Head loss during fluid movement. 2. The concept of smooth and rough pipes. 3. Types of local losses 4. Dependence of the local resistance coefficient on the Reynolds number 5. Generalization of pressure losses.
Purpose of the lesson: to acquaint students with the patterns of pressure loss in various cases, as well as the dependence of the local resistance coefficient on the Reynolds number.	
Tasks of the teacher: •describepressure loss in pipelines; • get acquainted with the conceptlocal resistance; •Summarize head losses; •Explain the dependence of the smaller coefficient of local resistance on the Reynolds number.	*Learning outcomes:* The student must learn: -pressure loss in pipelines; - local resistance; -head loss due to sudden expansion of flow; -dependence of the local resistance coefficient on the Reynolds number;
Means of education	Laser projector, visual materials, information support.
Forms of study	Collective, frontal work, work in pairs.
Conditions of education	An audience adapted to work with TCO.

Technological map of the lecture (7th lesson)

stages, time	Activity	
	teacher	**students**
Stage 1. Introduction (10 min.)	1.1.Informs the topic, purpose, planned results of the training session and the plan for its implementation.	1.1. Listen, write.
Stage 2. Basic (60 min.)	2.1.In order to update students' knowledge, asks focusing questions: - Whatreducing pressure in pipes? -Explain the roughness of pipe walls? - WhatReynolds number? Work in pairs to answer questions. Conducting a quiz. 2.3. Consistently presents the material of the lecture on the issues of the plan, uses visual materials. Gives the concept of smooth and rough pipes. How pressure loss occurs in pipelines. Focuses on the key points of the topic, offers to write them down	2.1. Listen. They take turns answering the questions. Listen to the correct answer. 2.3.Discuss schema content and tables, visual materials, clarify, ask questions. write down main.
3 stage. Closing (10 min.)	3.1.Conducting a quiz. Makes a final conclusion. Gives assignments for independent work. 3.2 Cluster the word "Pressure drop". Set ratings.	3.1. Reply to question. 3.2. Listen, write.

7.1. Pressure loss in pipelines.

Consider the basic formulas,used to determine head loss.

To do this, we turn to the main expression for the pressure loss atuniform motion:

$$h_{1-2} = \frac{\tau}{\gamma} \cdot \frac{L}{R}$$

If accepted, as suggested by Chezy on the basis of his experiences,back in 1775, the size $\frac{\tau}{\gamma}$ proportional to the square of the speed, with a proportionality factor $\left(\frac{1}{C}\right)^2$, then we get:

$h_{1-2} = \frac{v^2}{C^2} \cdot \frac{L}{R}$ (7-1)

Taking into account the fact that $\frac{h_{1-2}}{L}$ = i (where i is the hydraulic slope), from
The last expression yields the following formula for the velocity with uniform fluid motion:

$v=C\sqrt{Ri}$ (7-2)

commonly referred to as the Chezy formula.

Coefficient values*FROM* in the formula (7-2) are determined empirically; the dimension of this coefficient (i - dimensionless value) will be:

$$C = \frac{v}{\sqrt{Ri}} = \frac{[L]}{[T][L]^{\frac{1}{2}}} = \sqrt{\frac{[L]}{[T^2]}}$$

Therefore, the value*FROM* will have the dimension of acceleration.

For practical applications, however, it is more convenient to have the empirical coefficients dimensionless. To this end, subsequently the coefficient*FROM* was replaced by

$C = \sqrt{\frac{8g}{\lambda}}$,

where: λ -a dimensionless quantity, commonly referred to as the coefficient of hydraulic resistance.

Such a replacement allows formula (7-1) to be reduced to a very convenient, for practical use, form:

$$h_{1-2} = \lambda \frac{L}{4R} \cdot \frac{v^2}{2g} \quad (7\text{-}3)$$

Since for round pipes*4R-d,* then from here the so-called Darcy-Weisbach formula is obtained for determining the pressure loss with uniform fluid movement in round pipes:

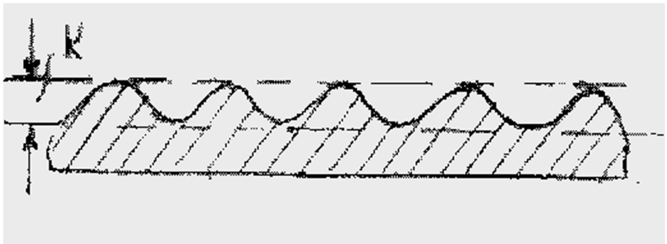
$h_{1-2} = \lambda \frac{L}{d} \cdot \frac{v^2}{2g}$(7-4)

Formulas (7-1) and (7-4) are the most common formulas for determining head loss; the first of them (7-1) is used mainly in the calculation of open flows, and the second (7-4) - pressure (in round pipes).

7.2. The concept of smooth and rough pipes.

Solid walls that restrict the flow of fluid always have a certain degree of roughness to some extent. Roughness is characterized by the size and shape of various, sometimes the smallest in size, protrusions and irregularities present on the walls, and depends on the material of the walls and their processing. Usually, over time, the roughness changes from the appearance of rust, corrosion, sedimentation, etc.

The main characteristic of roughness is the so-called "absolute roughness" - / s,



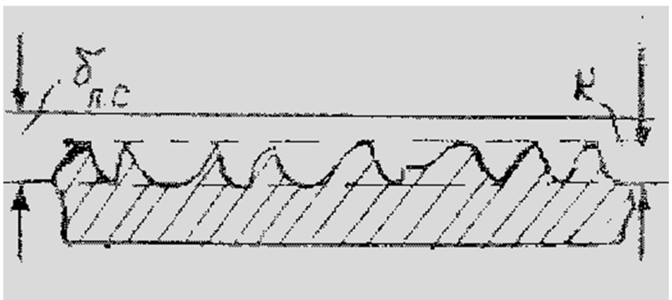
Rice. 7.1a

which is the average value of the indicated protrusions and irregularities, measured in linear units (Fig. 7.1, a).

Table 7.1. some values of the absoluteroughness for pipes made of various materials.

Table 7.1.

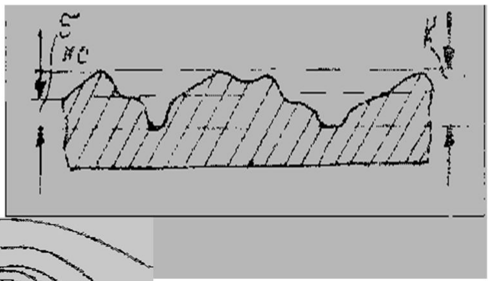
Pipes	k, mm
Clean, seamless drawn brass, copper and lead pipes New seamless drawn steel pipes Slightly corroded steel pipes New cast iron pipes Asbestos cement pipes Old steel pipes	0.01 0.05-0.15 0.2-0.3 0.3 0.03-0.8 0.5-2.0

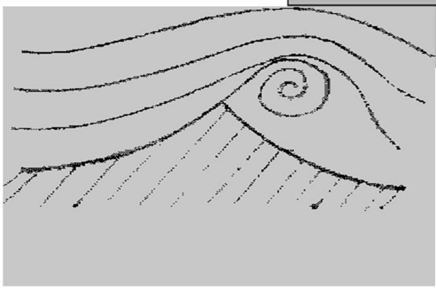


rice. 7.1.

Let (Fig. 7.1, b) the value of the roughness protrusions will be less,than the thickness of the laminar boundary layer. In this case, the wall irregularities will be completely immersed in this layer, the turbulent part of the flow will not come into direct contact with the walls and the movement of the fluid, and hence the energy loss, will not depend on the roughness of the walls, but will be determined by the properties of the fluid itself only such that they exceed the thickness of the boundary layer, wall irregularities will act as a turbulentnuyu area, increase the randomness of movement and in significantly influenceon the amount of loss.

Rice. 7.2.





Rice. 7.3.

In this case, each individual protrusion can be compared badlya streamlined body placed in a surrounding fluid flow and being a source of vortex formation (Fig. 7.3).

In accordance with what has been said, in hydraulics there aresurfaces are hydraulically smooth (k< δ_{ps}) and rough surfaces (k> δ_{ps}).Of course, such a division is arbitrary.

In fact, the thickness of the laminar boundary layer is not constant anddecreases with increasing Reynolds number. For walls that are hydraulically smooth from the beginning, with an increase in the Reynolds number, their roughness also begins to appear, since the boundary layer becomes thinner and the roughness protrusions, which were originally completely located in the boundary layer, begin to emerge from this layer, protruding into turbulent zone. Consequently, the same wall, depending on the value of the Reynolds number, can behave differently: in one case - as "smooth", in the other - as "rough". Therefore, "absolute roughness" cannot fully characterize the effect of walls on fluid motion. Naturally, walls with the same absolute roughness in flows of small transverse dimensions will have to introduce large perturbations into the fluid flow and show greater resistance to movement than in flows of large cross sections.

To characterize the effect of roughness on the value of hydraulic resistance, and also based on the conditions for observing similarity, the concept of “relative roughness” s is introduced in hydraulics, which is understood as a dimensionless ratio of absolute roughness tosome linear dimension characterizing the flow cross section in this way;

$$\varepsilon = \frac{k}{r} \quad (7\text{-}5)$$

In reality, however, as recent studies have shown, the value of hydraulic resistance is affected not only by the absolute value of the roughness (the height of the protrusions), but also to a large extent by their shape and density. It is practically impossible to take into account the influence of these factors by direct measurements of roughness.

7. 3. Loss of pressure with a sudden expansion of the flow.

With a suddenexpansion (Fig. 7.4), the head loss can be determined from the formula:

$$h_{MM} = \frac{(v_1 - v_2)^2}{2g}.$$

Bracketing the value v_2 we get:

$$h_{M.n.} = \left(\frac{F_2}{F_1} - 1\right)^2 \frac{v_2^2}{2g} = \zeta \frac{v_2^2}{2g}, \quad (7\text{-}7)$$

where $\zeta = \left(\frac{F_2}{F_1} - 1\right)^2$, *F1* and F2 - pipe sections before expansion and behind it.

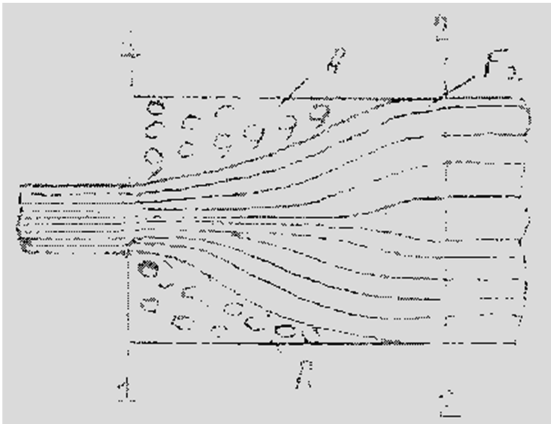


Fig.7.4.

Thus, formula (7-7) is reduced to a general form forexpressions of losses due to local resistance. Coefficient values ζ can be easily calculated in this case, based on the given pipe dimensions.

Head loss due to flow constriction.

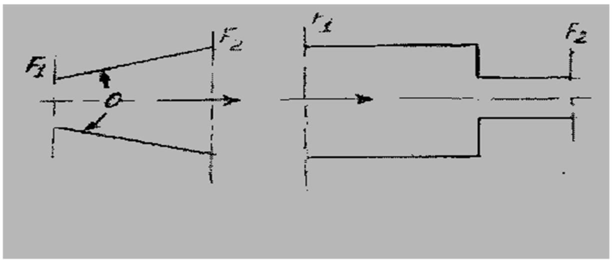
drag coefficient$Q$ at a sudden narrowing depends on the ratio $\frac{F_2}{F_1}$. The empirically determined values of this coefficient are contained in Table 7.2.

Table 7.2.

F2	0.01	0.1	0.2	0.4	0.6	0.8	1.00
	0.45	0.39	0.35	0.28	0.20	0.09	0.00

gradual narrowing (confusers-fig. 7.4). Coefficientresistance is found by the formula:

$$\zeta = \frac{\lambda}{8 \cdot \sin\frac{\alpha}{2}} \cdot \frac{n^2 - 1}{n^2} \quad (7\text{-}8)$$



Rice. 7.5.

7.4. Dependence of the coefficient of local resistance from the Reynolds number.

It has been established that the value of the coefficient of local resistancetivleniya ζ ,depends not only on the type of local resistance itself, but also on the nature of the fluid motion regime, i.e. from the Reynolds number Re.

Largest Changes with Reynolds Number*Re*coefficient C, undergoes in the area of laminar flow. For very small Reynolds numbers (Re<10), this coefficient is inversely proportional to Re:

$$\zeta = \frac{A}{\text{Re}}$$

For large values of the Reynolds number in the region of the laminar regime, the dependence of the local resistance coefficient on the Reynolds number has the form:

$$\zeta = \frac{B}{(\text{Re})^n}$$

A u B-coefficients depending on the type of local resistance.Approximately (according to F. P. Tovstoles), we can take the exponent n = 0.285. Then:

$$\zeta = \frac{B}{\text{Re}^{0,285}}$$

Coefficient valuesinthis formula for some special cases are given in table. 7.3.

Table 7.3.

Type of resistance	R
ball valve	48.8
Tee	32.5
Angle valve	21.7
Knee (rectangular)	16.3

A generalized formula, applicable both in laminar and turbulent regimes, is the formula of A.D. Altshulya:

$$\zeta = \frac{C}{\text{Re}} + \zeta_k$$

where: C-factor, depending on the type of local resistance;

ζ_k is the coefficient of local resistance in the quadratic region of the turbulent regime.

The values of the coefficients C and ζ_k are given in table 7.4

Table 7.4.

Type of resistance	FROM	

Elbow 90°	130	0.2
gate valve	400-2500	0.36-2.5
Cork faucet	150	0.40
Ordinary valve	3000	4.0
Angle valve	400	0.80
ball valve	500	1.6

For practical calculations, you can also use the Danfors graph (Fig. 7.5), which shows the equivalent lengths as a function of the Reynolds number*L*,some local resistances, expressed in pipe diameters.

It has been established that at*turbulent mode* changes in the coefficient of local resistance ζ ,depending on the Reynolds number are so insignificant that it is quite possible to neglect them. Therefore, in practical calculations in the turbulent regime, this coefficient is considered to depend only on the nature and design of local resistance.

7.5.Head loss summary.

In many cases, when movingliquids, both loss of pressure due to friction along the length and local loss of pressure take place simultaneously. The total head loss is defined in these cases as the arithmetic sum of all types of losses.

Therefore, for example, the total pressure loss in a pipeline with a length*L*, diameter d, having n local resistances, will be:

$$h_{1-2} = h_{л.п.} + \sum h_{M.п.} = \lambda \frac{Lv^2}{d2g} + \sum_{i=1}^{i=n} \zeta_i \frac{v^2}{2g}$$

$$h_{1-2} = (\lambda \frac{Lv^2}{d2g} + \sum_{i=1}^{i=n} \zeta_i) \frac{v^2}{2g}$$

The expression in brackets is called the drag coefficient of the system and is denoted as follows:

$$h_{1-2} = \lambda \frac{Lv^2}{d2g} + \sum_{i=1}^{i=n} \zeta_i \frac{v^2}{2g}$$

It is also possible to replace local resistances with equivalent lengths; in the case under consideration, the equivalent length corresponding to all local resistances will be:

$$L = \frac{d}{\lambda} \sum_{i=1}^{i=n} \zeta_i$$

Then, denoting L + Lp - Ln, you can determine the amount of losses according to the Darcy-Weisbach formula, introducing into it instead of the actual length of the pipeline L the so-called reduced length Ln. In this way,

$$h_{1-2} = \lambda \frac{L_n}{d} \cdot v^2 / 2g \quad (7\text{-}9)$$

If the pipeline consists of several sections with a length*L1, L2...., Lk,*different diameters d1, d2, ..., dk with n local resistances, the total head loss is found similarly to the previous one:

$$h_{1-2} = \sum_{i=1}^{i=k} h_{л.п.i.} + \sum_{i=n}^{i=n} h_{M.g.i}$$

$$\sum_{i=1}^{i=k} h_{k.g.c} = \lambda_1 \frac{L_1 v_1^2}{d_1 2g} \; h_{1-2} = \lambda \frac{L_2 v_2^2}{d_2 2g} + \lambda_k \frac{L_k v_k^2}{d_k 2g}$$

$\lambda_1 \lambda_2 ......\lambda_k, \zeta_1 \zeta_2 \zeta_3, v_1, v_2, v_k$ ~drag coefficients and average velocities for individual sections.

To simplify calculations, it often turns out to be appropriate to express all speeds in terms of some one "basic" speed on some
"main" section of the pipeline, which is chosen completely arbitrarily depending on the convenience of the solution and the conditions of the problem. Let us assume that such a site is the first one. Then from the equation of constancy of flow:

$$v_1 F = v_2 F_2 \; =,.... = v_k F_k$$

we get: $v_2 = v_1 F_1 / F_2,.... v_k = v_1 F_1 / F_k$

Substituting these values into expressions (*b*) and (c), and the latter - into the general equation for the total pressure loss (a), after transformations we find:

$$h_{1-2} = [\; \lambda_1 \frac{L_1}{d_1} + \lambda_2 \frac{L_2}{d_2} \left(\frac{F_1}{F_2} \right)^2 + \lambda_k \frac{L_k}{d_k} \left(\frac{F_1}{F^2} \right)^2 + \zeta_1 + \zeta_2 \left(\frac{F_1}{F_2} \right)^2 + ...+ \zeta_n \left(\frac{F}{F} \right)^2 \frac{v_1^2}{2g}$$

or - (system resistance coefficient) is indicated by the expression in square brackets).

When summing the losses, it is necessary to check whether the individual local resistances influence each other; this effect will not be if the resistances are located at a sufficiently large distance between them (equal to*20d*up to 50 d, depending on the type of local resistance).

Test questions:

1. Causes of pressure drop in pipes.
2. Pressure loss along the length of the pipeline.
3. Explain the roughness of the pipe walls.
4. The concept of smooth hydraulic pipes.
5. Local hydraulic resistance. Their main types.
6. Pressure loss during expansion of pipelines.
7. Head loss summary.
8. Explain the dependence of the smaller local resistance coefficient on the Reynolds number.
9. Explain the dependence of the larger local resistance coefficient on the Reynolds number.

Key words:head loss, in pipelines, for smooth and rough pipes, local losses, Reynolds numbers, at flow constriction, coefficient,value, local resistance.

Lecture 8

Hydraulic calculation of pipelines.

Learning technology for lecture No. 8

Time - 2 hours	Number of students: 20-30 people
Form of the lesson	Introduction, visual lecture
Lesson Plan	1. Hydraulic calculation of pipelines. 2. Series and parallel connection of pipelines. 3. Water hammer in pipes. 4. Zhukovsky's theory of hydraulic shock. 5. Methods for reducing water hammer.
Purpose of the lesson: teach students to do hydraulic calculation of pipelinesin various modes of motion, familiarize with the series and parallel connection of pipelines.	
Tasks of the teacher: • teach to calculatehydraulic calculations of pipelines; • Familiarize yourself withZhukovsky's hydraulic shock theories; •Summarize head losses; •Explainwater hammer reduction methods.	*Learning outcomes:* The student must learn: -hydraulic calculation of pipelines; - serial and parallel connection of pipelines; -water hammer in pipes; -Zhukovsky's theory of hydraulic shock -water hammer reduction methods;
Means of education	Laser projector, visual materials, information support.
Forms of study	Collective, frontal work, work in pairs. graphorganizers
Conditions of education	An audience adapted to work with TCO.

Technological map of the lecture (8th lesson)

stages, time	Activity	
	teacher	**students**
Stage 1. Introduction (10 min.)	1.1.Informs the topic, purpose, planned results of the training session and the plan for its implementation.	1.1. Listen, write.
Stage 2. Basic (60 min.)	2.1.In order to update students' knowledge, asks focusing questions: -Explain long and short pipes? -What is water hammer in pipes? - Whatserial and parallel connections? Work in pairs to answer questions. Conducting a quiz. 2.3. Consistently presents the material of the lecture on the issues of the plan, uses visual materials. Explains how the hydraulic calculation of pipelines is performed. Defines hydraulic shock. Familiarize yourself with methods to reduce water hammer. Focuses on the key points of the topic, offers to write them down	2.1. Listen. They take turns answering the questions. Listen to the correct answer. 2.3.Discuss schema content and tables, visual materials, clarify, ask questions. write down main.
3 stage. Closing (10 min.)	3.1.Conducting a quiz. Makes a final conclusion. Gives assignments for independent work. 3.2 Cluster the word "Hydraulic shock". Set ratings.	3.1. Reply to question. 3.2. Listen, write.

8.1 Hydraulic calculation of pipelines.

Examples of hydraulic calculation of simple pipelines in turbulent traffic conditions.

In the hydraulic calculation of simple pipelines, the pipeline length L is usually known. The roughness coefficient n is taken according to the data in Table. 8.1. Considering the basic calculation formula:

$$h_w = a\frac{LQ^2}{d^5}$$

note that under the conditions of a turbulent motion regime for given *L and n*it connects three quantities hW, d and Q. Therefore, to obtain certain solutions, it is necessary to specify two of them, or know them in advance.

In practice, it is necessary to determine: .

1) consumption Q in a pipeline of length L: the diameter of the pipeline d and the pressure loss in it hW are given;
2)head loss in a pipeline having a length L : the flow rate is given pipeline Q and its diameter d;
3)the required diameter of a pipeline having a length L to pass a given flow rate Q : the head loss hW is also given.

Example 1 (Uginchus). Water from the water tower is supplied to the plant through a pipeline of length L =3.5 km,diameter d =300 mm.Determine the flow rate of the pipeline, if the mark of the earth at the installation site. Determine the flow rate of the pipeline, if the ground elevation at the tower installation site is z = 130.0 m, the distance from the ground to the water level in the tower is H = 170.0, whether the ground elevation at the plant is z3 =110.0 m.Required water pressure at the plant Hsv =25.0 m (Fig. 8.1).

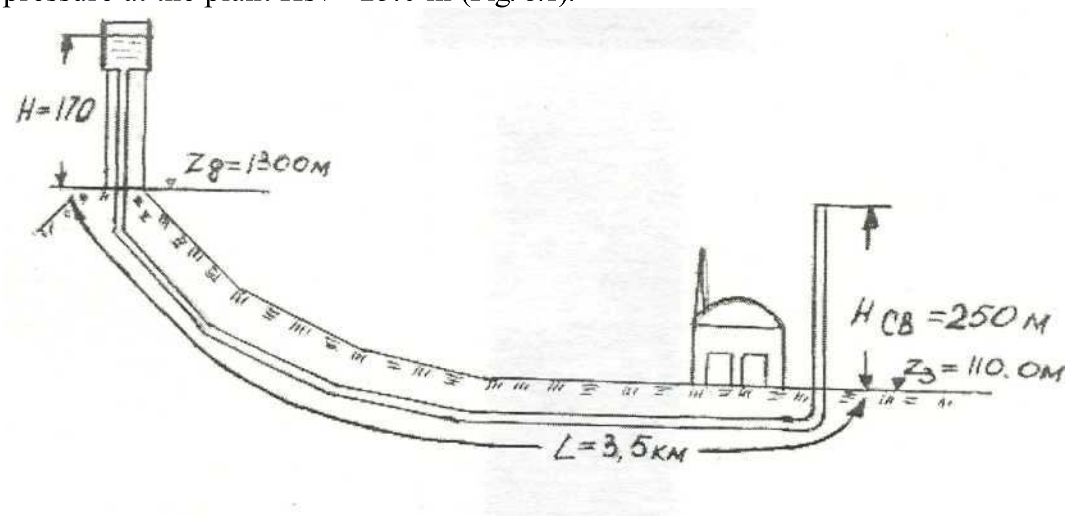


Fig.8.1

Table 8.1

Values of quantities: C, λ, a, K and b ($b = \frac{a}{d^5} = \frac{h_H}{LQ^2}$) for round pipes, calculated by the full formula Acad. N.N. Pavlovsky at n = 0.012.

d,m	FROM	λ	a	K, m3/sec2	b
0.050	44.79	0.0391	0.00323	0.00987	10340.0
0.075	47,45	0.0349	0.00288	0.0287	1214.0
0.100	49.46	0.0321	0.00265	0.0614	265.0
0.125	51.07	0.0301	0.00249	0.111	81.60
0.150	52.42	0.0286	0.00236	0.179	31.18
0.200	54.62	0.0263	0.00217	0.384	6,78
0.250	56.40	0.0247	0.00204	0.692	2,,11
0.300	57,90	0.0234	0.00193	1,121	0.794
0.350	59.18	0.0224	0.00185	1.684	0.354
0.400	6031	0.0216	0.00178	2.397	0.174
0.450	61.35	0.0209	0.00172	4.259	0.0932
0.500	62.28	0.0202	0.00167	4.324	0.0532
0.600	63.91	0.0192	0.00159	6.999	0.0204
0.700	65.32	0.0184	0.00152	10.517	0.00904
0.800	66,58	0.0177	0.00146	14.965	0.00495
0.900	67,70	0.0171	0.00141	20.430	0.00239
1,000	68,72	0.0166	0.00137	26.485	0.00137

According to the table (8.1) for n = 0.012 and d =300 mm we find the flow characteristic K \u003d 1, 121 m3 / s.

The consumption is determined by the formula:

$$Q = K\sqrt{\frac{h_H}{L}} = K\sqrt{\frac{z_б + H - (z_3 + H_{св})}{L}} = 1.121\sqrt{\frac{130.0+17.0-(110.0+25.0)}{3500}} = 0.0656 м^3/сек = 65{,}6 л/сек$$

Solving problems without the help of tables.

In the absence of tables of values $b = \frac{1}{K^2} = f(d)$ and a= f1(d) the main tasks of hydraulic calculation of a simple pipeline are solved as follows:

1. Determination of pipeline flow rate Q for given L, d and hw

According to the formula $a = \frac{64n^2}{\pi^2 (\frac{d}{4})^2}$ it is necessary to calculate the coefficient resistance a at a given roughness coefficient n and then determine the flow rate from the dependence:

$$Q = \sqrt{\frac{h_W d^5}{aL}}.$$

2. Determining head loss h_w ***given: L, Q and d***

Having determined the drag coefficient a by the formula

$$a = \frac{64n^2}{\pi^2 (\frac{d}{4})^{2y}}$$

we calculate the head loss according to the formula:

$$h_w = a\frac{LQ^2}{d^5}$$

3. Determination of the required pipeline diameter d for given: *L, Q and hw*

In this case, it is necessary to calculate the value of the known quantity:

$$\frac{a}{d^5} = \frac{h_W}{LQ^5}$$

Then, given different diameters of the pipeline, we determine for each of them the values $\frac{a}{d^5}$ and build a graph $\frac{a}{d^5} = f(d)$ .According to the given graph and the known value $\frac{a}{d^5} = \frac{h_W}{Q^2}$ find the desired diameter.

Examples of hydraulic calculation of simple pipelines under laminar flow conditions.

To perform hydraulic calculations, it is first necessary to set the value of the drag coefficient a in the main calculation formula:

$$h_W = a\frac{LQ^2}{d^5}.$$

Where

$$a = \frac{8A\nu\pi d^2}{\upsilon dg\pi^2}$$

The drag coefficient can be represented in another form replacing ν through $\frac{4Q}{\pi d^2}$, then:

$$a = \frac{8A\nu\pi d^2}{4Qdg\pi^2} = \frac{2A\nu d}{Qg\pi} \quad (8.1)$$

Let's consider the solution of some problems.

1. Determination of pipeline flow rate Q for given L, d and h_W

From the main calculation formula $h_W = a\frac{LQ^2}{d^5}$ determine the flow rate of the pipeline: $Q\sqrt{a} = \sqrt{\frac{h_W d^5}{L}}$. Let us replace the resistance coefficient a with its value according to the dependence:

$$Q\sqrt{\frac{2A\nu d}{Qd\pi}} = \sqrt{\frac{h_W d^5}{L}}.$$

where we get the expression for the flow:

$$Q = \frac{h_W d^4 g\pi}{2LA\nu} \quad (8.2)$$

2. Determination of head loss hw for given: L, Q and d

Since the speed v in this case is known, then. having determined the resistance coefficient a according to the formula (8.1), we find the pressure loss from the dependence:

$$h_W = a\frac{LQ^2}{d^5}$$

3. Determination of the pipeline diameter d given: L, Q and hw

To solve this problem, we use the dependency:

$$\frac{a}{d^5} = \frac{h_W}{LQ^5}$$

Let us replace the drag coefficient in it a according to equality (8.1):

aboutwe get here $\frac{2A\nu d}{Qd^5 g\pi} = \frac{h_W}{LQ^2}$

$$d = \sqrt[4]{\frac{2A\nu LQ}{g\pi h_W}} \quad (8.3)$$

8.2. Serial connection of pipelines.

Let us assume that the pipeline consists of several series-connected pipes of different diameters with separate local resistances and outlets at nodes 1, 2, 3 - quz1, quz2, quz3 (Fig. 8.2). If local resistance raceslaid along the length of the pipeline at a sufficient distance from each other, then the pressure loss along its entire length can be determined by a simple sumrationing of losses in separate sections. Head loss is calculated fromespecially for sections of the conduit with constant diameters and flow rates, because water is drained only at the nodes. Then the total head loss will be:

$$\sum h_W = H = h_{W1} + h_{W2} + ... + h_{Wn} = \sum Q_i A_i l_i \quad (8.4)$$

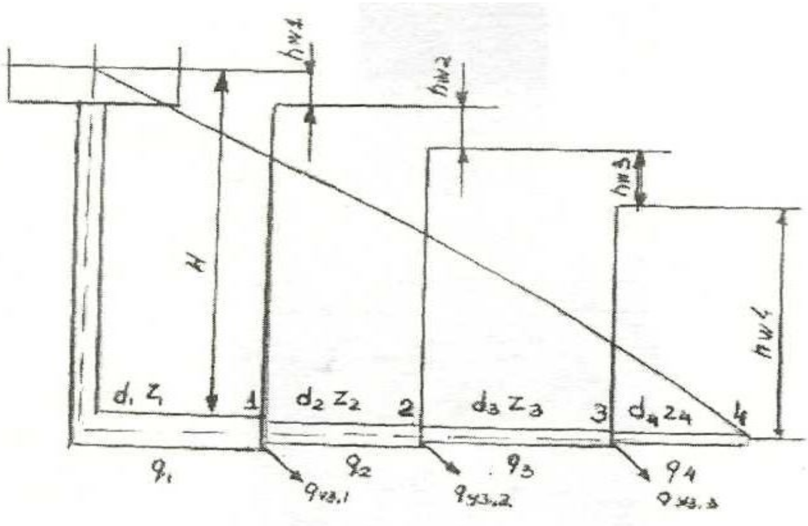
where: $h_{W\,i}$- pressure loss in separate sections; Qi - expenses; Ai - resistivity.

Dependence (8.4) is applicable in the case of passing a transit flow that does not change along the entire length of the pipeline.

For a simple pipeline without branches, the flow rate Q is expressed as:

$$Q = \sqrt{\frac{H}{\sum l_i A_i}} = \Pi_n \sqrt{H} \quad (8.5)$$

where: $\Pi_n = \sqrt{\frac{1}{\sum l_i A_i}} = (\sum l_i A_i)^{-\frac{1}{2}}$.



Rice. 8.2.

Serial connection of pipes.

With a series connection of resistance pipes on separatesections of the pipeline in all cases can be folded. The piezometric curve (without taking into account local resistances) with a series connection of pipes of different diameters has the form of a broken line (Fig. 8.2).

Parallel connection of pipelines.

Special caseend system of the water supply network (Fig. 8.3), when in practice it turns out, as it were, a parallel connection of a series of simple pipelines, i.e. flow is passed through several separate lines, can also be attributed tosimple pipelines. For each line of such a network, the pressure difference at the end points A and B must be the same. The distribution of flow between pipelines should be proportional to their throughput. For the pipeline in fig. 8.3 we get a system of equations:

$$H_1 - H_2 = q_2^2 A_1 l_1 k_{n1}$$
$$H_1 - H_2 = q_2^2 A_2 l_2 k_{n2}$$
$$\ldots\ldots\ldots\ldots\ldots\ldots$$
$$H_1 - H_2 = q_n^2 A_n l_n k_{nn}$$

$$(A_1 l_1 k_{n1})^{-\frac{1}{2}} \sqrt{H_1 - H_2} = q_1$$
Or $(A_2 l_2 k_{n2})^{-\frac{1}{2}} \sqrt{H_1 - H_2} = q_2$
$$(A_n l_n k_{nn})^{-\frac{1}{2}} \sqrt{H_1 - H_2} = q_n$$

The total flow passing through the initial section of the pipeline is determined by:

$$q_H = q_1 + q_2 + \ldots + q_n =$$
$$\sqrt{H_1 - H_2}\left[(A_1 l_1 k_{n1})^{-\frac{1}{2}} + (A_2 l_2 k_{n2})^{-\frac{1}{2}} + \ldots + (A_n l_n k_{nn})^{-\frac{1}{2}}\right] = (8.6)$$
$$= \sqrt{H_1 - H_2} \sum (A_n l_n k_{ni})^{-\frac{1}{2}}$$

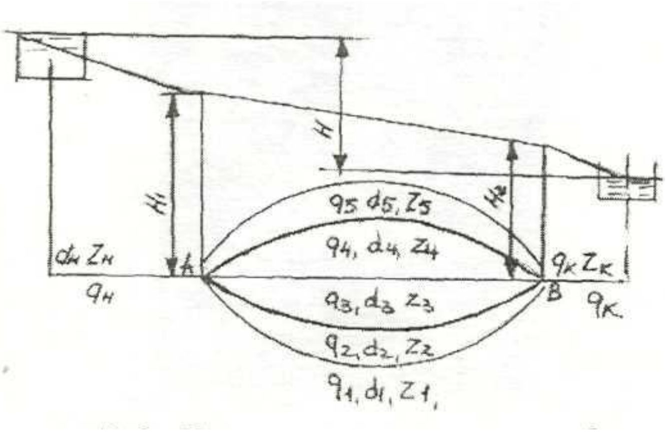


Fig.8.3

Therefore, when pipes are connected in parallel, in order to obtain the total conductivity of the entire system, it is necessary to add the conductivities of its individual elements, i.e. define $\sum(A_n l_n k_{ni})^{-\frac{1}{2}}$.

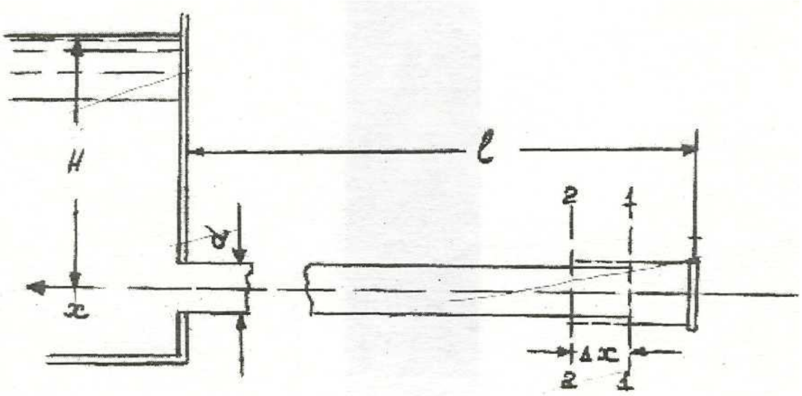
8.3. Water hammer in pipes.

Water hammer is a sudden change in pressure in a penstock due to a sudden change in fluid velocity over time.

Let us assume that liquid is moving in the pressure pipeline. Let us suddenly stop its movement by closing the valve. As a result of stopping the movement, there will be a sharp increase in pressure in the pipe due to the transition of the kinetic energy of the stopped fluid layers into the potential energy of the compressed fluid. In this case, first of all, the pressure will increase directly at the valve after stopping the first layers of liquid. Then, as successive layers stop, the pressure increase will rapidly propagate up the pipeline, creating a pressure wave. An increase in pressure, propagating through the pipeline at high speed, causes compression of the liquid and expansion of the pipe walls. The specified elastic deformation of the pipe occurs at the rate of propagation of the pressure increase along the lengthnot pipes. Distribution speedelastic deformationtions is called the velocity of propagation of the shock wave.

8.4. Zhukovsky's theory of hydraulic shock.

For the first time, the phenomenon of hydraulic shock was experimentally and theoretically studied by the famous Russian scientist, prof. NOT. Zhukovsky, who1898. created the theory of water hammer, which is the main theory of all research in this area. When deriving the main dependences of the hydraulic shock, Zhukovsky used the momentum theorem.



Let us consider a certain layer (compartment) of a stopped fluid, in the area of which there was an increase in pressure and expansion of the pipe walls. Suppose that during the time Δt between sections with 1-1 and 2-2 on the length Δxexpansion of the pipe walls. Let us denote the velocity of propagation of elastic deformations (velocity of propagation of the shock wave) through c. Then: $\Delta x = c\Delta t$.

Let us assume that before the expansion, the volume of liquid between the sections is under pressure p. In this case, the mass of the compartment is:

$$m = p\omega\Delta x = \frac{\gamma}{g}\omega\Delta x \ (8.7)$$

When the expansion of the pipe walls ended, the pressure reached the value p' = p + Δp, the volumetric weight of the liquid increased to y' = y + Δy and the free section area to γ' = γ + Δγ . This means that the mass of liquid in the compartment has increased

$$m^{/} = m + \Delta m = \frac{\gamma+\Delta\gamma}{g}(\omega + \Delta\omega) * \Delta x$$

Thus, the increase in mass is:

$$\Delta m = m^{/} - m = \frac{\gamma+\Delta\gamma}{g}(\omega + \Delta\omega) * \Delta x - \frac{\gamma}{g}\omega\Delta x =$$
$$= \frac{\Delta x}{g}(\gamma\omega + \gamma\Delta\omega + \omega\Delta\gamma + \Delta\gamma\omega - \gamma\omega).$$

Neglecting the product of infinitesimal values ΔyΔω, we finally obtain:

$$\Delta m = \frac{\gamma}{g}\omega\Delta x\left(\frac{\Delta}{\gamma} + \frac{\Delta\omega}{\omega}\right) = m\left(\frac{\Delta\gamma}{\gamma} + \frac{\Delta\omega}{\omega}\right).$$

Let's apply to the mass of fluid in the compartment between sections 1-1 and 2-2, the momentum theorem. The projection of the change in the momentum of the fluid mass on the x axis (if we neglect very small changes in the values of y and ω) will be equal to:

$$-m\Delta v = -\frac{\gamma}{g}\omega\Delta x\Delta v = -\frac{\gamma}{g}\omega c\Delta t\Delta v. \ (8.8)$$

The projection of the impulse of the pressure forces for the same time is equal to:

$$(\omega + \Delta\omega) * (p + \Delta p) * \Delta t - \omega p\Delta t = (\omega p + \omega\Delta p + p\Delta\omega + \Delta p\Delta\omega - \omega p)\Delta t$$

Neglecting the infinitely small value ΔpΔω, as well as the expression pΔω, which is small compared to the value ωΔp, we obtain:

$$\omega\Delta p\Delta t = -\tfrac{\gamma}{g}\omega c\Delta t\Delta v \quad (8.9)$$

or

$$\frac{\Delta p}{\gamma} = -\frac{c\Delta v}{g} \cdot \quad (8.10)$$

By equating dependencies, $\frac{\Delta m}{m} = \Delta p(\frac{1}{E_0} - \frac{d}{E\delta})$ and $\frac{\Delta m}{m} = -\frac{\Delta v \Delta t}{c\Delta t} = -\frac{\Delta v}{c}$ we get:

$$\Delta p = (\tfrac{1}{E_0} - \tfrac{d}{E\delta}) = -\tfrac{\Delta v}{c} \cdot (8.10/)$$

We multiply this dependence by equation (8.10)

$$\frac{\Delta v \Delta p}{c\gamma} = -\frac{\Delta p c \Delta v}{g}\left(\frac{1}{E_0} + \frac{d}{E\delta}\right) = -\frac{\Delta v}{c},$$

or

$$c = \frac{\frac{g}{\gamma}}{\frac{1}{E_0} + \frac{d}{E_0}} = \frac{\frac{E_0 g}{\gamma}}{1 + \frac{E_0 d}{E\delta}}.$$

Extracting the square root from the last expression, we obtain the well-known formula N.E. Zhukovsky for the velocity of propagation of the shock wave:

$$c = \frac{\sqrt{\frac{E_0 g}{\gamma}}}{1 + \frac{E_0 d}{E\delta}} \quad (8.11)$$

Expression $\sqrt{\frac{E_0 g}{\gamma}}$ is the rate of propagation of elastic deformations in a liquid with density ρ and elastic modulus Eo. For water:

$$c = \sqrt{\frac{E_0 g}{\gamma}} = 1425 м/сек$$

Therefore, for the case when water moves through the pipeline, formula (8.11) gets the following expression:

$$c = \frac{1425}{1 + \frac{E_0 d}{E\delta}} \quad (8.12)$$

Let us determine the magnitude of the pressure that occurs during hydraulic shock, according to expression (8.10), in which the values of Δp and Δv - replace them with differentials:

$$\frac{dp}{\gamma} = \frac{cdv}{g};\ dp = -\frac{\gamma}{g} cdv.$$

Integrating this expression, we get:

$$p - p_0 = -\frac{\gamma}{g} c(v - v_0) \quad (8.13)$$

where: p_0 *and vo* are the pressures and velocities corresponding to the initial moment before impact. From formula (8.13) it follows that the maximum pressure during hydraulic shock takes place in the case of a decrease in the fluid velocity to zero, i.e. for v = 0:

$$p - p_0 = \rho v_0 c \quad (8.14)$$

The resulting formula (8.14) is the well-known Zhukovsky formula for determining the maximum pressure during hydraulic shock.

8.5 Water hammer reduction methods.

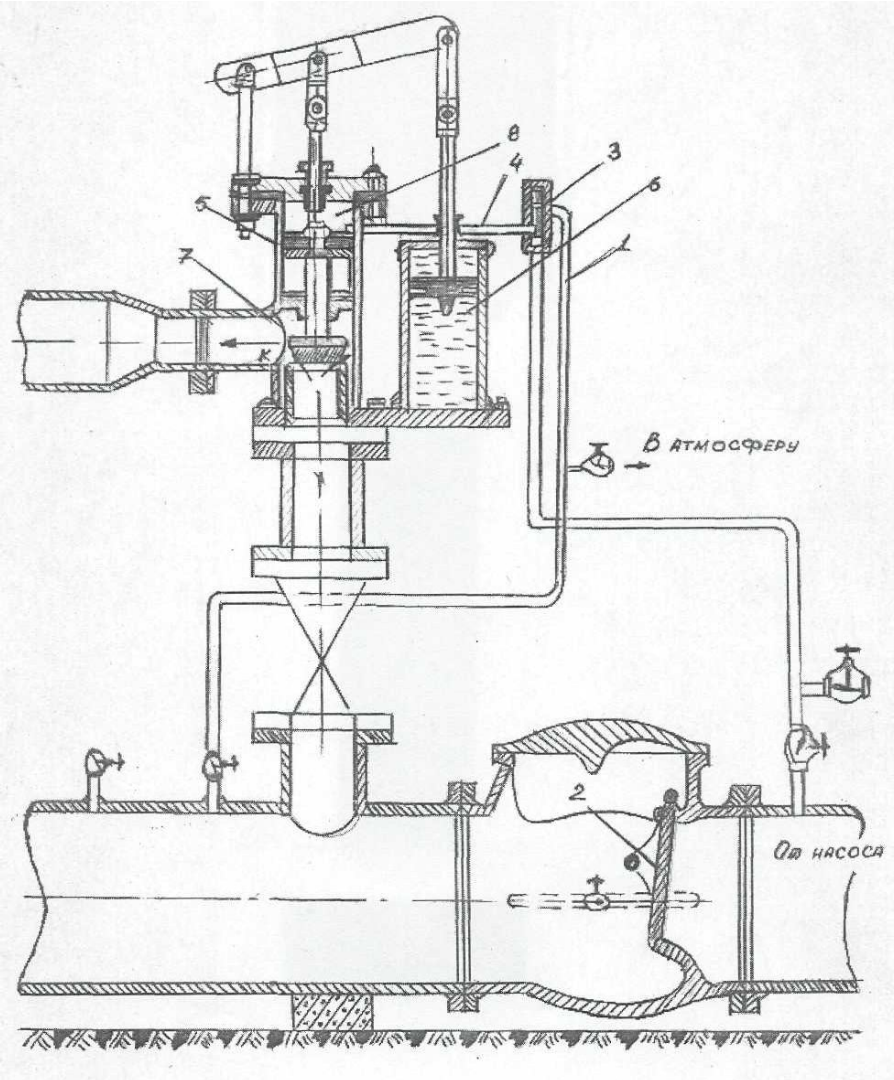
Since the high pressures that occur during water hammer are dangerous to the integrity of the pipes, there are many methods to deal with water hammer. For example, the magnitude of the pressure during water hammer can be significantly reduced by slowly closing the pipeline. In this case, the pressure value is determined by the following approximate formula:

$$p = \rho v_э c \frac{T}{T_э}, \quad (8.15)$$

Where T is the duration of the impact phase; Te is the closing time.

Water hammer can result from causes that cannot be controlled. So, for example, a sudden interruption in the supply of energy to pumps included in the pressurized water supply system causes water hammer, because. after a sudden stop of the pump, the movement in the water supply system drops sharply compared to the working one, and then quickly increases to a shock value. Currently, special hydraulic shock absorbers are used, which automatically open when the pressure rises or falls against the normal one, and discharges part of the water from the pipeline, thereby lowering the pressure. Let us consider an automatic hydraulic shock absorber of the Ukrvodgeo system designed by V.M. Papin, which is installed on the conduit after the return channel.

The principle of operation of the damper (Fig. 8.6) is based on the fact that during normal operation of the conduit, the damper is closed, because the working pressure transmitted through tubes 1 and 4 and the distributor in 3 in the piston space of the damper 8 presses the valve down. The same pressure acts on the valve*To*from below, but since the area of the valve is less than the area of piston 5, the absorber is in the closed state.



Rice. 8.6

When the pump is suddenly turned off, the pressure in the conduit drops to the check valve and the latter closes. The pressure also drops in the above piston space 8. The pressure after the check valve first drops, and then, as a result of a hydraulic shock, begins to rise. The rising pressure opens the valve K and connects the conduit to the discharge pipe 7. As a result, the pressure cannot rise above a predetermined value (usually operating and static pressure), and the shock is eliminated. Then the pistons of the distributor move to the lower position, and above the piston space of the absorber is connected to the conduit after the check valve. The pressure of the conduit is transferred to the damper piston, and the damper begins to close slowly. Speed is controlled by oil brake 6.

After closing the damper and starting the pumps, the distributor switches back to the upper position, and the damper is again ready for action.

Test questions:

1. How is the hydraulic calculation of pipelines made?
2. Explain long and short pipes.
3. Explain complex and simple pipes.
4. Give the equation for calculating simple hydraulic pipes.
5. Calculation of pipes in series connection.
6. Calculation of pipes with parallel connection.
7. The concept of hydraulic shock in pipes?
8. What is Zhukovsky's theory of hydraulic shock?

Key words:hydraulic calculation of pipelines, hydraulic calculation of simple pipelines under laminar flow conditions; serial and parallel,head loss, roughness coefficient, pipeline diameter, liquid volume, elastic deformation propagation rate.

Lecture 9

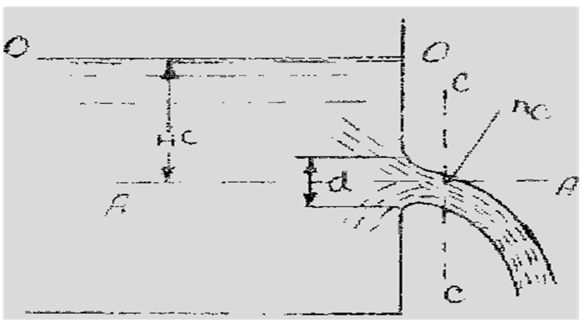
Flow of liquid through a small round hole and nozzles

Learning technology for lecture No. 9

Time - 2 hours	Number of students: 20-30 people
Form of the lesson	Introduction, visual lecture
Lesson Plan	1. The flow of liquid through a small round hole and nozzles. a) compressibility b) velocity and fluid flow rates c) fluid outflow at variable pressure 2. Weirs 3. Classification of holes and the main characteristics of the outflow of liquid.
Purpose of the lesson: to familiarize students with how expiration occursliquids through holes, what is the classification of holes through which fluid flows out, and also with the main characteristics of fluid outflow.	
Tasks of the teacher: • get acquainted with the types of nozzles; • acquaint withcompressibility, velocity and fluid flow rate; •explainclassification of holes and the main characteristics of the outflow of liquid; •Fluid outflow at variable impact pressure;	*Learning outcomes:* The student must learn: - the outflow of liquid through a small round hole and nozzles; -fluid flow through cylindrical nozzles; - classification of holes and the main characteristics of the outflow of liquid; - outflow of fluid at variable pressure. strike;
Means of education	Laser projector, visual materials, information support.
Forms of study	Collective, frontal work, work in pairs. graphorganizers
Conditions of education	An audience adapted to work with TCO.

Technological map of the lecture (9th lesson)

stages, time	Activity	
	teacher	students
Stage 1. Introduction (10 min.)	1.1.Informs the topic, purpose, planned results of the training session and the plan for its implementation.	1.1. Listen, write.
Stage 2. Basic (60 min.)	2.1.In order to update students' knowledge, asks focusing questions: -How does the liquid flow through the nozzle? -What types of nozzles do you know? -How does the outflow of liquid occur at a variable pressure? Work in pairs to answer questions. Conducting a quiz. 2.3. Consistently presents the material of the lecture on the issues of the plan, uses visual materials. Explains what a weir is, classification of orifices, fluid flow rates and coefficients, fluid outflow at variable head, compressibility, fluid outflow characteristics. Focuses on the key points of the topic, offers to write them down	2.1. Listen. They take turns answering the questions. Listen to the correct answer. 2.3.Discuss schema content and tables, visual materials, clarify, ask questions. write down main.
3 stage. Closing (10 min.)	3.1.Conducting a quiz. Makes a final conclusion. Gives assignments for self-studywork. 3.2 Compose a cluster on the word "Flow of a liquid through a small round hole." Set ratings.	3.1. Reply to question. 3.2. Listen, write.

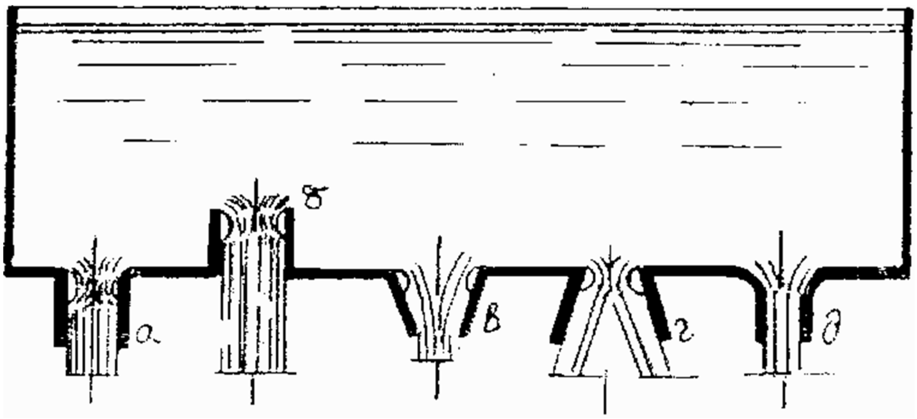


Rice. 9.1

9.1 The flow of liquid through a small round hole and nozzles.

Let us first consider the case of fluid outflow through a small round hole in a vertical wall atconstant pressure (Fig. 9.1). Here we can assume that the pressure at all points of the cross section of the hole is the same.
Fig.9.1

Assuming the hole is round, draw a comparison plane*BUT*-BUTthrough the center of gravity of a hole having a diameter d. designationchim through Hc - geometric head above the plane comparednia; through hC - jet thickness incompressed section C-C. Let us write the Bernoulli equation for the section0-0 (free surface level) and compressed jet section C - C:



Rice. 9.2

$$H_C + \frac{p_{атм}}{\gamma} + \frac{\alpha_0 v_0^2}{2g} = \frac{p_{атм}}{\gamma} + \frac{\lambda v_0^2}{2g} + \varsigma \frac{v_c^2}{2g},$$

where: v0 and vc are the velocities in the respective sections;
z -resistance coefficient that takes into account local energy losses within the hole.

Here we believe it is possible, in view of the smallness of the jet cross section, to consider the pressure in the compressed cross section*S*-*S*equal to atmospheric pressure, i.e. take rs = rs.
Let us denote by Ho the total head above the center of gravity of the hole:

$$H_0 = H_c + \frac{\alpha_0 v_0^2}{2g}$$

Then: $$H_0 = \frac{\alpha_0 v_0^2}{2g} + \zeta \frac{v_c^2}{2g}.$$

From here we obtain the expression for the average velocity in the compressed sectionS-S:

$$v_c = \sqrt{\tfrac{1}{\alpha_c + \varsigma}} \cdot \sqrt{2gH_0} = \varphi\sqrt{2gH_0},$$

where: $\varphi = \sqrt{\dfrac{1}{a_1 + \zeta}}$ - coefficient of hole speed.

Determine the flow rate of fluid passing through the hole:

$$Q = \omega_c v_c = \omega\varepsilon\varphi\sqrt{2gH_0}$$

Denoting:$\varepsilon\varphi=\mu$we obtain the final formula for the flow rate of liquid when flowing through a small hole:

$$Q = \mu\varphi\sqrt{2gH_0} ,$$

where: μ is the flow rate of the hole, determined empirically.

For small holes in a thin wall with perfect compression, the flow rate isR.is stable and is:

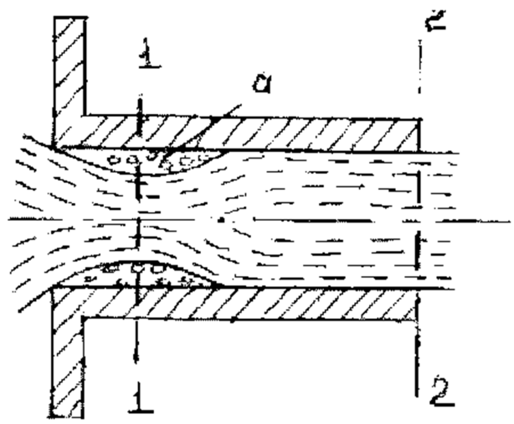
$$\mu = 0.62 \div 0.60$$

Therefore, small holes are often used as water meters. In the case of imperfect or incomplete compression, the fluid flow rate increases slightly. Special empirical formulas are used to take into account the indicated increase in the flow coefficient.

Fluid flow through nozzles

The most common types of nozzles are:
1) cylindrical nozzles: external (Fig. 9.3, a) and internal (Fig. 9.3, b);
2) conical nozzles, converging (Fig. 9.3. b) and diverging (Fig. 9.3, d);
3) conoidal nozzles of curvilinear shape,shaped compressed jet (Fig. 9.3, e).

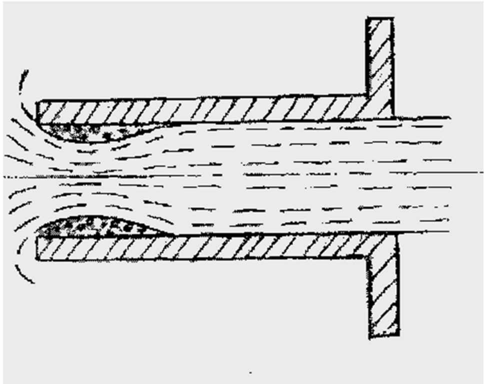
Consider the case: Consider first the outflow of liquid from an external cylindrical nozzle, which is a short, usually length l = (3-4) d, cylindrical tube attached to a hole in the vessel wall (Fig. 9.3).



Rice. 9.3.

In this case, the liquid jet exiting the vessel and entering the nozzle is subjected to some compression (d ≈ 0.8 d), then gradually expands and fills the entire cross section of the nozzle. The jet compression here occurs only inside the nozzle (internal compression), while the outlet section of the nozzle works completely, and thereforeTherefore, the compression ratio related to the outlet section will be a ≈ 1.

The cylindrical nozzle is made in the form of a tube attached to the hole from the inside of the vessel (Fig. 9.4).



Rice. 9.4

In this nozzle,compared with the externalThe pressure losses and, consequently, the pressure loss turn out to be large, since the conditions for the liquid to approach the nozzle worsen.

With nozzle length$l>2.5d$ the liquid fills the entire outlet section of the nozzle, the compression ratio in this section is a = 1, and the velocity coefficient turns out to be: φ = 0.71. At l < l.5d, the nozzles operate with an incomplete cross section, and the liquid flows out of the hole without touching the walls of the nozzle, which leads to a significant decrease in the flow rate (μ = 0.5).

In a conical converging nozzle (Fig. 9.5), in addition to the phenomenon of internal compression of the jet, which, however, has less effect here than in a cylindricala second (external) compression occurs at the exit from the nozzle, after which the liquid flows in parallel streams. Due to the insignificance of the internal compression, the pressure loss in this nozzle is less than in cylindrical nozzles, the velocity coefficient is large, and the compression ratio, due to additional compression in the outlet section, is smaller.

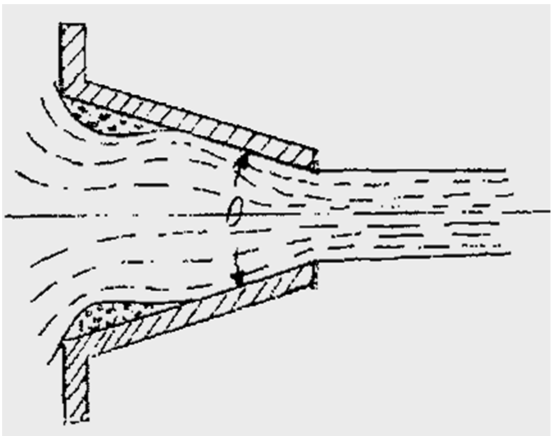


Fig.9.5.

All flow coefficients (a, φ, μ) for conical nozzles depend on the taper angle θ. Experience shows that in a conical converging nozzle, the velocity coefficient φ increases all the time with an increase in this angle; the flow coefficient first increases, reaching the maximum value μ = 0.946 at θ = 13, and then begins to decrease.

It should be borne in mind that here, as elsewhere, when considering
nozzle outflow, all coefficients refer to the outlet section of the nozzle. If, on the other hand, the flow coefficient is related to the cross section of the hole in the wall, then, due to the taper of the nozzle itself,

it will, of course, be much less;Therefore, conical converging nozzles at high output speeds, however, are characterized by lower liquid flow rates compared to cylindrical nozzles.
In conical divergent nozzles (Fig. 9.6), a liquid jet atnozzle inlet experiences significant compression, then rapidly expandsand fills the entire section. There is no external compression when exiting the nozzle; and consequently, the compression ratio a = 1. However, at an angle, the coneIf θ > 80, this nozzle ceases to operate with a full cross section, the jet flows out without touching the walls, and the outflow occurs as if from a hole in a thin wall. The flow coefficients in divergent nozzles, as well as in convergent ones, vary depending on the taper angle; on average (for θ > 80)
φ =μ = 0.45.

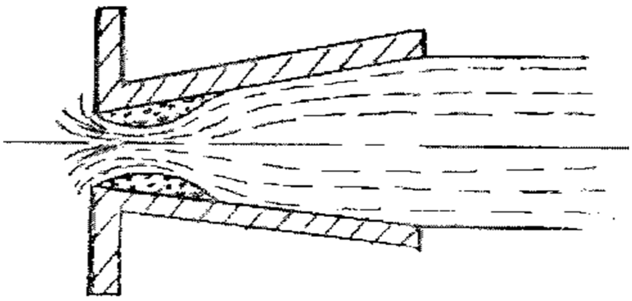
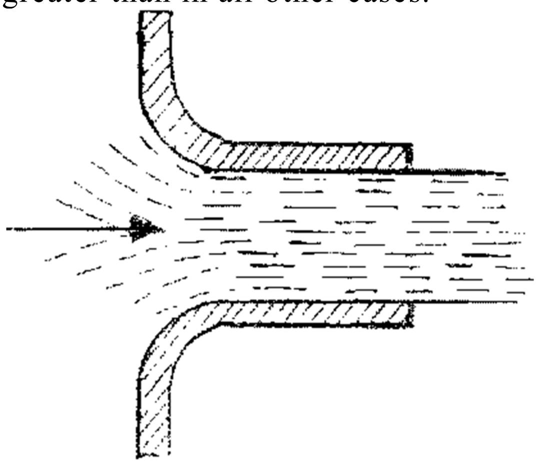


Fig.9.6

Thus, in conical divergent nozzles, the speed inoutlet section is much smaller than in all previous cases. The reason for this is the large pressure loss during sharp compression and expansion of the jet in the nozzle itself. The flow rate of the liquid here, on the contrary, increases significantly. At first glance, due to the smallness of the flow coefficient, this may seem somewhat strange. However, it must be taken into account that this coefficient refers to a large exit section of the nozzle; if it is attributed to a small output cross section, i.e. to the cross section of the hole in the wall, it will be much larger and reach a value equal to 2-3. In conical diverging nozzles, a significant vacuum is created at the point of compression of the jet, and therefore they have the suction property, and to an even greater extent than cylindrical nozzles.

Conoidal nozzles (Fig. 9.7) have a shape similar to the shape of a liquid jet that flows out of a hole in a thin wall. Naturally. that is why in these nozzles the internal compression is the smallest, there is no external compression (a≈1) and the velocity and flow coefficients must be greater than in all other cases.



Rice. 9.7

Experiments show the average value of these coefficients:φ= 0.45μ \u003d 0.97, and with special care and smooth walls - even up to 0.995.

Compressibility.CompressibilityThe property of a liquid to change its volume with changes in pressure and temperature is called. Dropping liquids are characterized by very low compressibility, as a result of which the volumetric compression ratio βw, i.e. a number that determines the relative decrease in the volume of a liquid with an increase in pressure by one atmosphere:

$$\beta_W = \frac{dW}{W_0 dp}$$

very small. Here: Wo is the initial volume, m3; *dW*— elementary volume change, m3; dp is the elementary pressure change, kg/m2.

So, for example, for fresh water, the volumetric compression ratio attemperature from 0 to 20°C averages:

$$\beta_W = 0.0000475 = \frac{1}{21000} см^2 / кГ$$

In the case of an increase in temperature and pressure, the compressibility of liquidsdecreases somewhat. In particular, the volumetric compression ratio for water when the temperature reaches 100°C and pressures up to 500 am decreasemessing around with $\frac{1}{21000}$ before $\frac{1}{24000}$ cm^2 */kg.*With an increase in pressure from 500 to 1000 am and maintaining normal temperature, the volumetric compression ratio of water decreases $\frac{1}{21000}$ before $\frac{1}{24000}$. cm2 /kg Compressibility data available. various drip

liquids make it possible to determine the values of their moduli of normal elasticity, i.e. values of the reciprocals of the coefficientvolumetric compression:

$$E = \frac{1 кГ}{\beta_W см^2}.$$

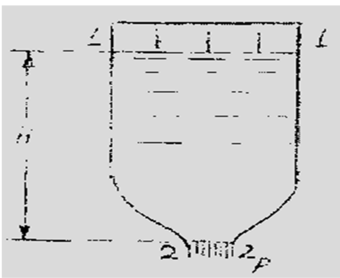
For fresh water, the modulus of normal elasticity is usually assumed to be E = 21,000 kg/cm2. For oil and mercury, the corresponding values are:

*BW*to G/cm2 *E*kg/cm2

Oil 0.0000740 = 1/1350013 500

Mercury 0.000 003 13 = 1/330 000 330 000

Velocity and fluid flow rates. Under normal flow conditions, with a large cross-sectional area of the vessel and a smallhole, the velocity of the liquid in the vessel itself, compared with the velocity of the outflow from the hole, will be very small.



Rice. 9.8

Therefore, upon expirationreal (viscous) liquid will be insignificant and the pressure loss when the liquid moves through the vessel, which will increase only when approaching the hole, in the immediate vicinity of it, and especially in the hole itself. All this suggests that in the case under consideration, pressure losses can be classified as local losses. With this circumstance in mind andinfluencing the Bernoulli equation for sections 7 and 2
(Fig. 9.8), we get:

$$H+\frac{p_1}{\gamma}+\frac{v_1^2}{\gamma}=\frac{p}{\gamma}+\frac{v_Д^2}{2g}+\varsigma\frac{v_Д^2}{2g},$$

where: vD is the actual outflow velocity;
z-flow resistance coefficient.
From here we find:

$$v_Д=\sqrt{\frac{2g\left(H+\frac{p_1}{\gamma}-\frac{p_2}{\gamma}\right)}{1+\varsigma-\left(\frac{f}{F}\right)^2}} \quad (9.1)$$

In the particular case when p1 = p = ratm:

$$v_Д=\frac{1}{\sqrt{1+\varsigma}}\cdot\sqrt{2gH} \quad (9.2)$$

It can be seen from the obtained formulas for the actual exhaust velocity that this velocity, as expected, is always somewhat less than the theoretical exhaust velocity. This is explained by the fact that some of the energy possessed by the liquid in the vessel is spent on overcoming the hydraulic resistances that arise during its movement, and less pressure is used to create speed than was previously accepted. The ratio of the actual outflow velocity to the theoretical one is called the velocity coefficient and is usually denoted by φ; Consequently:

$$\varphi=\frac{v_Д}{v_T}=\frac{1}{\sqrt{1+\zeta}},$$

whence the drag coefficient ζ is expressed in terms of the velocity coefficient as follows:

$$\zeta=\frac{1}{\varphi^2}-1.$$

The outflow of liquid at a variable pressure.

The problem of fluid outflow at variable pressure is usually reduced to determining the time of emptying or filling of all or some part of the vessel, depending on the initial filling, the shape and size of the vessel and the hole.

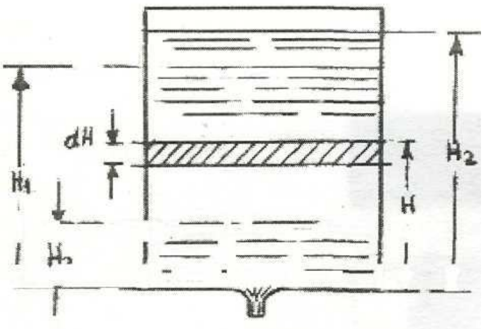


Fig.9.9

Let us consider, as the simplest, the case of outflow into the atmosphere through a bottom hole with an area / from an open vertical cylindricalvessel, the same cross-section F over the entire height (Fig. 9.9.). Elementary volume of liquid dQ, passedsewing through the holean infinitely short period of time dT during which the liquid level in the vesselcan be approximately taken constant, will be equal to:

$$dQ = \mu f v dT = \mu f \sqrt{2gH}\, dT,$$

where: H is the depth of the liquid in the vessel for a certain position of its level;
μ is the flow coefficient (which varies depending on the pressure and on the shape and size of the hole).

On the other hand, during the same time the liquid level in the vessel will drop by dH and the volume of liquid in it will change by:

dV=-FdH

Due to the continuity of the movement:

dQ=-FdH!
or:

$$\mu f \sqrt{2gH}\, dT = -FdH,$$

where:

$$dT = -\frac{FdH}{\mu f \sqrt{2gH}}.$$

The total emptying time of the vessel is determined by integrating the last equation:

$$\int_0^T dT = -\int_{H_0}^{0} \frac{FdH}{\mu f \sqrt{2gH}},$$

where: HH is the depth of the liquid in the vessel before the start of the outflow.

Changing the limits of integration on the right side, making the assumption μ= const and taking the constants out of the integral sign, we will have:

$$T = \frac{F}{\mu f\sqrt{2g}}\int_0^H \frac{dH}{\sqrt{H}}$$

which after integration leads to the final expression:

$$T = \frac{2F\sqrt{H}\,H}{\mu f\sqrt{2g}} \cdot \quad (9.3)$$

9.3. Classification of holes and the main characteristics of the outflow of liquid.

In hydraulics, outflows through holes in a thin and thick wall (nozzles) are distinguished; depending on the conditions of jet compression, there are holes with perfect and imperfect, as well as with complete and incomplete compression.

holein a thin wall such a hole is called, the edges of which have a sharp edge, and the wall thickness does not affect the shapemu and jet outflow conditions.

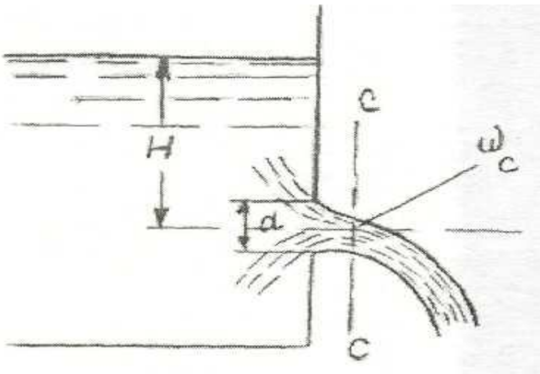


Fig.9.10

ys. There is a so-called compressed section, which has the smallest area and almost parallel jet flow; further, the jet falls under the action of gravity. On fig. 9.11 shown on a large scale compressedthat section C-C.

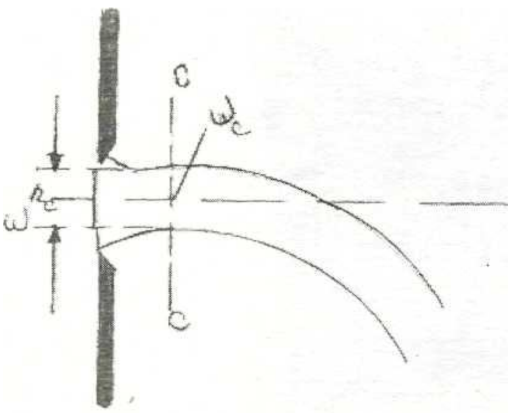
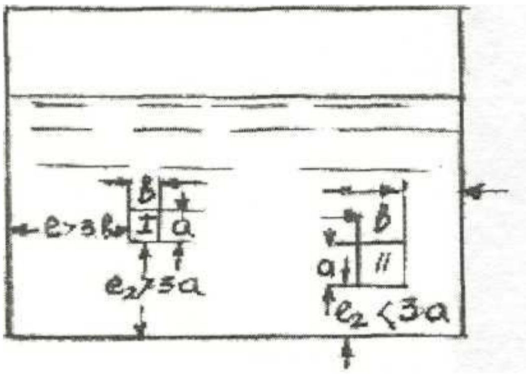


Fig.9.11

Jet, youpenetrating from the hole, does not retain its shape, but aftereffect of the action of surface tension forcesthe foam is deformed. This phenomenon is called inversion.these jets. For example, a jet flowing out of a triangular hole takes the form of a triangular star, and a jet flowing out of a round hole gradually acquires an elliptical cross section.

A hole with perfect compression is such a hole, the boundaries of which are sufficiently removed from the boundaries of the liquid in the tank, and the walls of the tank do not affect the conditions of jet compression. It has been established by experience that the walls of the tank affect the compression of the jet only when the distance of the hole from the side wall or bottom is less than three times the diameter for a round hole or three times the size of the side for a rectangular hole.

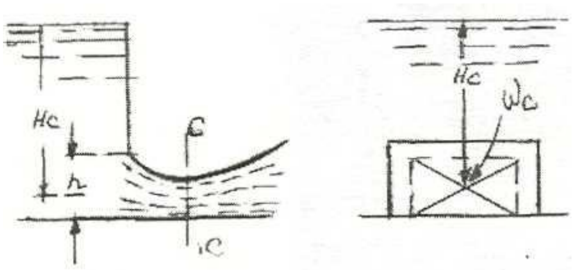
A hole with imperfect compression is a hole, one or more sides of which are at a close distance from the surface of the liquid or the wall of the tank. On fig. 9.12 hole I - with perfect compression, and hole II with imperfect.



Rice. 9.12.

A fully compressed orifice is one in which the jet is compressed from all sides.

An orifice with incomplete compression is an orifice in which the jet is not compressed on one or more sides. An orifice with incomplete compression is an orifice in which the jet is not compressed on one or more sides. An example of it is a bottom hole, in which there is no compression along the bottom, and the jet is compressed only from three sides (Fig. 9.20).



Rice. 9.13

To assess the degree of compression of the jet in hydraulics, the concept of the compression ratio of the jet is used. The jet compression ratio ε is the ratio of the area of the compressed section to the area of the hole.

$$\frac{\omega_C}{\omega} = \varepsilon$$

It has been established that for small holes with sharp
edges: ε = 0.64-0.60

In small holes (with a vertical side size of no more than 0.1 N), the compression ratio s is fairly constant, while in large holes it varies depending on a number of factors, including the pressure H and the size of the hole.

Test questions:

1. How does the outflow of liquid through a small round
hole and fittings?
2. Give a practical and theoretical formula for speed and flow
fluid as it flows through a small orifice.
3. The concept of compressibility? Talk about speed and odds
fluid flow?
4. How does the liquid flow through the nozzle?
5. What kinds of nozzles do you know?
6. How do conical divergent nozzles work?
7.Where are conical descending nozzles used?
8. How do conoid divergent nozzles work?
9. How does the outflow of liquid occur at a variable pressure?

Key words:weir, classification of openings, velocity and coefficients of liquid flow, outflow of liquid at variable head,compressibility, fluid flow characteristics.

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Lecture 10

Interaction of a flow with a solid body and calculation of gas pipelines

Learning technology for lecture No. 10

Time - 2 hours	Number of students: 20-30 people
Form of the lesson	Introduction, visual lecture
Lesson Plan	1. Complex pipelines. 2. Interaction of a flow with a solid body. 3. The movement of gases in pipelines. 4. Calculation of gas pipelines.
Purpose of the lesson: to familiarize students with methods for reducing water hammer, complex pipelines, the movement of gases in pipelines, teach them how to calculate short pipelines and siphons and complex pipelines, gas pipelines.	
Tasks of the teacher:	*Learning outcomes:* The student must learn: -hydraulic calculations for short pipelines and siphons; -hydraulic calculations of complex pipelines; -active and reactive interaction between a jet and a solid barrier; -movement of gases in pipelines;
Means of education	Laser projector, visual materials, information support.
Forms of study	Collective, frontal work, work in pairs. graphorganizers
Conditions of education	An audience adapted to work with TCO.

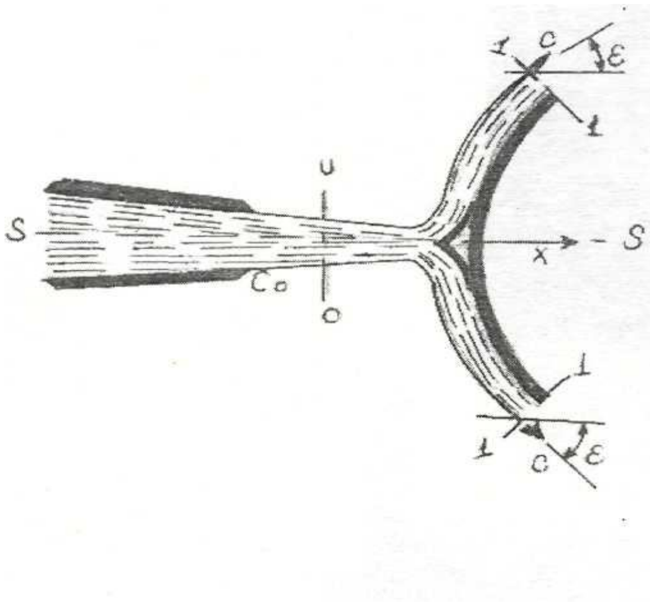
Technological map of the lecture (10th lesson)

stages, time	Activity	
	teacher	students
Stage 1. Introduction (10 min.)	1.1.Informs the topic, purpose, planned results of the training session and the plan for its implementation.	1.1. Listen, write.
Stage 2. Basic (60 min.)	2.1.In order to update students' knowledge, asks focusing questions: 2.3. Consistently presents the material of the lecture on the issues of the plan, uses visual materials. Focuses on the key points of the topic, offers to write them down	2.1. Listen. They take turns answering the questions. Listen to the correct answer. 2.3.Discuss schema content and tables, visual materials, clarify, ask questions. write down main.
3 stage. Closing (10 min.)	3.1.Conducting a quiz. Makes a final conclusion. Gives assignments for self-studywork. 3.2 Compose a cluster on the word "vane hydraulic machines". Set ratings.	3.1. Reply to question. 3.2. Listen, write.

Interaction of flow with a solid body.

Active and reactive interaction between a jet and a solid barrier. Active interaction between a jet and a solid barrier occurs when the jet flowing out of the nozzle hits a fixed or moving barrier, for example, in the form of a convex curved plate (Fig. 10.1). After hitting the plate, the jet spreads over its surface at a speed c. There is a vortex zone in the center of the plate. When this is formed, the jet will deviate from its original direction by an angle £, as a result of which the plate will experience a pressure force X in the direction of the nozzle axis 5-5. Force X is the force of the active pressure of the jet on the fixed plate.

The force of the active pressure of the jet on the barrier is determined by applying the theorem on the change in the momentum to the fluid compartment between sections 0-0, 1-1, 1-1. Let us take the nozzle axis SS as the projection axis.



Rice. 10.1

Let us make a projection on this axis of the change in the momentum over time Δ t, which should be equal to the projection of the force impulse for the same time:

$$mc_0\Delta t - \frac{m}{2}c \cdot \cos\varepsilon\Delta t - \frac{m}{2}c \cdot \cos\Delta t = X\Delta t$$

where: m is the mass of liquid entering the compartment through the 0-0 section during the time Δt.

Taking c0 = c (energy losses in the flow section between sections 0-0 and 1-1 can be neglected), we have:

$$X\Delta t = mc0\ (1 - \cos\varepsilon)\Delta t$$

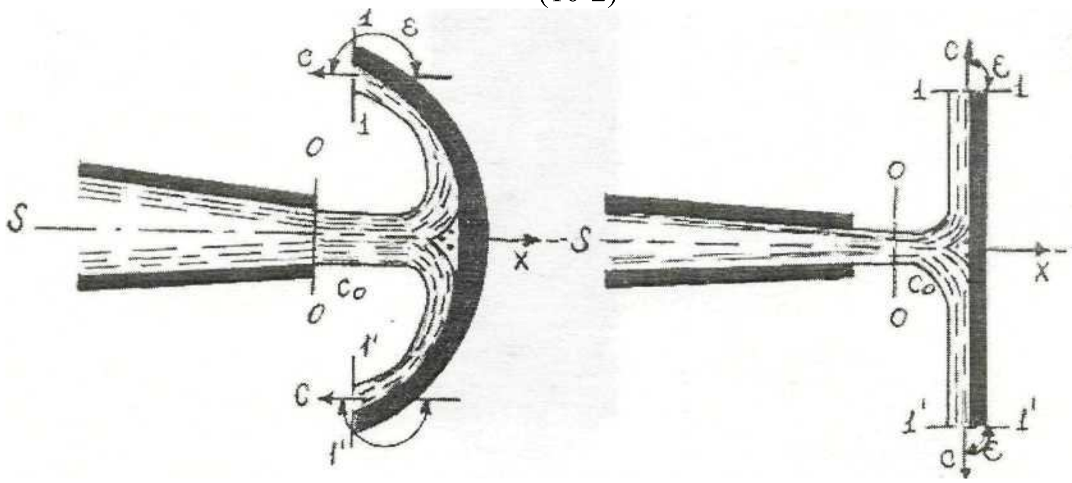
Assuming $\Delta\ t$ =1 sec, finally we get:

$$X = pQc0(1 - \cos\varepsilon)\ (10\text{-}1)$$

where: Q is the nozzle flow rate.

If the plate is concave (Fig. 10.2). then the angle ω greater than 90 , and cos s is negative. That's why. According to dependence (10-1), the active pressure for a concave plate will be greater than for a convex one. In a particular case, when ε =90° and cos ε =0 (Fig. 10.3),

$$X = pQc0 = \frac{\varphi}{g} Qc_0 \qquad (10\text{-}2)$$



Let us assume that the cross-sectional area of the nozzle is equal to ω and the nozzle is closed with a flat valve. Then the pressure on the valve is:

$$P = \gamma\ \omega N.$$

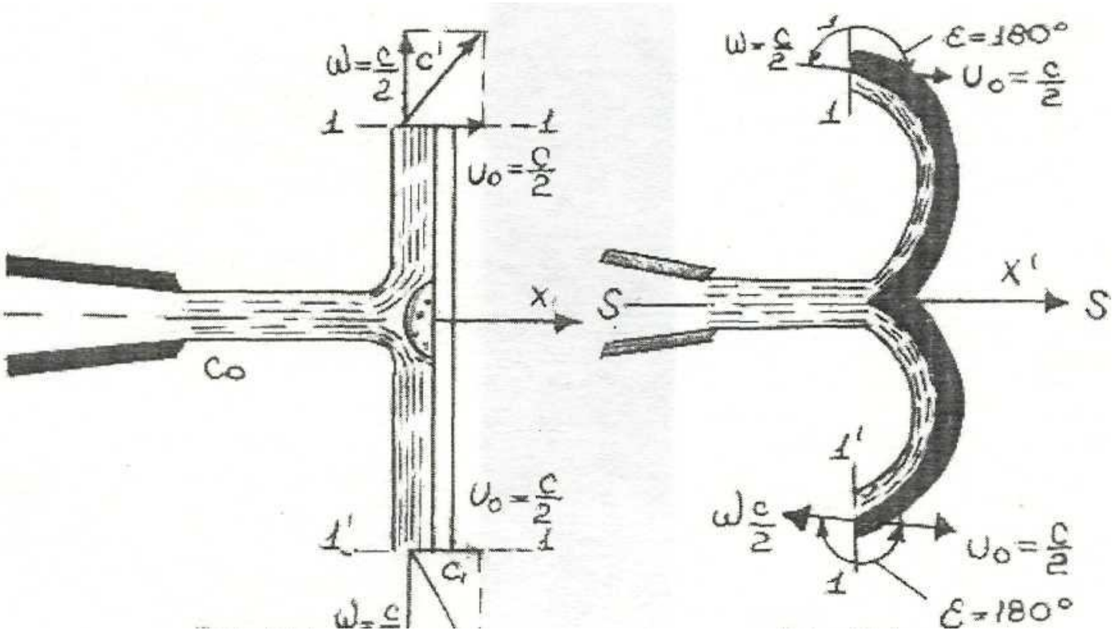
where: H is the pressure above the center of gravity of the nozzle.

On the other hand, c0 = $\sqrt{2gH}$ (if $\varphi \cong 1$) and Q= ω $c0$. Then the active pressure X can be represented by the following dependence:

$$X = \frac{\gamma}{g} Qc_0 = \frac{\gamma}{g} \omega c_0^2 = 2\gamma\ \omega N.$$

Therefore, the active pressure of the flow on the flat plate is 2 times greater than the hydrostatic pressure that would act on the closed valve of the nozzle with a head H corresponding to the speed.

Let us consider the interaction of a jet and a system of plates moving with a speed and (an example of such an interaction is the scheme



bucket turbine, shown in fig. 10.5. Let X denote the active pressure of the jet on the moving plate (Fig. 10.4). In this case, the liquid will move along with the plate at a speed and simultaneously move along the plate with a relative speed u. Since the velocities have one direction, the relative velocity of the jet along the plate will be equal to w = c0-u and the active pressure will be expressed by the dependence:

$$X' = \frac{\gamma}{g} Q\omega = \frac{\gamma}{g} Q(c_0 - u). \ (10\text{-}3)$$

Power is equal to the product of the force and the path in 1 second

$$N = X'u = \frac{\gamma}{g} Q(c_0 - u)u \ = \frac{\gamma}{g} Qc_0 u \ - \frac{\gamma}{g} Qu^2. \ (10\text{-}4)$$

Equation (10-4) is a function N = f (u) with Q = cons and t c0 - const. If the plate is stationary, then the active pressure will be maximum, but the power is zero. At and = c, the active pressure X and power are equal to zero:

$$\frac{dN}{du} = \frac{\gamma}{g} Qc_0 - 2\frac{\gamma}{g} Qu = \frac{\gamma}{g} Q(c_0 - 2u) = 0,$$

$$u = \frac{c_0}{2}. \ (10\text{-}5)$$

Thus, as a result of the interaction of the jet and systems of vertical flat plates moving at a speed and only half of the energy possessed by the jet flowing from the nozzle is used.

Let's determine where the remaining unused kinetic energy is concentrated. Water when leaving the plates has a relative speed:

$$w = c0 - u0 = c0 - \frac{c_0}{2} = \frac{c_0}{2}.$$

The absolute speed when the jet leaves the plates c' is (Fig. 10.4), and the kinetic energy is:

$$\frac{mc_0^2}{2}=\frac{\frac{\gamma}{g}\cdot Qc_0^2}{4}=\frac{\gamma Qc_0^2}{4g}.$$

Thus, the unused part of the energy is contained in the jet descending from the plates. If instead of plates to install blades in the form of buckets (Fig. 10.5), then you can increase the use of energy. In this case, the jet is divided into two equal parts, each of which flows around its own hemisphere, and the jet rotation angle is equal to ε = 180". The pressure force on a fixed blade of this configuration will be equal to:

$$X=\frac{\gamma}{g}Qc(1 - cos1800)=\gamma gQc2 = 2\frac{\gamma}{g}Qc, (10\text{-}6)$$

those. twice as much as vertical; flat plate. It can be shown that for the blades of a bucket turbine, the greatest power will be obtained at absolute (transfer) speed. and u=$\frac{c_0}{2}$ what corresponds

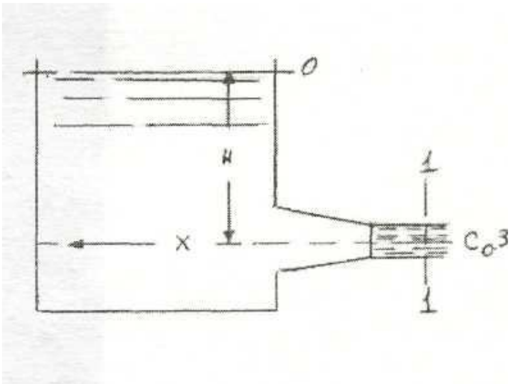
$$N0=X'u0=X'\frac{c_0}{2}\ (10\text{-}7)$$

maximum possible power:
On the other hand,

$$X' = 2\frac{\gamma}{g}Qw = 2\frac{\gamma}{g}Q\frac{c_0}{2}\left(c_0 - \frac{c_0}{2}\right) = 2\frac{\gamma}{g}Q(c_0 - u_0) = \frac{\gamma}{g}Qc_0.$$

Thus, when the jet interacts with the moving blades of a bucket turbine, the theoretically used power is equal to the total kinetic energy of the jet flowing out of the nozzle. In reality, it is somewhat less due to the presence of energy losses during the flow around the blades.

A reactive interaction between a jet and a solid body occurs when a jet flows out of a vessel. In this case, a reactive force acts on the wall of the vessel along the axis of the hole, which tends to move the vessel in the direction opposite to the movement of the jet (Fig. 10.6).



The reactive force is determined by applying the law of momentum to the volume of liquid between sections 0-0 and 1-1. For the projection axis, we take the line SS passing through the center of gravity of the hole. Since the liquid does not enter the vessel, but flows out through the hole, the projection of the change in the momentum between sections 0-0 and 1-1 on the SS axis, equal to the projection of the impulse of forces, will be expressed by the dependence:

0-mc0=X

where:

$$X = \frac{\gamma}{g}Qc_0 = \frac{\gamma}{g}\omega c_0^2 \text{ (10-9)}$$

But since c0 = $\sqrt{2gH}$ at $\varphi \approx 1.0$

X = -$\frac{\gamma}{g}$ w2gH = -2 π *wh.*

Consequently, the reactive force that occurs when the liquid flows out of the vessel is directed in the direction opposite to the jet movement. In this case, the reactive force is twice the hydrostatic pressure force that would act on a flat valve if the hole was closed. In this respect, we have a complete analogy with active pressure.

Let us assume that the vessel will move under the action of a reactive force. Then, as a result of the interaction of the jet and the vessel, work will be done. The action of jet turbines is based on this principle, in which the jets, flowing out of the channels (vessels) formed by the blades of the impeller, create a reactive force. The force of the reactive pressure causes the formation of a torque in the turbine, which sets the impeller in motion.

10.2. The movement of gases in pipelines.

In industry and public utilities, the pumping of gaseous liquids - gases, air and superheated steam - through pipes is very widely used (for various technical and domestic purposes). The transportation of these liquids (gases) through pipelines, in comparison with the movement of ordinary drop liquids, is characterized by a number of significant features due to differences in the physical properties of drop and gaseous liquids.

When gas moves through a pipeline of constant cross section, due to inevitable pressure losses, the gas pressure, which usually exceeds atmospheric pressure in the initial section, then continuously decreases along the length of the pipeline. In this case, the gas expands, the specific volume of the gas increases, and the specific gravity, on the contrary, decreases; the specified change in the specific gravity of the gas, in contrast to the case of dropping liquids, turns out to be very significant and must be taken into account in the calculation.

In the case of steady motion, the weight amount of gas passing through any cross section of the pipeline per unit time (gas weight flow$G$), due to the continuity of the movement remains unchanged; volumetric gas flow Q=$\frac{G}{\gamma}$ will increase, and therefore, will increase along the length of the pipeline and the value of the average gas flow velocity

$$v=\frac{Q}{F}.$$

In the general case, due to the expansion of the gas and the phenomenon of heat transfer, there will also be a continuous change in the temperature of the gas along the length of the pipeline. However, in a number of cases it turns out to be quite possible to take the temperature constant, thus assuming that the process of gas expansion occurs isothermally.

In an isothermal process, due to the constancy of temperature, the value of the absolute viscosity of the gas will also remain constant along the length of the pipeline (a change in viscosity with a change in pressure becomes noticeable only at very large pressure fluctuations and is not taken into account in calculations for normal conditions). In this case, as it is easy to see, the Reynolds number will also remain constant.

Indeed: $\mathrm{Re} = \frac{\upsilon d}{\nu}$

but since: $\upsilon = \frac{\mu}{\rho}$, $\upsilon = \frac{4Q}{\pi d^2} = \frac{4G}{\gamma \pi d^2}$

then the Reynolds number can also be represented as follows:

$$\mathrm{Re}=\frac{4G}{\mu g \pi d}$$

Given that: $\frac{\rho}{\gamma} = \frac{1}{g}$

finally we get: $\mathrm{Re}=\frac{4G}{\mu g \pi d}$

The right side of the resulting expression includes only those quantities that remain constant along the length of the pipeline; therefore, the Reynolds number will also be constant

along the length of the pipeline, and also, therefore, which is a function of this number, the coefficient of hydraulic resistance λ ,. The original equation
to determine the pressure drop and gas flow in a gas pipeline, the usual Bernoulli equation is used. However, taking into account the above features observed during the movement of gas in the gas pipeline (change in the specific gravity of the gas and the average velocity of its flow along the length of the gas pipeline), this equation in the case under consideration must be written in differential form.

$$dz + \frac{dp}{\gamma} + \frac{dv^2}{2g} = -\lambda \frac{dL}{d} \cdot \frac{v^2}{2g}$$

or $-\frac{dp}{\gamma} = \lambda \frac{dL}{d} \cdot \frac{v^2}{2g} + dz + \frac{dv^2}{2g}$ (10-11)

Calculations show that the second and third terms of the right-hand side of this equation under normal gas flow conditions (with a horizontal pipeline and low subsonic flow velocities) turn out to be small compared to the first term, which takes into account the resistance to movement, and therefore they can be neglected.
Then instead of equation (10-11) we will have:

$$-\frac{dp}{\gamma} = \lambda \frac{dL}{d} \cdot \frac{v^2}{2g}$$

Expressing further the average gas flow rate through the weight flow:

$$v = \frac{G}{\gamma F}$$

we get $-\frac{dp}{\gamma} = \lambda \frac{dL}{d} \cdot \frac{G^2}{2g\gamma^2 F^2}$

or $-\gamma\, dp = \lambda \frac{dL}{d} \cdot \frac{G^2}{2gF^2}$ (10-12)

For isothermal gas flow according to Boyle's law:

$$\gamma = \frac{p\gamma_1}{p_1}$$

where: p1 and γ_1 - pressure and specific gravity of the gas at the beginning of the pipeline.

Substitute the resulting value γ into equation (10-12) and integrate this equation in the range from p1 to p2
where: p1 - pressure at the end of the pipeline, length L;

$$-\frac{\gamma_1}{p_1} \int_{p_1}^{p_2} p\,dp = \frac{\lambda G^2}{d2gF^2} \int_0^L dL$$

Test questions:

1. On what indicators does the force of the flow acting on the barriers depend?
2. What is the reaction force?
3. Explain the force of the flow acting on the walls at different angles.
4. Application in technology of the force acting on the walls.
5. Explain the difference between the Bernoulli equation.

Key words:presses the valveabsorber, receiving tank, reactive force, head loss, active and reactive interaction, jet energy, gas movement in pipelines, gas pipeline calculation, solid barrier.

BRANCH OF THE FEDERAL STATE AUTONOMOUS EDUCATIONAL INSTITUTION OF HIGHER EDUCATION
"National Research Technological University "MISiS" in Almalyk

METHODOLOGICAL INSTRUCTIONS FOR THE PERFORMANCE OF LABORATORY WORKS

by subject

"Hydraulics"

L A B O R A T O R N A Y R A B O T A No. 1

STUDY OF REGIMES OF LIQUID MOVEMENT

ON THE REYNOLDS INSTRUMENT

PURPOSE OF THE WORK:

1. Visual observation of laminar and turbulent motion regimes.
2. Determination of the values of the Reynolds number in laminar and turbulent modes of motion.

BRIEF THEORETICAL INFORMATION

When a fluid moves in a pipeline (channel), two flow regimes are possible - laminar and turbulent.

The laminar regime is characterized by parallel-jet motion, in which individual layers of liquid move without mixing with each other. Such movement occurs at low speeds and small liquid flow cross sections, when moving through capillaries, when moving viscous liquids (oil, fuel oil, oils), when moving in the pores of the soil, etc.

The turbulent regime is characterized by disordered, chaotic motion, when fluid particles move along complex, ever-changing trajectories. Due to the presence of velocity components transverse to the direction of motion in the turbulent flow, intensive mixing occurs in the liquid. In engineering practice, during the movement of water and other low-viscosity liquids (kerosene, gasoline, alcohol, etc.), in heating, ventilation, gas supply, heat supply, and water supply systems, a turbulent regime is most often observed.

The existence of two modes of fluid motion was clearly shown by the English physicist O. Reynolds. Reynolds' experiments, later confirmed by other scientists, showed that the criterion for determining the regime of fluid movement in a round pipe is the expression:

$$\mathrm{Re} = \frac{V \cdot d}{\upsilon} ,$$

where Re is a dimensionless criterion called the Reynolds number:

V is the average velocity of the fluid, cm/s;

d - pipe diameter, cm;

υ - kinematic coefficient of viscosity, cm2/s.

The value of the Reynolds number, the Reynolds experiments at which the transition from laminar to turbulent occurs, is called the critical Reynolds number - Recr

At**Re<Recr** the motion mode is laminar, with Re>Recr turbulent.

Within a certain range of numbers**Re**there is an unstable region where both regimes are possible, depending on the nature of the change in velocities. The value of the critical number Recr depends on a number of circumstances: the conditions of the entrance to the pipe, the roughness of the walls of the pipe, the absence or presence of initial disturbances, etc. and can take on different values in each individual case.

For round pipes, usually take**Recr=2320**. The speed at which the turbulent regime passes into the laminar regime of fluid motion is called the critical speed.

At Re≤2320 – laminar mode.

At Re>2320 - turbulent mode.

DESCRIPTION OF THE PILOT SETUP

The pilot plant (Fig. II) will consist of a pressure tank /I/, into which water from the water supply network flows through the pipeline /2/. To maintain a constant water level in the tank there is a weir /4/. A grate /5/ is installed inside the tank, which serves to calm the water entering it, and a thermometer /8/ to measure the water temperature.

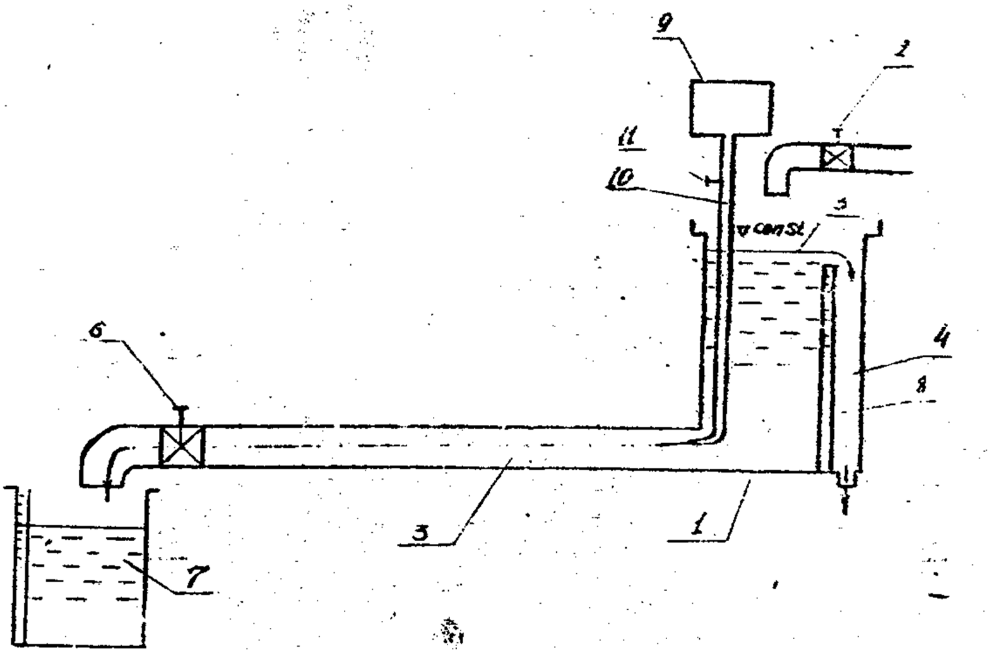


Fig.1.1. Scheme of the pilot plant

To tank /I/ a glass tube /3/ is attached, at the end of which a tap /6/ is installed to control the speed of water movement. Water consumption is determined using a measuring tank /7/. The unit has a small tank /9/ for the dye with a tube /10/ and a tap /11/.

In the experiment, the mode of motion is observed in the main glass tube /3/ when the dye is introduced into the main flow. Changing the mode is achieved by regulating the flow of liquid through the pipe using a valve /6/.

EXPERIMENTAL PROCEDURE

1. With the taps /6/ and /11/ closed, fill the pressure tank /1/ with water.
2. By slightly opening the cock /6/, a liquid flow rate is set in the pipe /3/, at which a slow flow takes place.
3. Having slightly opened the tap /11/, the dye is introduced into the main stream. Observe the nature of the movement of the liquid in the glass tube. The jet movement of the paint will indicate the presence of a laminar regime. Gradually increase the opening of the valve /6/ and observe a change in the mode of movement with increasing speed. First, the tinted stream acquires a wavy character and the laminar regime becomes unstable. With a further increase in speed, the colored stream disappears, the entire liquid is uniformly colored - the laminar mode of motion has switched to turbulent.
4. With steady motion, the water flow in the pipe is determined. For each mode of motion, the volume of water entered into the measuring tank W during the time t is determined, and the water temperature is simultaneously recorded.

PROCESSING OF EXPERIMENTAL DATA

1. Kinematic viscosity coefficient υ determined from the table.

Table 1.1

Water temperature in deg. C0	0	5	ten	fifteen	twenty	25
kinematic coefficient. viscosity υ, cm2/s	0.0173	0.015	0.0131	0.0114	0.0102	0.0090

1. Water consumption:

$$Q = \frac{W}{t} \text{(cm3/s)},$$

where W is the volume of water in the measuring tank, cm3.

t – tank filling time, s.

The average velocity of the liquid in the pipe $V = \frac{Q}{\omega}$ (cm/s);

where ω - open area, pipes, cm2 $\omega = \frac{\pi d^2}{4}$

d is the diameter of the glass pipe, cm.

2. From the known d, v, υ, the value of the Reynolds number is calculated for each experiment

$$\text{Re} = \frac{v \cdot d}{\upsilon}$$

The results of measurements and calculations are entered into a table.

Table 1.2

№№	Measurement data		Calculation data			Driving mode	Constants d=2.0 cm
	W	t	Q	V	Re		
	cm3	With	cm3/s	cm/s			
one	2	3	four	5	6	7	eight

test questions

1. What are the main elements of fluid movement?
2. What is a trajectory, a streamline, an elementary trickle, a stream?
3. What are the hydraulic elements of the flow?
4. What is the fluid flow rate?
5. What is the average flow rate?
6. What modes are observed during the movement of liquid in pipelines?
7. What characterizes the laminar flow regime?
8. What characterizes the turbulent flow regime?
9. Draw the graphs of the distribution of velocities over the flow section for various section modes?
10. What kind of tinted stream should be in laminar mode?
11. What is the appearance of a colored jet in turbulent conditions?

L A B O R A T O R N A Y R A B O T A No. 2

EXPERIMENTAL STUDY OF THE BERNULLI EQUATION

PURPOSE OF THE WORK:

1. Empirical determination of the values of potential energy (piezometric head), specific kinetic energy (velocity head) and total specific energy (hydrodynamic head) in various flow sections.
2. Construction on the basis of experimental data of piezometric and pressure lines for a pipeline of variable cross section.

BRIEF THEORETICAL INFORMATION

The Bernoulli equation for a steady flow of a real fluid is a special case of the law of conservation of energy. Any moving fluid flow has a certain energy. This energy can be manifested in three forms: position energy, pressure energy, and kinetic energy. The ratio between the individual types of energy for the driving flow is established by the Bernoulli equation.

For a real fluid flow with steady motion, the Bernoulli equation has the following form for two arbitrary sections:

$$z_1 + \frac{P_1}{\rho g} + \frac{\alpha_1 V_1^2}{2g} = z_2 + \frac{P_2}{\rho g} + \frac{\alpha_2 V_2^2}{2g} + h_w \qquad \text{(one)}$$

where z1, z2 are the vertical coordinates of the centers of gravity of the sections;
R_{one}, P2 – pressure in the centers of gravity;
V1, V2 – average flow rates;
α1, α2 are the kinetic energy coefficients, taking into account the uneven distribution of velocities over the free flow section.

In practical calculations with turbulent motion, the kinetic energy coefficient can be taken equal to 1.0 - 1.1.

The first term of the above equation determines the height of the position of the center of gravity of the live section of the flow above an arbitrary horizontal comparison plane 0 - 0 (Fig. 2-1) and is called the geometric height or geometric head; it characterizes the specific potential energy of the position.

Second member $\frac{P}{\rho g}$ represents the height of the liquid column corresponding to the hydrodynamic pressure at a given point of the flow cross section and is called the piezometric height, its value characterizes the specific potential energy of pressure.

The sum of the geometric and piezometric heights $z+\frac{P}{\rho g}$ is called the piezometric head, the value of which determines the total supply of specific potential energy.

The third term of the equation $\frac{\alpha V^2}{2g}$ is called velocity head, which determines the stock of specific kinetic energy.

Sum $z+\frac{P}{\rho g}+\frac{\alpha V^2}{2g}$ represents the value of the total specific energy of the flow and is called the hydrodynamic head H.

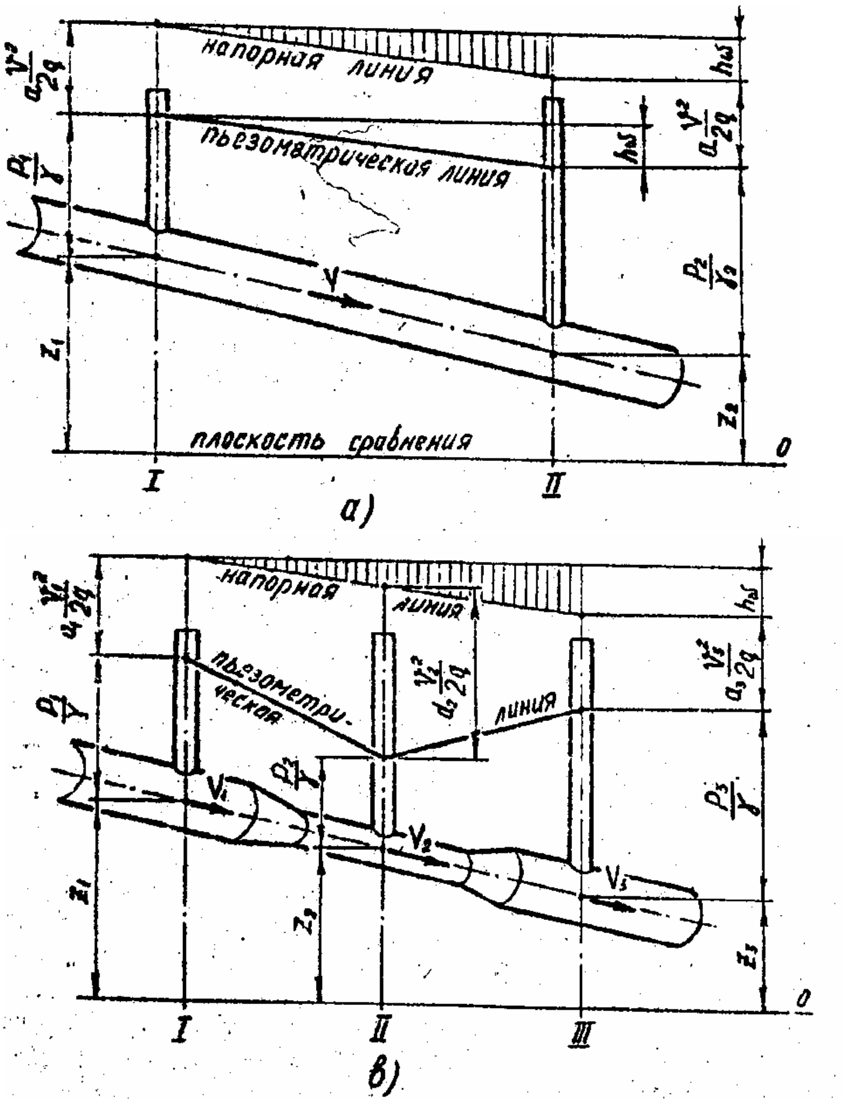
The last term on the right side of the equation hw expresses the total loss of pressure (energy) to overcome the hydraulic resistance when the fluid moves between the sections under consideration. The change in hydrodynamic head (total energy) in living sections along the length of the flow relative to an arbitrarily chosen comparison plane is characterized by a pressure line. The pressure line is built by the sum of the three terms of the Bernoulli equation. Since part of the total specific energy is spent on overcoming hydraulic resistance, the pressure line can also decrease from section to section.

For a pipeline of constant cross section (Fig. 2.1a), the kinematic characteristics of the flow are constant along its length α1=α2, V1=V2, therefore, the dynamic head has the same value in all sections $\frac{\alpha V^2}{2g}$ = const. Then from the Bernoulli equations we get:

$$h_w = (z_1 + \frac{P_1}{\rho g}) - (z_2 + \frac{P_2}{\rho g})$$

that is, the loss of pressure due to friction is equal to the decrease in the specific potential energy (piezometric pressure) of the flow and is expressed by the difference in piezometric levels in the initial and final sections of the pipeline.

Since friction losses are proportional to the length of the section, the pressure and piezometric lines in this case are parallel descending straight lines.



Rice. 2.1 Graph of pressure in the pipeline:

a) constant cross section

c) variable section

In a pipeline of variable cross section (Fig. 2.1 b), when a liquid moves, one type of liquid energy is converted into another, which is accompanied by a change in velocity along the flow. The piezometric line in this case may decrease (with increasing speed). If the free cross section decreases in the direction of motion, then the kinetic energy increases due to the decrease in potential energy. And vice versa, if the free cross section of the flow increases, then the kinetic energy decreases, and the potential energy increases.

DESCRIPTION OF THE PILOT SETUP

The pilot plant for studying the Bernoulli equation (Fig. 2.2) consists of a pressure tank /1/ filled from the water supply network through a tap /5/, a pipeline with a horizontal axis /2/ of variable cross section with diameters D and d and a measuring tank /7/. A constant water horizon in the tank is maintained with the help of a weir /4/. Due to the constancy of the level in the tank /1/, the movement of liquid in the pipe will be steady. Piezometers /3/ are installed in six characteristic sections of the pipeline, the zero of the scale of which coincides with the axis of the pipe. According to the readings of the piezometers, the piezometric pressures in the sections I - YI are determined. The regulation of the flow through the pipe is performed by a tap /6/. Consumption is determined by the volumetric method according to the water level in the measuring tank.

EXPERIMENTAL PROCEDURE

1. The pressure tank /I/ is filled with water.
2. The absence of air in the piezometers is checked.
3. With a certain opening of the tap /6/, a steady movement of the liquid in the pipe is achieved, evidence of which is the invariance of the water level in the piezometers.
4. For a given mode of motion, the volume of liquid W that enters the measuring tank /7/ is measured during the experiment t /
5. Simultaneously with measuring the volume of liquid, readings of piezometers /3/ are taken.
6. The measurement results are entered in Table 2.1.

Vertical distance z from pipeline axis to plane

comparisons are taken in calculations z = 0.7 m.

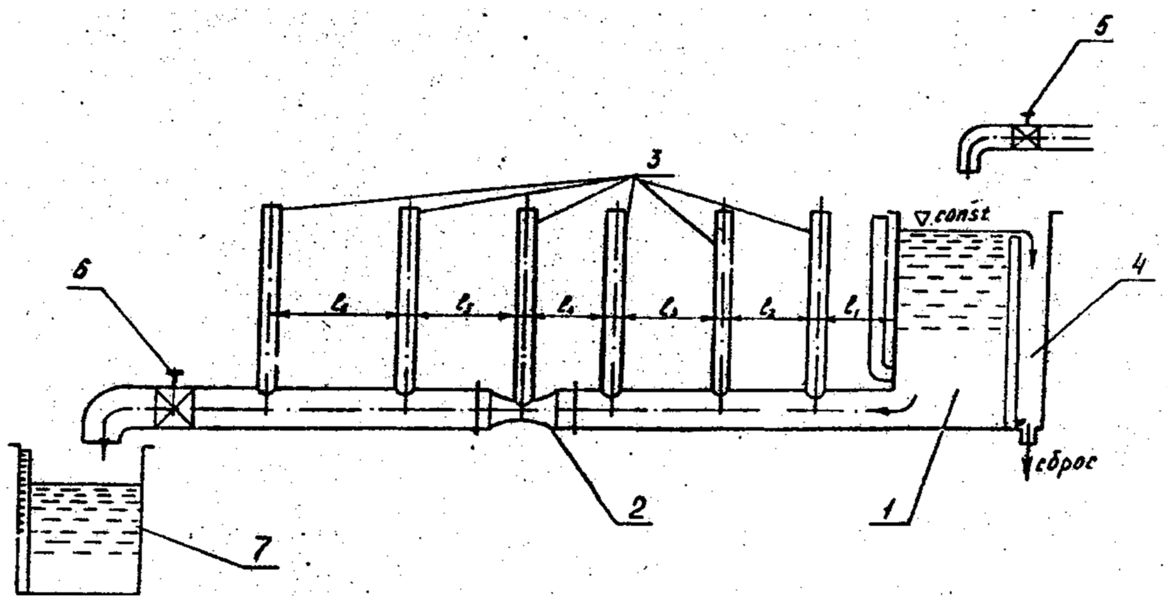


Fig. 2.2 Scheme of the pilot plant

Table 2.1.

№№	Piezometer readings						W	t	Constants
	$\frac{P_1}{\rho q}$	$\frac{P_2}{\rho q}$	$\frac{P_3}{\rho q}$	$\frac{P_4}{\rho q}$	$\frac{P_5}{\rho q}$	$\frac{P_6}{\rho q}$			D=2.0 cm, d=1.0 cm z=0.7 m, L=1.0
	cm	cm	cm	cm	cm	cm	cm3	With	
one	2	3	four	5	6	7	eight	9	ten

Table 2.2

№№	Indicators	Units measurements	Numbers of live sections
			I II III IY Y YI
one	2	3	4 5 6 7 8 9
one. 2. 3. four. 5. 6. 7.	Pipe diameter Living section average speed Specific kinematic energy Specific potential energy Total specific energy head loss	cm cm2 cm/s cm cm cm cm	

PROCESSING OF EXPERIMENTAL DATA

1. Fluid flow $Q = \frac{W}{t}$ (cm3/s)
2. Average speeds in each flow section: $V = \frac{Q}{\omega}$ (cm/s)

Where ω - area of the free section of the pipeline $\omega = \frac{\pi d^2}{4}$ (cm2)

3. Specific potential energy Ep= Z+$\frac{P}{\rho g}$ (cm)
4. Specific kinetic energy Eк=$\frac{\alpha V^2}{2g}$ (cm)
5. Total specific energy Z+$\frac{P}{\rho g} + \frac{\alpha V^2}{2g}$ (cm)
6. Energy loss hw= E1 – Ei

where E_{one}- total specific energy in the 1st section,

Ei - total specific energy in the i - th section.

test questions

1. What is the steady motion of a fluid. Name other types of movement and give their characteristics?
2. What is the main meaning of the continuity equation?
3. What is the meaning of D. Bernoulli's equation?
4. Terms of use D. Bernoulli?
5. What is hydrodynamic head?
6. What is piezometric pressure?
7. How does the piezometric and hydraulic slopes change along the flow length?
8. What is head loss?

L A B O R A T O R N A Y R A B O T A No. 3

CALIBRATION OF A VENTURI FLOWMETER

PURPOSE OF THE WORK

1. Mastering the technique of measuring water flow with a Venturi pipe
2. Calibrating the flowmeter and building a calibration chart

BRIEF THEORETICAL INFORMATION

To measure the flow rate of a liquid (gas) moving uniformly in a pressure pipeline, special devices are used - nozzles, diaphragms, Venturi pipes.

The use of these devices is based on the existence of a certain relationship between the pressure drop (created in the flow as a result of the narrowing of the pipe flow area) and the flow rate of the liquid. For each specific narrowing device, this dependence can be found from the basic equations of hydraulics: the Bernoulli equation and the flow continuity equation.

The Venturi flow meter is a pipe of variable cross section, consisting of two sections - smoothly tapering and gradually expanding. The flow velocity in the constriction increases and the pressure decreases. A difference (difference) of pressure arises, which is measured by a pair of piezometers installed at the beginning of the cone and in the cylindrical section.

The theoretical fluid flow in the pipeline can be determined by the formula:

$$Q = V_4 \omega_4 = \sqrt{\frac{2gh}{1 - \frac{\omega_1}{\omega_2}}} \cdot \omega_4$$

where $\Delta h = \frac{P_3}{\rho g} - \frac{P_4}{\rho g}$

or $Q = C\sqrt{\Delta h}$

where C-value, constant for a given flowmeter and equal to

$$C = \sqrt{\frac{2g}{1 - \frac{\omega_4}{\omega_3}}} \cdot \omega_4$$

Knowing the value of C and observing the readings of piezometers, it is possible to determine the flow in the pipeline for any moment of time using the formula:

$$Q = C\sqrt{\Delta h}$$

For standard flowmeters, resistance coefficients and flowmeter constants are given in special reference books. The constant C can also be calculated theoretically, but more precisely, it is determined from the experiment, i.e., as a result of the calibration of the flow meter. When taring, it is convenient to present the results of experiments in the form of a dependence graph

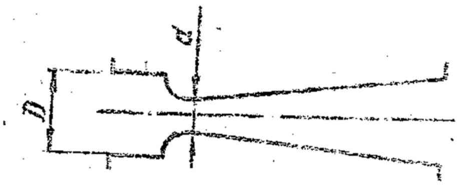
$$\Delta h = f(Q).$$

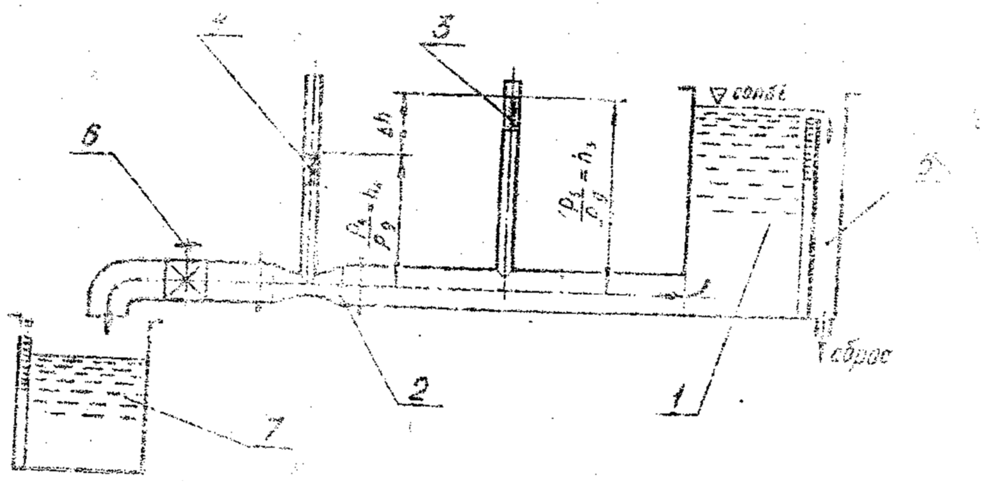
In this case, you can determine the flow directly from the schedule, without resorting to calculations.

DESCRIPTION OF THE EXPERIMENTAL SETUP.

The installation (Fig.3.1) includes: a pressure tank /1/, a pipeline /2/, at the end of which a tap /6/ is installed, a measuring tank /7/. A Venturi pipe is installed in the middle part of the pipeline. To measure the pressure drop, piezometers /3/ and /4/ are connected to the flowmeter. A constant pressure in the tank is maintained by means of a weir /5/.

Venturi tube





Rice. 3.1. Scheme of installation for tare

Venturi flowmeter

ORDER OF EXPERIMENTS.

1. The pressure tank /1/ is filled with water.

2. The absence of air in the piezometers is checked.
3. Using the valve /6/, different water flow rates are set in the pipeline and piezometer readings are measured for each experiment.

$$h_3 = \frac{P_3}{\rho g};$$

$$h_4 = \frac{P_4}{\rho g};$$

A total of at least 5 measurements are taken.

4. At the same time, the amount of water entering the measuring tank W during the experiment t is determined.

Measurement data are entered in Table 3.1.

PROCESSING OF EXPERIMENTAL RESULTS.

1. The actual flow rate is calculated

$$Q = \frac{W}{t} \text{ (cm3/s)}$$

2. The difference between the readings of the piezometers /3/ and /4/ is determined

$$\Delta h = h_3 - h_4$$

3. Flow meter constant is calculated

$$C = \frac{Q}{\sqrt{\Delta h}}$$

4. Based on the results of the experiments, a calibration chart is built

$$\Delta h = f(Q).$$

The calculation results are entered into a table.

Table 3.1

No.	Measurement data				Calculations			
	W	T	h3	h4	Q	Δh	C	Wed
one	2	3	four	5	6	7	eight	9

Based on the results of the experiments, a calibration chart is built $\Delta h = f(Q)$.

Test questions:

1. For which flows is a Venturi tube used to measure liquid flow.
2. What is a Venturi flow meter?

How is the constant coefficients determined for a given flow meter?

L A B O R A T O R N A Y R A B O T A No. 4

DETERMINATION OF THE HYDRAULIC COEFFICIENT

LENGTH FRICTION

PURPOSE OF THE WORK.

1. Empirical determination of the coefficient of hydraulic friction λ for various modes of fluid movement.
2. Determination of the area of resistance, the choice of calculation formulas for calculating the value of the coefficients of hydraulic friction, depending on the mode of fluid movement.
3. Comparison of the results of the experimental determination of the coefficients of hydraulic friction with those calculated using the calculation formulas.

BRIEF THEORETICAL INFORMATION

A fluid flow uniformly moving in a pipe loses some of its energy due to friction on the pipe surface, as well as internal friction in the fluid itself. These losses are called friction pressure losses along the length of the flow.

In accordance with the Bernoulli equation, the head loss along the length is determined as the difference between the total specific energies in two sections of the considered section of the pipeline and for a horizontal pipe of constant diameter can be expressed as:

$$h_e = \frac{P_1}{\rho g} - \frac{P_2}{\rho g} \qquad \text{(one)}$$

where $\frac{P_1}{\rho g}$ and $\frac{P_2}{\rho g}$ - piezometric heads in the corresponding sections of the flow.

Equation (1) is the main one in the experimental determination of pressure losses due to friction.

To calculate the pressure loss due to friction during the movement of fluid through pipes, the Darcy-Weisbech formula is used:

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

where **λ -**coefficient of hydraulic friction;

V-the average velocity of the fluid;

l**-**pipeline length;

d-pipeline diameter;

g-free fall acceleration, g = 9.81 m/s2, Formula (2) is valid for various modes of fluid motion. However, the values of the coefficients λ for laminar and turbulent regimes will be different and, in the general case, λ will also depend on the relative roughness of the pipe walls, i.e.

$$\lambda = f(\mathrm{Re}, \frac{\Delta}{d})$$

where Δ is the absolute size of the roughness protrusions.

The coefficient λ is determined on the basis of experimental data or known empirical dependencies. Experience has shown that in laminar flow, roughness does not affect the resistance to movement. The coefficient λ in this case depends only on the Reynolds number and can be calculated by the formula:

$$\lambda = \frac{64}{\mathrm{Re}} \qquad (3)$$

Head loss in laminar flow is proportional to the velocity to the first power: $h_e = kV$

In a turbulent flow, a thin layer of liquid with a laminar regime is formed near the walls. The bulk of the fluid (the core of the flow), in which the movement is turbulent, is connected with this layer by a transition zone. The combination of the laminar layer and the transition zone is called the boundary layer. The thickness of the boundary layer is measured in fractions of mm, denoted**δ**and depends on the Reynolds number.

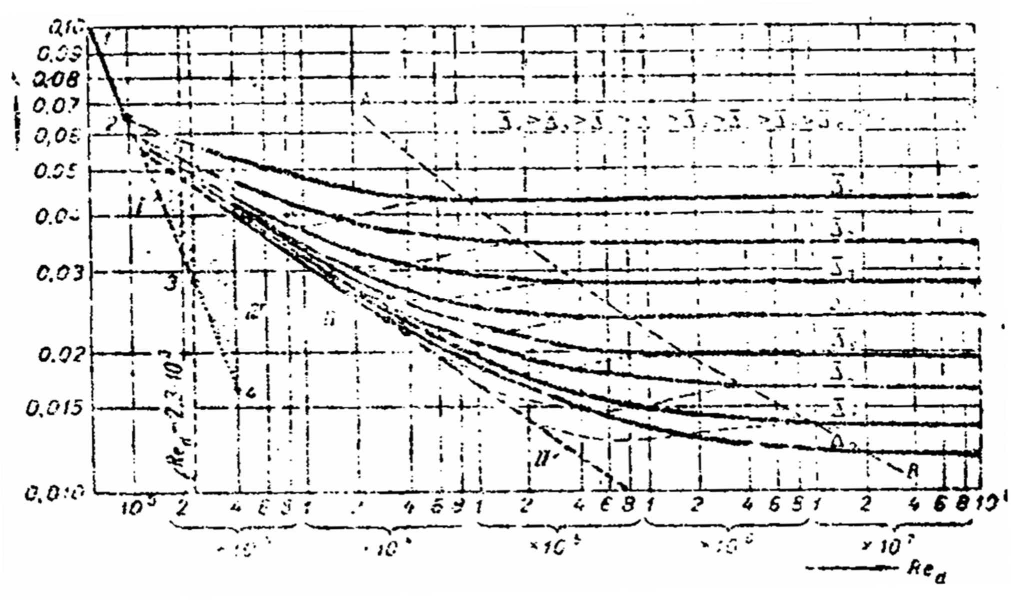
While the average value of the protrusions that form the roughness of the pipe surface (the absolute equivalent roughness Δ, is less than the thickness of the boundary layerΔ<**δ**), the turbulent flow does not come into direct contact with the protrusions, the roughness does not affect the magnitude of the head loss. Such surfaces are called hydraulically smooth.

With the increase*Re*the thickness of the boundary layer decreases and becomes less than the roughness peaks (Δ>δ). The ledge enters the turbulent core of the flow and increases the head loss. Such surfaces are called hydraulically rough.

To characterize the effect of roughness on the magnitude of losses, the concept of equivalent relative roughness is introduced $\overline{\Delta} = \frac{\Delta}{d}$,

where d is the diameter of the pipe.

The dependence of the coefficient of hydraulic friction on the roughness and*Re*for pipes with natural roughness (technical pipes) is shown in fig. 4.1 (graph by Nikuradze).



Rice. 4.1 Nikuradze's schedule

The first zone is the laminar regime zone, it is represented by the straight line 1-2-3 (see formula (3)).

The second zone, the zone covered with oblique shading, is the zone of the unstable mode. Here the Reynolds numbers range from 1000 -2300 to 4000.

The third zone is the turbulent regime zone. This zone is located on the right verticalIII, corresponding to Re=4000. This zone, in turn, is divided into three areas of resistance:

1) The area of hydraulically smooth pipes is a straight line with a gradual transition to a curve for relative roughness Δ=0.000005 at Re=105. In this region, λ depends only on the Reynolds number and is determined by the Blasius formula:

$$\lambda = \frac{0{,}3164}{\mathrm{Re}^{0.25}}$$

2) The quadratic resistance area on the chart is located between lines I and II. To determine, the Altshul formula is used:

$$\lambda = 0{,}11(\overline{\Delta} + \frac{68}{\mathrm{Re}})^{0.25}$$

3) The area of quadratic resistance (self-similar) on the chart, this area is located to the right of line II. In this area, friction pressure losses are proportional and the coefficient of hydraulic friction is calculated using the Shifrinson formula:

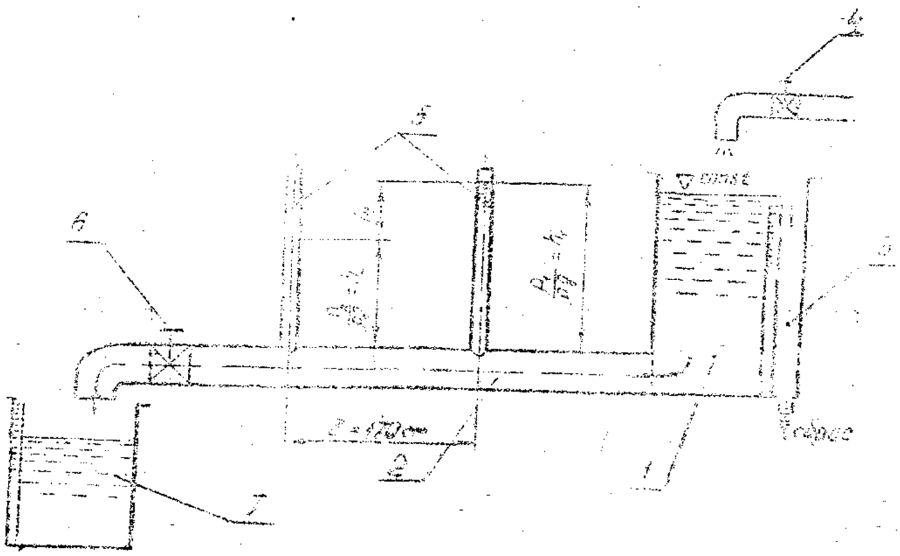
$$\lambda = 0{,}11\left(\overline{\Delta}\right)^{0,25}$$

All of the above is conveniently summarized in Table 4.1.

DESCRIPTION OF THE PILOT SETUP

The pilot plant (Fig. 4.2) consists of a tank /1/ from which a pipeline /2/ with a diameter of d = 2.5 cm departs. The pipeline has a straight section with a length l =170 cm. Piezometers /5/ are installed at the beginning and end of the section.

A weir /3/ is installed in the tank, maintaining a constant pressure. A measuring tank /7/ is installed at the end of the pipe. The water flow is regulated by taps /4/ and /6/.



Rice. 4.2 Installation diagram for determining losses

pressure along the length of the pipe

EXPERIMENTAL PROCEDURE

The pressure tank is filled with water to a constant level.

By opening the valve /6/ in the pipeline, the flow regime is established, corresponding to the minimum liquid flow rate in the experiment. It is recommended to carry out experiments at least three times with different tap openings /6/.

For each mode is defined:
A) the volume that entered the measuring tank W during the experiment t.
B) Readings of piezometers h1 and h2.

PROCESSING OF EXPERIMENTAL DATA

1. The pressure loss in the selected area is determined from the Bernoulli equation, compiled for sections 1-1 and 2-2.

$$z_1 + \frac{P_1}{\rho g} + \frac{\alpha_1 V_1^2}{2g} = z_2 + \frac{P_2}{\rho g} + \frac{\alpha_2 V_2^2}{2g} + h_e$$

because z1=z2, V1=V2, hl= $\frac{P_1}{\rho g} - \frac{P_2}{\rho g}$

2. The flow rate and speed are average, the movement of fluid in the pipeline.

   Q=W/t (cm3/s), V=Q/ω (cm/s).

3. To determine the drag coefficient λ, the Darcy-Weisbach formula is used:

$$\lambda = h_l \frac{d}{l} \cdot \frac{2g}{V^2}$$

4. To determine the resistance area, the Re numbers are calculated

$$\mathrm{Re} = \frac{Vd}{\nu}$$

5. Depending on the area of resistance, a formula is selected to determine the theoretical value of the coefficient of hydraulic friction along the length.
6. The results of measurements and calculations are entered in table 4.2.

Table 4.1

Mode	Turbulent		
Region resistance	Hydraulically smooth pipes	Up to quadratic resistance	quadratic resistance
General dependence of the coefficient of hydraulic friction	$\lambda = f(\mathrm{Re})$	$\lambda = f(\mathrm{Re}, \overline{\Delta})$	$\lambda = f(\overline{\Delta})$
Criteria for determining the area of resistance	$\mathrm{Re} < \mathrm{Re}'_{кр} = \frac{20}{\overline{\Delta}}$	$\mathrm{Re}'_{кр} < \mathrm{Re} < \mathrm{Re}''_{кр}$	$\mathrm{Re} > \mathrm{Re}_{кр} = \frac{500}{\overline{\Delta}}$
Calculation formula example	$\lambda = \frac{0{,}3164}{\mathrm{Re}^{0.25}}$	$\lambda = 0{,}11(\overline{\Delta} + \frac{68}{\mathrm{Re}})^{0.25}$	$\lambda = 0{,}11(\overline{\Delta})^{0{,}25}$

Table 4.2

No.	Determination of head loss along the length			Determination of average speed				Determination of the coefficient of hydraulic friction			
	$\frac{P_1}{\rho g}$	$\frac{P_2}{\rho g}$	he	W	t	Q	V	λ cn	Re	Region resist.	λ t
	cm	Cm	Cm	cm3	With	cm3/s	cm/s				

Test questions:

1. How is the pressure loss determined along the length of the pipeline using the D. Bernoulli equation?
2. Give the formula for the head loss along the length for a horizontal pipeline with a constant diameter?
3. Write down the Darcy - Weyesbach formula and show the scope of these formulas?
4. Show the values of the coefficient of hydraulic friction for different modes of fluid movement?

L A B O R A T O R N A Y R A B O T A No. 5

DETERMINATION OF LOCAL RESISTANCE COEFFICIENTSII.

PURPOSE OF THE WORK.

1. Determine empirically the values of the coefficients of local resistance.

2. Compare the obtained values of the coefficients with the results of calculations using theoretical formulas or those given in reference books.

BRIEF THEORETICAL INFORMATION.

One of the most important issues in applied hydraulics is the determination of energy losses during the movement of liquids. A special case of energy loss during the movement of fluid through a pipeline is the loss of energy in local resistances.

Local hydraulic resistances are such elements of pipelines in which, due to a change in the size or configuration of the channel, the flow velocity changes, the transit jet is separated from the channel walls and vortex formation occurs. Local resistances are found in all hydraulic systems. Most often, these are various shutoff valves (taps, gate valves, etc.), expansion and contraction of flow sections, turns, elbows, etc.

Energy losses are ultimately due to the viscosity of the liquid, and therefore, the lost mechanical energy is dissipated and converted into heat.

To calculate the head loss caused by local resistances, use the formula:

$$h_м = \xi \frac{V^2}{2g},$$

where hм – pressure loss due to local resistance, cm;
V is the average flow velocity, cm/s;
ξ is the coefficient of local resistance.

The coefficient of local resistance significantly depends on the type of local resistance, its geometric shape, the fluid flow rate, its density, viscosity, and also on the diameter of the pipe through which the flow moves. This coefficient is usually determined empirically.

1. For a sharp expansion of the flow (Fig. 5 a), the magnitude of the head loss can be obtained theoretically from the Borda formula:
2.

$$h_{pp} = \frac{V_d - V_D}{2g}$$

where hpp - loss of pressure during a sharp expansion, cm;

Vd is the average fluid velocity before expansion, cm/s;

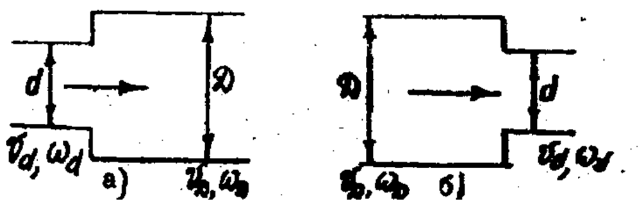
VD - the same after expansion.

After transformation, this formula looks like: $h_{pp} = \xi_{pp}\dfrac{V^2}{2g}$

where - $\xi = (\dfrac{\omega_D}{\omega_d} - 1)^2$

ωd is the open area before expansion, cm2;

ωD - open area after expansion.



Rice. 5.

3. For a sharp narrowing of the flow (Fig. 4)

$$h_{pc} = \xi_{pc}\frac{V^2}{2g}$$

The value of the coefficient of local resistance with a sharp narrowing is theoretically determined by the formula

$$\xi_{pc} = 0.5(1 - \frac{\omega_D}{\omega_d})$$

4. For a plug valve, the coefficient of local resistance depends on its design and degree of opening. The values of the coefficients ξcr depending on the angle of rotation of the plug valve are given in Table 5.1.

Table 5.1

Angle of rotation	5	ten	twenty	thirty	40	fifty	60	65
Coef. resist.	0.05	0.029	1.56	5.47	17.3	52.6	206	485

INSTALLATION DESCRIPTION

The pilot plant (Fig.5.1) consists of a tank /1/, from which a pipe /2/ departs. The water level in the tank is kept constant by means of a weir. On the pipeline there are local resistances in the form of a sharp expansion /5/, a sharp narrowing /6/, a tap /7/. Piezometers /3/ are installed before and after each local resistance. A measuring tank /4/ is installed at the end of the pipeline

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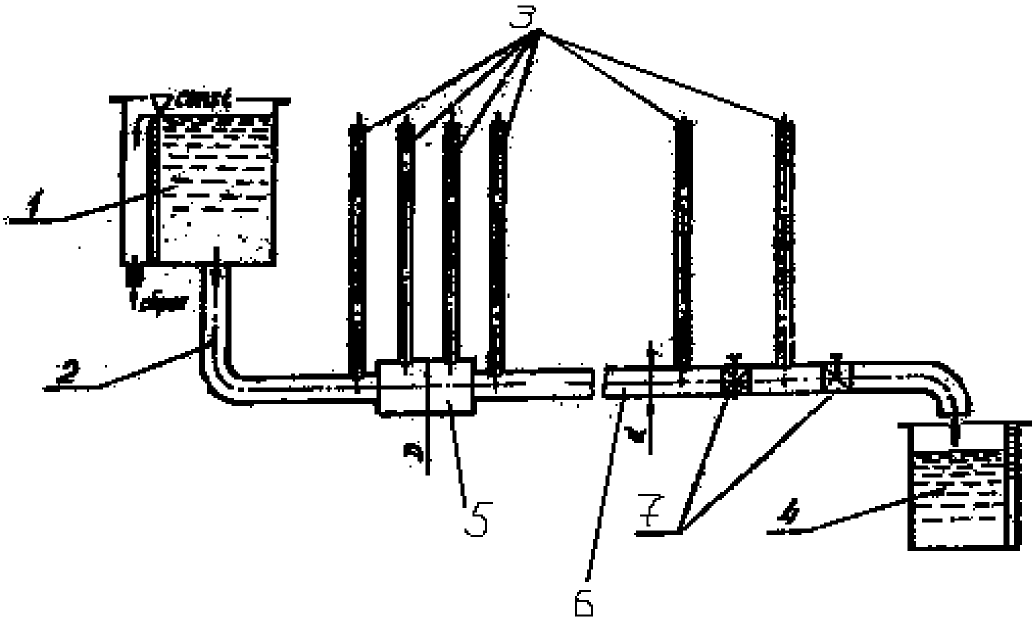


Rice. 5.1

Scheme of installation for the study of local resistances

EXPERIMENTAL PROCEDURE

When opening the tap /7/ set the flow rate in the pipeline. Upon reaching a steady-state movement of the liquid before and after local resistance, the piezometric head is measured, and the volume of water in the measuring tank /4/ and the time of its filling are also determined. The results are recorded in a table. Experiments are carried out at least three times at different flow rates, which are regulated by a tap /7/.

PROCESSING OF EXPERIMENTAL DATA.

The flow rate of water and the average speed of its movement are determined in the following way:

$$Q = \frac{W}{t}, V_d = \frac{Q}{\omega_d}; V_D = \frac{Q}{\omega_D},$$

where $\omega_d = \frac{\pi d^2}{4}, \omega_D = \frac{\pi D^2}{4}$

Here d- diameter of the pipeline by expansion;

D - the same after expansion.

Then the head loss in local resistances is determined. To do this, use the Bernoulli equation:

$$z_1 + \frac{P_1}{\rho g} + \frac{\alpha_1 V_1^2}{2g} = z_2 + \frac{P_2}{\rho g} + \frac{\alpha_2 V_2^2}{2g} + h_{w_{1-2}}$$

z1=z2 since the pipeline is horizontal, then

$$\frac{P_1}{\rho g} + \frac{\alpha_1 V_1^2}{2g} = \frac{P_2}{\rho g} + \frac{\alpha_2 V_2^2}{2g} + h_{w1-2}$$

Head loss between sections: hw1-2=hl+hm

where hl-pressure loss along the length;

hM- the same for local resistance.

Since the loss along the length is very small, then

$$h_{W_{1-2}} = \text{hM} = \left(\frac{P_1}{\rho g} + \frac{\alpha_1 V_1^2}{2g}\right) - \left(\frac{P_2}{\rho g} + \frac{\alpha_2 V_2^2}{2g}\right)$$

here $E = \frac{P}{\rho g} + \frac{V^2}{2g}$ is the total specific energy of the flow.

Since for the crane V1=V2=Vd, then hcr=$\frac{P_5}{\rho g} + \frac{P_6}{\rho g}$

The pressure loss during expansion and contraction of the pipeline is determined by the difference in the total specific energies before and after local resistance.

$$hp.p = E1 - E2 = \left(\frac{P_1}{\rho g} + \frac{V_d^2}{2g}\right) - \left(\frac{P_2}{\rho g} + \frac{V_D^2}{2g}\right)$$

$$hpc = E3 - E4 = \left(\frac{P_3}{\rho g} + \frac{V_D^2}{2g}\right) - \left(\frac{P_4}{\rho g} + \frac{V_d^2}{2g}\right)$$

The experimental values of the local resistance coefficients are calculated according to the formula:

$$\xi = \frac{h_M 2g}{V^2}$$

The theoretical values of the local resistance coefficients are calculated and compared with the experimental ones. The results are entered in the table.

Table 5.2

No.	Piezometer readings						W	T	Constants
	Sharp exp.		Sharp narrowing.		tap				d=2 cm; D=50 cm
	$\frac{P_1}{\rho g}$	$\frac{P_2}{\rho g}$	$\frac{P_3}{\rho g}$	$\frac{P_4}{\rho g}$	$\frac{P_5}{\rho g}$	$\frac{P_6}{\rho g}$			
	cm	cm	cm	cm	Cm	cm	cm3	c	
one	2	3	four	5	6	7	eight	9	ten

Table 5.3

No.	Q	Vd	VD	hpp	hpc	hcr	ξpp	ξrk	ξcr	ξrrt	ξrst	ξcrt
	cm3/s	cm/s	cm/s	cm	cm	Cm						
one	2	3	four	5	6	7	eight	9	ten	eleven	12	13

test questions

1. What is local hydraulic resistance?
2. What is a stop valve?
3. Give the formula for determining the pressure loss caused by local resistances?
4. Give the Bordeaux formula and explain the scope of these formulas?

Translated from Russian to English - www.onlinedoctranslator.com

L A B O R A T O R N A Y R A B O T A No. 6

LIQUID OUTFLOW THROUGH A SMALL HOLE

IN A THIN WALL.

PURPOSE OF THE WORK

Investigate the characteristics of the outflow, determine experimentally the values of the compression ratio E, speed φ, local resistance ξ, flow rate μ, characterizing the outflow of fluid through a small hole in a thin wall (Fig. 6.1 a).

BRIEF THEORETICAL INFORMATION.

A hole is considered small if its diameter is d≤ $0.1H$,

where H - head above the center of the hole.

A thin wall is one whose thickness$\delta<3d$*res*does not affect the nature of the outflow of liquid from the hole, as well as the wall, the edges of which in the hole have a sharp edge.

Due to the fact that the liquid approaches the round hole from all sides, the streamlines at the beginning of the jet turn out to be curvilinear and, having passed the hole plane, continues to approach the jet axis. For this reason, the jet at the outlet of the hole is compressed and at a distance different (0.5 ÷ 0.1) dresp, it acquires compression, this section is called the compressed section (Fig. 6.1b).

The degree of jet compression is determined by the compression ratio

$$\varepsilon = \frac{\omega_{сж}}{\omega}$$

where ωcompressed area,

ω is the hole area.

The average speed in the compressed section of the jet is determined by the formula.

$$V = \varphi\sqrt{2gH}\,, \qquad \varphi = \sqrt{\frac{1}{\alpha + \xi j}}\,,$$

where φ - speed coefficient, taking into account the decrease in the theoretical value of the speed $V_T = \varphi\sqrt{2gH}$ due to the presence of flow resistances and is the ratio of the actual speed to the theoretical

$$\varphi = \frac{V}{V_T};$$

ξj - coefficient of local resistance,

α- Coriolis coefficient in compressed sections, α=1.0

The actual speed V is determined from the equation of the trajectory of the fall of the jet, (parabola).

$$V = X\sqrt{\frac{y}{2Y}},$$

"X" and "Y" are the coordinates of arbitrary points of the jet relative to the origin of coordinates, which coincides with the center of gravity of the compressed section. Knowing the speed coefficient φ, it is possible to determine the coefficient of local resistance.

$$\xi_j = \frac{1}{\varphi^2} - 1$$

Fluid flow through a small hole in a thin wall

$$Q = \mu \cdot \omega \cdot \sqrt{2gH},$$

where ω - hole area,

μ - flow coefficient equal to the ratio of the actual flow to the theoretical flow, i.e. obtained without taking into account the resistance and compression of the jet:

$$\mu = \frac{Q}{Q_T} \text{ or } \mu = \varepsilon \cdot \varphi$$

where $Q_T = \omega \cdot \sqrt{2gH}$

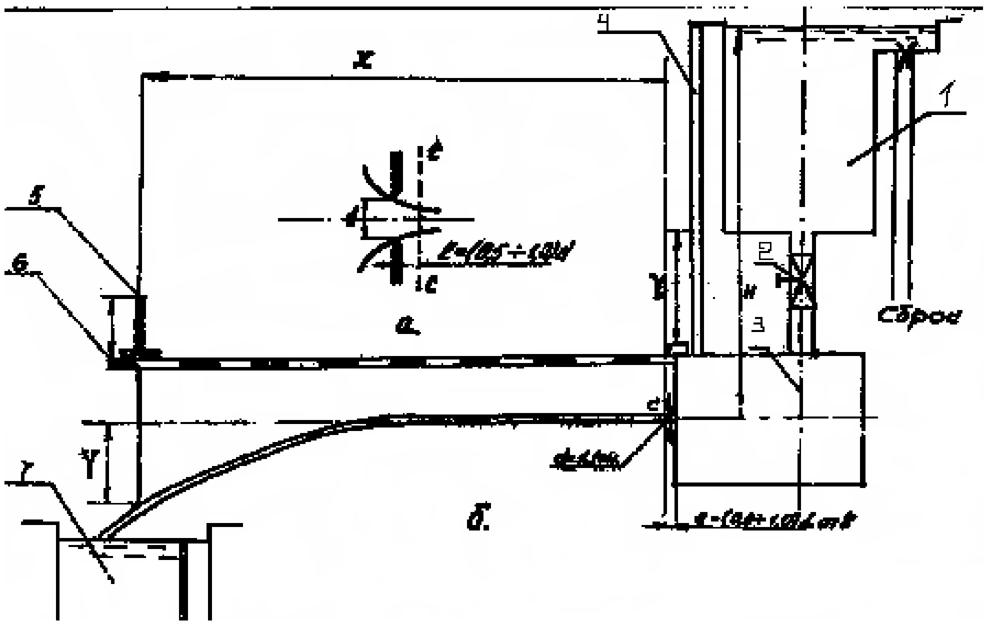
Based on experimental data for small holes in a thin wall under perfect compression.

$\varepsilon = 0.64$; $\xi_j = 0.06$; φ=0.95; μ=0.62.

DESCRIPTION OF THE EXPERIMENTAL SETUP.

The pilot plant (Fig. 6.1a) consists of a pressure tank /1/, in which a constant level is maintained by means of a weir. The pressure tank is connected by a vertical pipe to a tank of a smaller volume /3/, in the wall of which there are holes dov=1.1 cm with sharp edges. The pressure above the hole center is measured with a piezometer /4/.

By changing the opening of the tap /2/, different pressures are set above the center of the hole. To determine the actual speed, the coordinates of the incident jet are measured. To determine the horizontal coordinate "X", a rail with divisions /5/ is installed. Using the Spitzenscale /6/, the vertical coordinate of the jet "U" is determined. The volume of water is measured with a measuring vessel /7/.



Rice. 6.1 Scheme of the pilot plant

Jet Compression Factor Definitions

Table 6.1

No.	dczh	ωco	ε	ε_{cp}	Constant
	Cm	cm2			
one	2	3	four	5	6
one. 2.					d=11

Determination of the flow rate

Table 6.2

No.	H	W	t	Q	QT	μ	μav
	Cm	cm3	sec	cm3/sec	cm3/sec		
one	2	3	four	5	6	7	eight
one.							

2.							

Determination of the velocity coefficient and hydraulic resistance.

Table 6.3

No.	H	X	Y	Yi	V	VT	φ	φav	ξav	Constant
	cm	Cm	cm	cm	cm/s	cm/s				
one	2	3	four	5	6	7	eight	9	ten	eleven
one. 2.										

ORDER OF EXPERIMENTS.

1. The valve /2/ is opened and, according to the readings of the piezometers, the desired pressure is set above the center of the hole.
2. The shape of the cross section of the jet is observed and the compressed section of the jet is measured with a caliper.
3. To determine the actual speed, the coordinates "X" and "Y" are measured. The rail /5/ is displaced relative to the “U” axis by the value “U0” (Fig. 7.1a), determined by the Spitz scale along the axis of the jet in the compressed section. For three points of the trajectory of the incident jet, its coordinates are measured.
4. Measure the volume of water in the measuring vessel /7/ and the time of its filling.

The measurement results are entered in tables 6.1, 6.2, 6.3.

PROCESSING OF EXPERIMENTAL DATA.

The area of the compressed section of the jet is determined by the diameter of the jet in the compressed section

$$\omega_{сж} = \frac{\pi d_{сж}^2}{4}$$

And the compression ratio of the jet $\varepsilon = \frac{\omega_{сж}}{\omega}$

Calculate the actual and theoretical fluid flow through the small hole and the flow rate.

$$Q = \frac{W}{t}; \qquad Q_T = \omega\sqrt{2gH}\,; \qquad \mu = \frac{Q}{Q_T}$$

The calculated value of the "y" coordinate is determined by the formula

Y=Y0-Y,

"U0" is the coordinate of the jet in the compressed section, which is not measured during the experiments.

Determine the actual speed

$$V = X\sqrt{\frac{g}{2Y}};$$

theoretical speed $V_T = \sqrt{2gH}$;

speed and local resistance coefficients

$$\varphi = \frac{V}{V_T};\ \xi_{\kappa p} = \frac{1}{\varphi_{cp}^2} - 1.$$

Test questions:

1. What holes are called small?
2. What is the definition of thin wall?
3. Give the formula for determining the jet compression ratio?
4. Give the formula for determining the average speed in a compressed stream?
5. How is the actual velocity in the compressed section of the jet determined?

$$W_{om} = EW_2 = E\varphi\sqrt{2gH} = \alpha\sqrt{2gH}$$

Or volume flow: $V_x = \alpha F_{om}\sqrt{2gH}$,

where E=F2/Fot – compression ratio;

$\alpha = \varphi E$ - consumption coefficient;

Fot - cross-sectional area, m2

The flow rate is determined experimentally. The flow rate of liquids by properties that are not very different from water is equal to:

- $\alpha = 0{,}62$ when flowing through the hole;

- $\alpha = 0{,}82$ when flowing through nozzles.

It can be seen from the above formula that the flow rate of a liquid in a thin wall of a vessel with a constant liquid level depends on the liquid level and on the size of the hole, but does not depend on the shape of the vessel.

Now let's find the time spent on changing the fluid flow from H1 to H2. To do this, we write the fluid flow rate for a very short time dt:

$$dV = V_x d\tau = \alpha F_{om} \sqrt{2dH}\, d\tau \text{ (four)}$$

Over this time $d\tau$ the liquid level also changes by dH, and since the cross-sectional area of the vessel is constant, then

dV=-Fdh,

where F-cross-sectional area of the vessel, m2.

The minus sign on the right side of the equation indicates a decrease in the liquid level in the vessel.

Equate the above two equations:

$$\alpha F_{om} \sqrt{2dH}\, d\tau = \text{-Fdh(5)}$$

$$d\tau = -\frac{FdH}{\alpha F_{om}\sqrt{2gH}}.$$

Integrating, we get: $\tau = -\dfrac{2F(\sqrt{H_1} - \sqrt{H_2})}{\alpha}$

Scheme of the pilot plant: The water supply to the vessel (1) through the pipeline (5) comes from the city water supply and is regulated by the water supply valve (2). Filling the vessel with water up to a certain height is fixed on the scale (3) installed on the side of the vessel. And at the bottom of the vessel there are four holes - nozzles of different diameters.

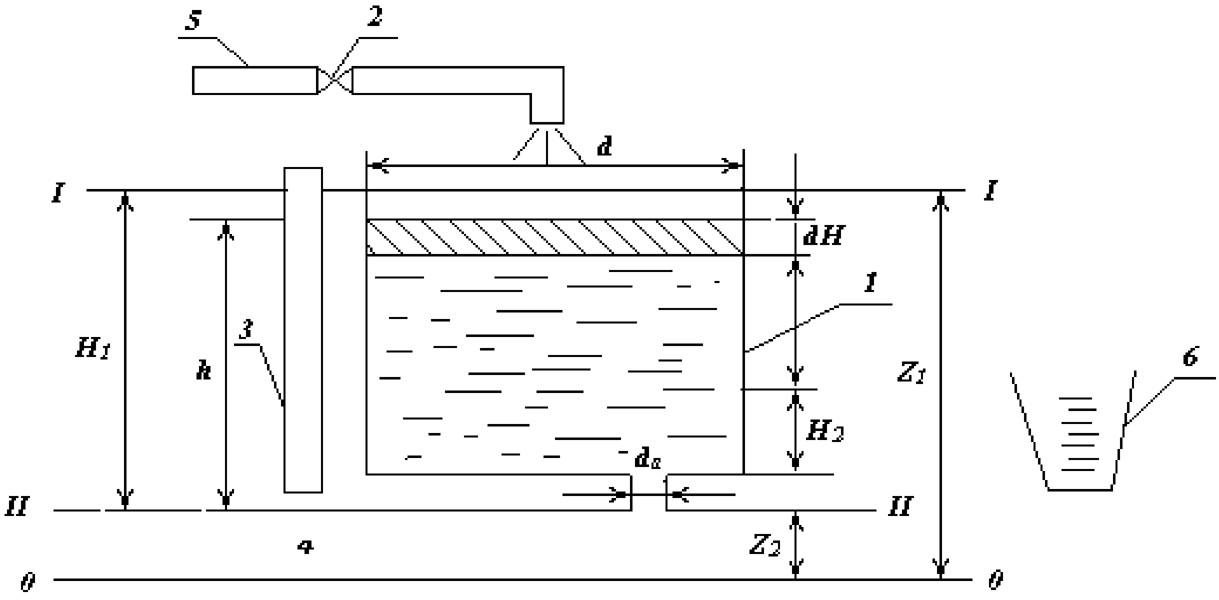


Figure 7.1 Scheme of an installation designed to study the outflow of liquid from a hole in a vessel.

The work consists of two parts. In the first part - the water level in the vessel (1) is constant. Each time before the start of the experiment, the vessel (1) is filled with water to a certain level using the valve (2), then the valve (2) is closed.

In the second part of the work, the flow coefficient is found at a constant and variable liquid level. To maintain a constant water level in the vessel, a drain pipe (7) is installed in it to overflow excess liquids. At the same time, valve (2) must be open for further experiment. The flow rate of the outflowing liquid is measured using a measuring tank (6). When performing the second part of the work, only one of the holes (the largest) installed in the bottom of the vessel is used. Only under the condition that the bottom of the vessel is smooth and even with a hole installed to it - a nozzle (part of the pipe) is the flow coefficient.

The order of the work.

In the first part of the work, the valve (2) is opened; the vessel (1) is filled with water to a certain level*H*, while all holes in the bottom of the vessel (1) must be closed, and the valve (8) under the measuring tank (6) must be open. The selected level H1 is written in a notebook. Then one of the holes in the bottom of the vessel (1) opens and the stopwatch starts. After some outflow of liquid, the hole is closed with a plug and the stopwatch stops. The next selected water level (H2) in the vessel (1) and the stopwatch readings are also recorded in the notebook. For each hole, the experiment must be repeated at least twice.

After all measurements are completed, calculations begin.

After the liquid has flowed out of the hole in the bottom of the vessel; the time for the water level in the vessel to decrease from the height H_{one}up to height H2 is found by the following formula:

$$\tau = -\frac{2F(\sqrt{H_1} - \sqrt{H_2})}{\alpha F_{om}\sqrt{2g}},$$

where *F*is the cross-sectional area of the vessel, m2.

All measured and calculated values are entered in the calculation table 7.1.

Table 7.1.

No.	measurements			Computing	
	Initial fluid level: H1 (m)	Final liquid level: H2 (m)	Experienced Time: τ_{op}(sec)	Cross-sectional area of the vessel: F (m2)	Hole cross-sectional area: Fo (m2)
one					
2					

2 - part of the order of work.

Before the start of the experiment, all 4 holes in the bottom of the vessel (1) are closed, and the valve (2) is opened. In this case, the nozzle of the largest hole must be removed. Initially, the experiment is carried out for a variable water level in the vessel (1). To do this, the valve (2) opens and the vessel (1) is filled with water to a certain level*H1*, then valve (2) closes. The height H1 is written in a notebook.

After that, the largest hole in the bottom of the vessel (1) is opened and the stopwatch starts. After the water level drops to a height*H2*the hole closes and the stopwatch stops. The time spent on changing the water level from H1 to H2 is recorded in a notebook. The vessel (1) is again filled to the water level H1 and the experiment is carried out 3-4 times.

Then the experiment is carried out for a constant water level in the vessel (1). Before the start of the experiment, the valve (8) and all openings of the vessel (1) are closed, and by opening the valve (2), the vessel (1) is filled with water to the level of the drain pipe (7).

In continuation of the experiment, the valve (3) should be opened so that the flow rate of the liquid flowing out of the pipeline (5) should be slightly greater than the flow rate of the liquid flowing out of the hole in the bottom of the vessel. Then the largest hole in the bottom of the vessel opens (1). The volume of liquid flowing out of the hole and entering the measuring tank (6) by opening the valve (8) releases the measuring tank, and the measurements are repeated. And here is the experience.

Now, having installed the nozzle on the checked hole in the bottom of the vessel (1), the experiments are repeated 6-8 times in the above order.

After repeated measurements, their results are used.

Generalization of the results of the experiment and the construction of the calculation:

With a variable water level, the flow coefficient is found from equation (5), and at a constant water level, from equation (3). The volume flow is found from the equation:

$$V_X = V/\tau ,$$

where V is the volume of fluid flowing out of the hole, m3;

τ - fluid outflow time, sec.

The measured and calculated values at a variable water level are entered in Table 7.2., and at a constant level - in Table 7.3.

Table 7.2.

No.	measurements			Flow rate	Add-ons
	Initial water level H1 (m)	Final volume H2 (m)	experience time, τ (sec)		
one 2 3					

Table 7.3.

No.	measurements			Computing		
	Initial volume of water; H1 (m)	Water outflow time; τ (sec)	Final volume of water; H2 (m)	Water consumption; V_X m3/s	Flow rate;	additions
one 2 3						

Test questions:

1) What tubes are called nozzles?
2) What are the nozzles used for?
3) At what sizes and types of nozzles does the greatest fluid flow pass through them?
4) What types of nozzles are there?
5) What formula is used to determine the time for liquid to flow from a large volume vessel through a nozzle?
6) Give and determine the formula for the theoretical flow rate of liquid flowing out of the nozzle.

L A B O R A T O R N A Y R A B O T A No. 8

CHARACTERISTICS OF THE CENTRIFUGAL PUMP

Objective:

Pumps are used in many branches of the national economy. All pumps are divided into two main groups: dynamic and volumetric.

Dynamic pumps are those in which the energy of the liquid is communicated by the action of hydrodynamic forces on an open volume of liquid with a constant communication of the input and output of the pump.

Volumetric pumps are called in which the communication of energy to the liquid is carried out periodically by changing the closed volume with its variable communication with the inlet and outlet of the pump.

Vane pumps are called pumps in which the energy of the liquid is communicated by flowing around the working class blades. Vane pumps combine in turn two groups of pumps: centrifugal and axial.

Centrifugal pumps are called vane pumps with the movement of liquid through the impeller from the center to the periphery, and axial - vane pumps with the movement of liquid through the impeller in the direction of its axis.

Friction and inertia pumps are a group of dynamic pumps in which fluid movement is carried out by friction and inertia forces. This group includes vortex, screw, labyrinth, worm and jet pumps.

The group of volumetric pumps combines piston, plunger, diaphragm, rotary, gear, screw.

Consider the working diagram of a centrifugal pump (Figure 8.1)

The advantages of centrifugal pumps are compactness, relatively low weight, small dimensions with high performance, the ability to directly connect to an electric motor, smooth and continuous fluid supply, ease of start-up and adjustment.

Disadvantages: head instability - with an increase in productivity (withn=const) the pressure created by the pump decreases, low efficiency. for small productivity.

Inside the fixed housing 1, an impeller 2 is placed, mounted on a shaft 3. The pump housing is connected by nozzles 4 and 5 to the suction and pressure pipelines.

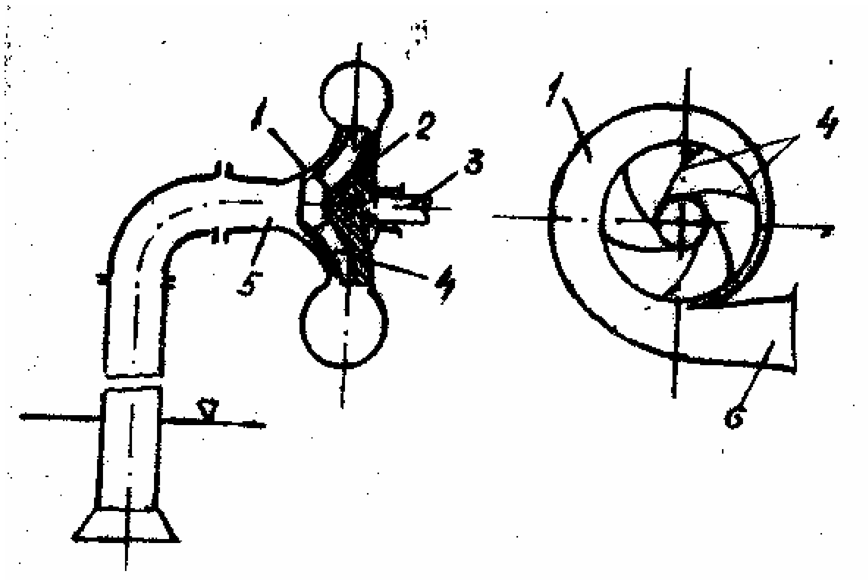


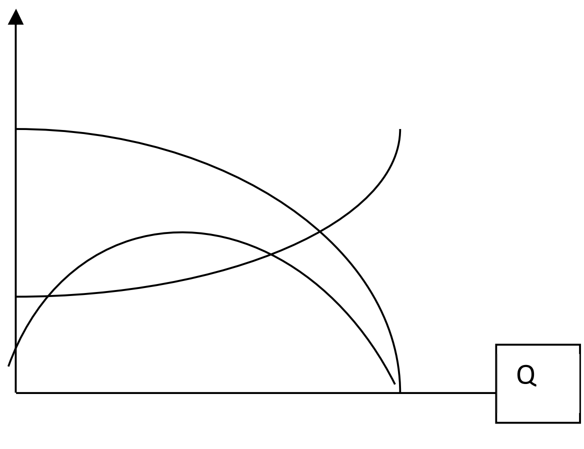
Figure 8.1

If the suction pipeline and the pump housing are filled with liquid, and then the impeller is rotated, then the liquid filling the channels between the blades will be thrown from the center of the wheel to the periphery under the action of the central force. After leaving the wheel, the liquid enters the spiral chamber and further into the discharge pipeline. In this case, before the liquid enters the impeller, a vacuum is formed, under the influence of which the liquid from the receiving tank enters the pump through the suction pipeline.

Centrifugal pumps can be not only single-stage, but also multi-stage, but the principle of their operation in all cases remains the same - the movement of fluid is carried out under the action of centrifugal force developed by a rotating impeller.

In a centrifugal pump, with a change in performance, other parameters of its operation also change - pressure, power,

Figure 8.2.



Characteristics of a centrifugal pump.

Before start-up, centrifugal pumps are filled with the pumped liquid. When changing within small limits, the number of revolutions "K" of the centrifugal pump, its flow Q, head "H" and power consumption "N" change in the following ratios:

$$\frac{Q_1}{Q_2}=\frac{n_1}{n_2};\frac{H_1}{H_2}=\left(\frac{n_1}{n_2}\right)^2;\frac{N_1}{N_2}=\left(\frac{n_1}{n_2}\right)^3$$

Dependencies QH; QN; Q-η are called pump characteristics and are established empirically.

Description of the installation.

The centrifugal pump (3) is mounted on the same shaft as the AC motor. The number of revolutions is measured. The water is sucked in by the pump from the supply tank (5). A suction valve (6) is installed on the suction pipe, which prevents water from escaping when the pump is filled through the suction pipe (7). A pressure gauge (9) and a valve for regulating the flow (supply) of water (10) are installed on the discharge pipeline (8). Water from the discharge pipeline enters one of the measuring tanks (11). Each tank has a water meter scale (4), which is graduated in units of volume (l), and a drain pipe is mounted in the tank to avoid overfilling. At the bottom of the tanks there are branch pipes with valves (1), through which water from the measuring tank is drained (1) into the supply tank, from where it is sucked again by the pump.

The methodology of the work.

When testing the pump, the installations determine the values \u200b\u200bnecessary to build the characteristics of the pump: QH, QN, Q-η. Tests are carried out at a constant number of revolutions, but at different, ever-increasing flow rates (feeds) Q of the pump. The change in the supply Q is carried out by gradually opening the valve (12). The first observation is carried out with the valve completely closed, the subsequent ones with a gradual opening of a quarter of a turn. In this case, it is necessary to measure: pump flow, vacuum in the suction pipe, pressure on the discharge pipe, voltage of the electric current on the engine.

Measurement of the performance of the pumping unit is carried out as follows.

Feed: closes the drain valve in one of the measuring tanks and starts the stopwatch. The amount of water measured on the water meter scale and the measurement time are recorded in the table. The pressure expressedw.m. the column of the supplied liquid (water) is determined as follows:

$$H=P_m+P_b+\frac{W_H^2-W_b^2}{2g}+h$$

Pm and Pb- indication of the pressure gauge and vacuum gauge in meters of the column of the supplied liquid;

Wm and Wv- water velocity at the points of connection of the manometer and vacuum gauge tubes.

h - The distance between the connection levels of the vacuum gauge and pressure gauge.

The suction and discharge pipelines are of the same diameter, so Wm and Wv are the same, and then H=Pm+Pv+h.

Processing of experimental data and reporting.

Performance (delivery) of the pump (m3/s); $Q = \dfrac{Q^1}{1000\tau}$ where

Q1- the volume of water determined by the water gauge glass, dm (or l);

τ is the measurement duration, s.

Power consumed by the pumps in the installation

$$N = \frac{VJ}{1000}$$

V- current voltage, J - current strength, A.

The efficiency of the pump is determined from the formula

$$N = \frac{QHg\rho}{1000\eta} \text{ where } \eta = \frac{QHg\rho}{1000N}$$

where Q - performance (pump flow), m3 / s

ρ is the liquid density, kg/m^3;

g – free fall accelerations, m/s2;

H is the total head created by the pump, in meters of the supplied liquid column.

The work ends with the construction of graphs: QN, Q-η, QH.

Table 8.1

No.	RPM	Duration of measurement, s	Qty water, dm3	PM pressure		Vacuum RV		Full head H	Power kW	efficiency %
				$\frac{кгс}{см^2}$ or mm. rt. Art.	m.v. st	$\frac{кгс}{см^2}$	m.water st			
	n	τ	Q	RM	HM	PC	HB	H	N	η
one										
2										

For each feed (Q) take 3 measurements. In the table, enter the average value of 3 measurements.

Installation scheme

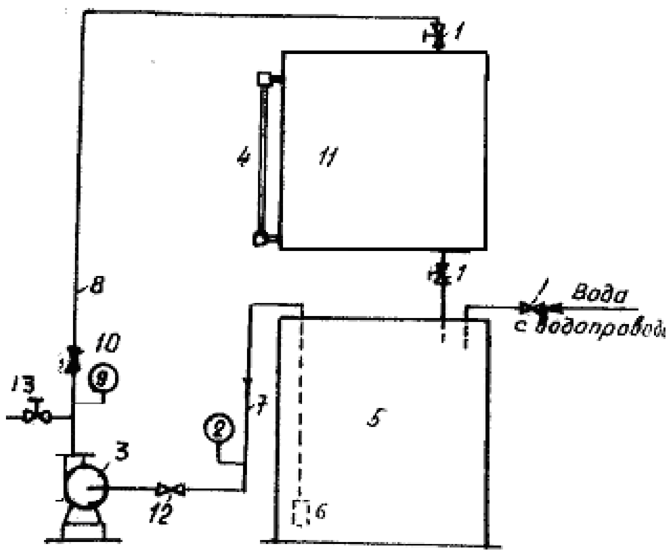


Figure 8.3

1. Valves 2. Vacuum gauge. 3. Pump 4. Gauge glass 5. Service tank. 6. Check valve 7. Suction pipeline 8. Discharge pipeline 9. Manometer 10., 12, Control valves 11. Measuring tanks. 13 Relief valve.

Test questions:

1) Centrifugal pump device.
2) Characteristics of a centrifugal pump.
3) Suction height and cavitation phenomenon.
4) The pressure developed by the pump.
5) Dependence of the main parameters of the operation of a centrifugal pump on the number of revolutions of the impeller.

Types and designs of centrifugal and piston pumps

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GLOSSARY

BY DISCIPLINE:

"HYDRAULICS»

Bunpressurizedoe dmovementis the movement of a fluidthe flow is not limited on all sides by solid wallskami, but has a free surface.

Vacuum-the difference between atmospheric and absolute pressure, which characterizes the lack of pressure to the ambient atmospheric pressure.

Internalliquids—these are the forces of interaction between the individual particles of the volume of liquid under consideration.

spillway- this is any wall blocking the flow through which the liquid overflows.

wave pressure- deviation of the hydrodynamic pressure in the presence of waves from the conditional hydrostatic pressure at the same point in space.

Viscosity is the property of a fluid to resist shear shear forces.

Hydraulica - applied technical science that studies the laws of equilibrium and motion of dropping liquids and considers the application of these laws to the solution of specific technical problems.

hydraulic accumulator-appliance,office workerfor accumulation, i.e. accumulation, collection of energy.

Hydraulic diameter$\boldsymbol{D_г}$- dimensional value equal to the quadruple hydraulic radius:$D_г = 4 * R_г$

hydraulic machines - machines servingto convert the mechanical energy of the engine into the energy of the fluid being moved (pumps) or the hydraulic energy of the fluid flow into mechanical energy (hydraulic motors).

Hydraulically the most advantageous section- this is such a cross section, which, for a given area of the living section ω, slope i, roughness coefficient n, has the highest throughput.

Hydraulic Press- a hydraulic machine used to obtain large compressive forces.

Hydraulic radiussections - aboutthe ratio of the open area to the wetted perimeter R=F/A.

Hydraulichit -a sharp change in pressure in the pressure pipeline due to a sudden change in the speed of the fluid in time.

Hydraulic drive (transmission)- consists of bladed hydraulic machines - pump and turbine wheels, extremely close to each other and located coaxially.

hydraulic jump- the transition of the transit flow from a turbulent state to a calm one.

Hydraulic resistance- resistance that appears in a moving fluid due to the action of external or internal friction forces, and manifests itself in pressure losses.

hydraulic motors-hydraulic machinesto convert fluid pressure energy into mechanical energy.

Hydrodynamica-branch of hydraulics that studies the laws of fluid motion.

Ghydromechanics-the sciencelaw studentequilibrium and motion of fluids, in which only strictly mathematical methods are used, which make it possible to obtain general theoretical solutions to various problems related to the equilibrium and movement of fluids.

Hydraulic drive -a set of devices - hydraulic machines and hydraulic devices designed to transfer mechanical energy and convert fluid.

hydrostaticpressure-Withcompressive stress that occurs inside a fluid at restand.

Depth in compressed section- the minimum depth of flow in the flow behind the weir, on the crest of the weir with a wide threshold or when draining from an orifice, where the fluid movement can be considered smoothly changing.

Flow depthis the distance from the stream bottom to its upper boundary (usually the free surface), measured in the vertical longitudinal plane normal to the bottom line.

Saturated vapor pressure or vaporization pressureis the pressure at which a liquid boils at a given temperature. The magnitude of the pressure depends on the type of liquid and its temperature.

Living sectionflow-the cross-sectional area of the flow, drawn normally to the direction of the streamlines, i.e. normal to the direction of velocities of elementary jets

Liquidbody,or **liquidand** -physical bodies that easily change their shape under the influence of the most insignificant forces.

Ideal Fluid- a liquid characterized by absolute mobility, i.e. the absence of tangential stresses in the liquid, and the absolute invariability in volume with a change in temperature or under the influence of any forces, i.e. no compressive or tensile deformations.

Overpressure$\boldsymbol{P_{изб}}$is the difference between absolute pressure P and atmospheric pressure . P*$P_a P_{изб} = P_a$

Excess piezometric height- the height to which, under the action of pressure at a given point, a liquid can rise, on the free surface of which the pressure of an external gaseous medium (atmospheric pressure) acts.

Evaporation- vaporization occurring only on the surface of a dropping liquid.

cavitationI (from the Latin word "cavitas" - cavity)-the formation in a moving liquid of cavities filled with steam or air (gas).

Cavitation reserve- the excess of the total pressure of the liquid in the suction pipe of the pump over the pressure of the saturated vapors of this liquid.$P_{н.п.}$

Cavitation mode of the pump- the mode of operation of the pump under cavitation conditions, causing a change in the main technical indicators.

dripliquids - These are liquids found in nature and used in technology: water, oil, gasoline, etc.

Boiling- vaporization throughout the volume of the liquid. It occurs at a certain temperature, depending on pressure.

shorte pipelines-pipelines in which pressure losses are mainly composed of local losses.

Coefficientfeed unevenness- aboutthe ratio of the maximum ordinate of the graph to the average.

Compression ratio- the ratio of the area of the compressed section ωszh to the area of the hole ω.

Speed ratio- coefficient φ, taking into account pressure losses.

backwater curve- curve of the free surface of the flow, the depth of which increases along the direction of flow.

Free Surface Curve- the line of intersection of the free surface of the flow with a vertical surface drawn through the axis of the flow.

decline curve- curve of the free surface of the flow, the depth of which decreases along the direction of flow.

Laminar fluid flow-liquid moves in layers without transverse mixing, and there are no velocity and pressure pulsations. The criterion for determining the mode of motion is the dimensionless Reynolds number.

Streamlineis the direction of motion of various particles belonging to this line.

Local friction head loss- a decrease in the total head due to the work of the forces of internal friction of the liquid with local deformation of the flow.

local resistance- resistance causing a sharp deformation of the flow.

pressureis the height of the liquid column above the considered level.

pressure headtraffic-movement of a fluid in a stream without free rotation-hnosti; it is usually observed in closed pipelines or other guides.raw systems.

Hupopuswaspis the energy deliveredpump for every kilogram of pumped liquid.

Nozzle or spigot- a very short pressure pipe (along its entire length), in the hydraulic calculation of which the pressure loss along the length hl should be neglected, only local pressure losses hj should be taken into account.

Pumps-hydraulic machines used to convert the mechanical energy of the engine into the energy of a moving fluid.

Non-viscous (ideal) liquid- some conditionalliquid with absolutelyand mobility of particles, consideringsya absolsnugly incompressible, not possessingviscosity - not withresistiveIXia tangential stressm.

Uneven (accelerated and slow) movement- this is a movement in which its cross section and, consequently, the average speed change along the length of the stream.

UninstalledXia movement-this kind of movement in which all the components listed above are a function of not only coordinates, but also time.

Nominal duty of the pump- the mode of operation of the pump, providing the specified technical indicators.

Back shock wave-Ppressure drop that is transmitted from layer to layer and propagates towards the valve.

Pump displacement -the volume of liquid supplied by the pump per unit of time.

Positive displacement pumps-hydraulic machines,serving to supply liquid under pressure.

Optimal pump mode- pump operation mode at the highest efficiency value.

vaporization- the property of dropping liquids to change their state of aggregation to gaseous.

Smoothly changing movement– motion in which the curvature of the streamline and the angle of divergence between them are very small and tend to zero in the limit.

Surface tension (capillarity) - this is a property of a liquid, which is due to the forces of mutual attraction that arise between the particles of the surface layer and cause its stressed state.

Surface forces- these are the forces acting on the surface of the studied volumes of liquid, for example, the pressure force of the piston on the surface of the liquid.

Flowis a set of elementary streams.

full head- the sum of the piezometric and velocity pressures.

Loss of pressure due to friction along the length- a decrease in the total head over a certain length of the watercourse, due to the work of friction forces on the outer boundary of the flow.

Performancepump- aboutliquid volume,pumped into the pipelineper unit of time.

Pisometric height-the height of the rise of the liquid in the piezometric tube,whichcharacterizes the excess pressure in the vessel and can serve as a measure of the day for determining its value.

Piezometric head- the sum of the piezometric height at a given point in space occupied by a fluid at rest or in motion, and the height of this point relative to a conditional horizontal plane (comparison plane).

Uniformtraffic -this type of steady motion, in which all components of the motion - speed, pressure, channel shape, depth - do not change along the length (x axis) of the flow.

Consumptionis the amount of fluid flowing through the free flow area per unit time.

Free liquid surface- the interface between the liquid and the external gaseous medium.

free jet– the flow is not limited by solid walls at all.

CompressibilityThe property of a liquid to change its volume under pressure.

Siphon -a short pipeline that carries liquid from supply tank A to receiving tank B.

velocity head- the height to which a liquid can rise above a given point in space under the action of the flow velocity at this point.

wettedperimeter-dlinapart of the perimeter of the open section, along which the flow comes into contact with the walls limiting it.

Solid (continuous) movement- such a movement in which the fluid occupies the entire space of its movement without the formation of voids (breaks) inside the flow.

Perfect compression- compression that occurs when the side walls and the bottom of the vessel practically do not affect the degree of compression of the jet (they do not affect the outflow).

Average fluid flow rate- conditional speed, equal to the ratio of the flow rate to the area of the free section.

Pipelinesare pressure pipe systems.

Turbulentth movement- dmovement, in which all fluid particles move randomly, i.e., layering is violated.

Liquid Specific Gravityis the weight of a unit of its volume.

Specific volume -the volume occupied by a unit mass of a liquid.

Specific fluid flow- fluid flow rate per unit width of the free section.

Specific energy of liquid- a measure of the mechanical energy of a liquid, equal to the energy belonging to the unit mass of this liquid, related to the acceleration of free fall.

steady motion- this kind of movementwhere velocities, accelerations, pressures, depths do not change over time, but depend only on the position of the point in question in the fluid flow, being a function of the coordinates.

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WORKING CURRICULUM

MINISTRY OF SCIENCE AND HIGHER EDUCATION OF THE RUSSIAN FEDERATION

Federal State Autonomous Educational Institution of Higher Education "National Research Technological University "MISiS"

Work program of the discipline (module)

Hydraulics

Assigned to the	Department of mining equipment, transport and mechanical engineering
Direction of training	21.05.04 MINING
Profile	Mining machines and equipment

Qualification	**Mining engineer (specialist)**	
Form of study	**full-time**	
General labor intensity	**5 Z**	
Hours according to the	180	Forms of control in semesters:
including:		credit score 6
Auditory lessons	136	
independent work	44	

Distribution of discipline hours by semesters					
Semester (<Course>.<Semester on course>)	**6 (3.2)**		Total		
Weeks	17				
Type of occupation	UP	RP	UP	RP	
Lectures	34	34	34	34	
Laboratory	51	51	51	51	
Practical	51	51	51	51	
Total aud.	136	136	136	136	
Contact work	136	136	136	136	
Myself. Work	44	44	44	44	
Total	180	180	180	180	

The program was compiled by:
Candidate of Sciences, Associate Professor, Gubanov Sergey Gennadievich

Working programm
Hydraulics

Developed in accordance with OS VO:
Self-established educational standard of higher education Federal State Autonomous Educational Institution of Higher Education "National Research Technological University" MISiS ", specialty 21.05.04 MINING (order dated 02.12.2015 No. 602 o.v.)

Compiled on the basis of the curriculum:
21.05.04 MINING, 21.05.04-GEM-15-1.PLX

The work program was approved at the meeting of the department
Department of mining equipment, transport and mechanical engineering

Minutes dated 09.06.2020, No. 10

Head Department Kakhkharov Sergey Karimovich

1. GOALS OF DEVELOPMENT	
1.1	To form students' knowledge, skills and abilities about the basic laws of hydraulics, their applications in engineering tasks, in relation to hydraulic drives of mining machines, hydraulic systems of mining equipment and hydro-pneumatic automation systems.

2. PLACE IN THE STRUCTURE OF THE EDUCATIONAL PROGRAM	
Cycle (section) OP:	B1.B
2.1	**Requirements for the preliminary preparation of the student:**
2.1.1	Physics
2.1.2	Maths
2.1.3	Theoretical mechanics
2.2	**Disciplines (modules) and practices for which the development of this discipline (module) is necessary as a previous one:**
2.2.1	State exam
2.2.2	Equipment for the installation of mining machines (operational orientation)
2.2.3	Hydraulic pneumatic drive of mining machines
2.2.4	Maintenance and repair of quarry equipment (operational focus)
2.2.5	Quarry mechanical equipment
2.2.6	Mining machines and underground mining equipment
2.2.7	Preparation for the defense and defense of the final qualifying work

3. LEARNING OUTCOMES IN THE DISCIPLINE CORRELATED WITH THE FORMATED COMPETENCES

UK-6.1: demonstrate a deep knowledge and understanding of the fundamental sciences, as well as knowledge in interdisciplinary areas of professional activity
Know:
UK-6.1 -Z1 general laws of hydraulics; prospects for the development of hydraulics; methodological problems in hydraulics; the importance of hydraulics and hydraulic drives in transport, transport-technological machines, their units and technological equipment.
Be able to:
UK-6.1-U1 use scientific, technical and reference literature, including foreign ones, to solve specific problems in hydraulics; apply methods of analysis for the calculation of hydraulic systems and their elements.
Own:
UK-6.1-V1 by various methods for calculating the hydraulic systems of transport and technological machines; methods for ensuring the operability and efficiency of hydraulic systems.

4. STRUCTURE AND CONTENT

Activity code	Name of sections and topics / type of lesson /	Semester / Course	Hours	Compete nt tions	Literature and e. resources	Note	Control measures	Work in progres
	Section 1. Section 1. Physical properties of the liquid							
1.1	Basic concepts /Lek/	6	2	UK-6.1 -Z1	L1.1L2.2 E1 E2 E3			
1.2	Physical properties of the liquid /Lek/	6	2	UK-6.1 -Z1	L1.1L2.1 E1 E2 E3			
1.3	Heating the liquid in the pipeline / Pr /	6	2	UK-6.1-U1 UK-6.1-V1	L1.1L2.2L3.2 E1 E2 E3			
1.4	Determination of the bulk modulus of elasticity /PR/	6	2	UK-6.1-U1 UK-6.1-V1	L1.1L2.2L3.2 E1 E2 E3			

1.5	Determination of the permissible heating of a vessel filled with liquid / Pr /	6	3	UK-6.1-U1 UK-6.1-V1	L1.1L2.2L3.2 E1 E2 E3			
1.6	Determination of the dependence of the coefficient of dynamic viscosity on	6	3	UK-6.1-U1 UK-6.1-V1	L1.1L2.2L3.2 E1 E2 E3			
1.7	Experimental study of the dependence of the viscosity of a liquid on temperature /Lab/	6	four	UK-6.1-U1 UK-6.1-V1	L1.1L2.2L3.1 E1 E2 E3			
1.8	Development of lecture material. Independent study of literature. Independent study of recommended open sources. Preparation for laboratory work. /Wed/	6	12	UK-6.1 - Z1	L1.1L2.2L3.3 E1 E2 E3			
	Section 2. Section 2. Hydrostatics							
2.1	Mathematical model of an ideal fluid. Hydrostatic pressure /Lek/	6	four	UK-6.1 - Z1	L1.1L2.1 E1 E2 E3			
2.2	Transfer of pressure through a liquid. Pascal's Law /Lek/	6	four	UK-6.1 - Z1	L1.1L2.1 E1 E2 E3			
2.3	Transmission of force through liquid /Lek/	6	2	UK-6.1 - Z1	L1.1L2.1 E1 E2 E3			
2.4	Fluid pressure force on a flat side wall /Lek/	6	2	UK-6.1 - Z1	L1.1L2.1 E1 E2 E3			
2.5	Interaction of a liquid with a solid body immersed in it /Lek/	6	2	UK-6.1 - Z1	L1.1L2.1 E1 E2 E3			
2.6	Transfer of effort through the lever /PR/	6	6	UK-6.1-U1 UK-6.1-V1	L1.1L2.1L3.2 E1 E2 E3			
2.7	Determination of the required weight of a solid body to immerse it to a given depth / Pr /	6	four	UK-6.1-U1 UK-6.1-V1	L1.1L2.1L3.2 E1 E2 E3			
2.8	Determine the resultant force of the liquid pressure on the inclined flat side wall of the container and the position of the center of pressure on it / Pr /	6	four	UK-6.1-U1 UK-6.1-V1	L1.1L2.1L3.2 E1 E2 E3			
2.9	Determination of the fluid pressure that must be supplied to the piston cavity of the hydraulic cylinder in order to overcome the load on the rod / Pr /	6	four	UK-6.1-U1 UK-6.1-V1	L1.1L2.1L3.2 E1 E2 E3			
2.10	Development of lecture material. Independent study of literature. Independent study of recommended open sources. Preparation for laboratory work. /Wed/	6	12	UK-6.1 - Z1	L1.1L2.1L3.2 E1 E2 E3			

	Section 3. Section 3. Hydrodynamics							
3.1	Ideal fluid model /Lek/	6	2	UK-6.1 - Z1	L1.1L2.2 E1 E2 E3			
3.2	Bernoulli equation /Lek/	6	2	UK-6.1 - Z1	L1.1L2.2 E1 E2 E3			
3.3	Hydraulic resistance /Lek/	6	four	UK-6.1 - Z1	L1.1L2.2 E1 E2 E3			
3.4	Determination of pressure in the cross section of the flow of an ideal liquid under given conditions / Pr /	6	four	UK-6.1-U1 UK-6.1-V1	L1.1L2.2L3.2 E1 E2 E3			
3.5	Determining the liquid level using a Venturi flow meter / Pr /	6	four	UK-6.1-U1 UK-6.1-V1	L1.1L2.2L3.2 E1 E2 E3			
3.6	Determine the pressure in the hydraulic line with the given parameters / Pr /	6	3	UK-6.1-U1 UK-6.1-V1	L1.1L2.2L3.2 E1 E2 E3			
3.7	Study of methods for determining fluid flow rates. Comparison of manual and semi-automatic methods /Lab/	6	four	UK-6.1-U1 UK-6.1-V1	L1.1L2.2L3.1 E1 E2 E3			
3.8	Illustration of the Bernoulli equation. Pressure diagram /Lab/	6	four	UK-6.1-U1 UK-6.1-V1	L1.1L2.2L3.1 E1 E2 E3			
3.9	Illustration of the Bernoulli equation using the Droplet device /Lab/	6	four	UK-6.1-U1 UK-6.1-V1	L1.1L2.2L3.1 E1 E2 E3			
3.10	Determination of head loss in a given fluid flow using the device "Droplet" / Lab /	6	four	UK-6.1-U1 UK-6.1-V1	L1.1L2.2L3.1 E1 E2 E3			
3.11	Investigation of pressure losses (pressure) during the flow of liquid through local resistance in the form of a diaphragm /Lab/	6	5	UK-6.1-U1 UK-6.1-V1	L1.1L2.2L3.1 E1 E2 E3			
3.12	Study of pressure losses (pressure) during the flow of liquid through local resistance in the form of a valve /Lab/	6	5	UK-6.1-U1 UK-6.1-V1	L1.1L2.2L3.1 E1 E2 E3			
3.13	Study of the force impact of an unflooded jet on a mechanical barrier /Lab/	6	5	UK-6.1-U1 UK-6.1-V1	L1.1L2.2L3.1 E1 E2 E3			
3.14	Development of lecture material. Independent study of literature. Independent study of recommended open sources. Preparation for laboratory work /Wed/	6	9	UK-6.1 - Z1	L1.1L2.2L3.3 E1 E2 E3			
	Section 4. Section 4. Hydraulic calculation of pipelines							
4.1	Hydraulic calculation of pipelines /Lek/	6	four	UK-6.1 - Z1	L1.1L2.2 E1 E2 E3			

4.2	Calculation of a typical pipeline / Pr /	6	6	UK-6.1-U1 UK-6.1-V1	L1.1L2.2L3.2 E1 E2 E3			
4.3	Determination of the pressure characteristics of the pump /Lab/	6	5	UK-6.1-U1 UK-6.1-V1	L1.1L2.2L3.1 E1 E2 E3			
4.4	Investigation of the characteristics of the pump with their parallel connection /Lab/	6	5	UK-6.1-U1 UK-6.1-V1	L1.1L2.2L3.1 E1 E2 E3			
4.5	Development of lecture material. Independent study of literature. Independent study of recommended open sources. Preparation for laboratory work. /Wed/	6	6	UK-6.1 -Z1	L1.1L2.1L3.2 E1 E2 E3			
	Section 5. Section 5. Outflow of fluid from holes and nozzles							
5.1	Fluid outflow from a hole in a thin wall /Lek/	6	2	UK-6.1 -Z1	L1.1L2.1 E1 E2 E3			
5.2	Fluid outflow from nozzles /Lek/	6	2	UK-6.1 -Z1	L1.1L2.1 E1 E2 E3			
5.3	The outflow of liquid from the container through the hole and nozzles / Pr /	6	6	UK-6.1-U1 UK-6.1-V1	L1.1L2.1L3.2 E1 E2 E3			
5.4	Development of lecture material. Independent study of literature. Independent study of recommended open sources. Preparation for laboratory work /Wed/	6	5	UK-6.1 -Z1	L1.1L2.1L3.2 E1 E2 E3			
5.5	Expiration of liquid from the container through the hole and nozzles /Lab/	6	6	UK-6.1-U1 UK-6.1-V1	L1.1L2.1L3.1 E1 E2 E3			

5. FUND OF EVALUATION MATERIALS

5.1. Questions for self-preparation for the exam (test with assessment)

Questions for current control

1. Surface forces acting on a liquid. The concept of pressure in a liquid. Basic units of measurement and their dimensions
2. The phenomenon of cavitation in a liquid. The physical essence of the phenomenon, conditions of occurrence, consequences, methods of combating cavitation
3. Basic equation of hydrostatics. Its conclusion and special cases
4. The concept of pressure in a liquid. Units of measurement, their ratio in various systems of units, indicate the dimension
5. Euler's total differential pressure. Mathematical expression, application in fluid mechanics
6. Property of liquid viscosity. Petrov formula. Dynamic viscosity coefficient μ, its physical meaning and dimension
7. Bernoulli's equation for an elementary stream of an ideal liquid. mathematical expression. The physical meaning of the terms of the equation, their dimension. What parameters of a moving stream are mathematically linked by this equation?
8. Bernoulli equation for real fluid flow. The physical meaning of each term of the equation and their dimension. The practical meaning of the equation
9. Devices for measuring pressure in a liquid. Types, scope, accuracy class, measurement error. Pressure gauge selection rules
10. Geometry of fluid flows. Concepts: open section, wetted perimeter, hydraulic radius, fluid flow. Mathematical expression, dimension
11. Coefficient of hydraulic resistance λ. What does it depend on. Graphs by Nikuradze-Mukhin.
12. Interaction of a liquid with an inclined solid wall
13. Toricelli's formula as a consequence of Bernoulli's equation

14. Hydraulic resistance. The concept of linear pressure losses. Darcy formula, hydraulic resistance coefficient λ, its expression for hydraulically smooth pipes
15. Turbulent regime of fluid motion. Plot of fluid particle velocities over the flow cross section. Coriolis coefficient
16. Turbulent regime of fluid motion. The concept of hydraulically smooth and hydraulically rough pipes. Where are these terms used?
17. The outflow of liquid from the holes. The concept of a hole in a thin wall. Perfect and imperfect compression of the jet, the phenomenon of jet inversion. Fluid flow in the hole
18. Water hammer in a pipe. physical entity. Impact phases. shock wave speed. Formula N.E. Zhukovsky. The concepts of complete and incomplete hydraulic shock. Methods of dealing with water hammer
19. Local hydraulic head loss. Weisbach formula. The main types of local resistance. Equivalent length of local losses. The concept of short pipelines
20. Property of liquid compressibility. Mathematical expression, evaluation criteria. What is the property of compressibility of liquid in hydraulic systems of machines?

5.2. The list of works performed in the discipline (module, practice, research) - essays, abstracts, practical and settlement-graphic works, term papers, projects, etc.

Practical work 1. Heating liquid in the pipeline 2. Determination of the bulk modulus of elasticity 3. Determining the allowable heating of a vessel filled with liquid 4. Determination of the dependence of the dynamic viscosity coefficient on temperature 5. Transmission of force through the lever 6. Determining the required weight of a solid body to immerse it to a given depth 7. Determine the resultant force of the liquid pressure on the inclined flat side wall of the container and the position of the center of pressure on it 8. Determination of the fluid pressure that must be supplied to the piston cavity of the hydraulic cylinder in order to overcome the load on the rod 9. Determination of pressure in the cross section of an ideal fluid flow under given conditions 10. Determining the liquid level using a Venturi flow meter 11. Determine the pressure in the hydraulic line with the given parameters 12. Calculation of a typical pipeline 13. Outflow of liquid from the container through the hole and nozzles Laboratory works 1. Experimental study of the temperature dependence of the viscosity of a liquid 2. Study of methods for determining fluid flow rates. Comparison of manual and semi-automatic methods 3. Illustration of the Bernoulli equation. Pressure diagram 4. Illustration of the Bernoulli equation using the Droplet device 5. Determination of head loss in a given fluid flow using the device "Kapelka" 6. Study of pressure losses (pressure) during the flow of liquid through local resistance in the form of a diaphragm 7. Study of pressure losses (pressure) during the flow of liquid through local resistance in the form of a valve 8. Study of the force impact of an unflooded jet on a mechanical barrier 9. Determination of the pressure characteristics of the pump 10. Study of the characteristics of the pump when connected in parallel 11. The outflow of liquid from the container through the hole and nozzles
5.3. Assessment materials used for the exam (description of tickets, tests, etc.)
The discipline provides for a credit with an assessment
5.4. Methodology for assessing the development of the discipline (module, practice. Research)
The discipline is considered mastered under the following conditions: - the current lecture control has positive marks ("satisfactory"; "good"; "excellent"); - All laboratory work has been completed and defended; - all practical works have been completed and defended; - the test was passed for a positive assessment ("satisfactory"; "good"; "excellent"). Criteria for grading an assessment with an assessment "2" (unsatisfactory) "3" (satisfactory) The student did not complete and (or) did not defend all practical and laboratory work during the semester. "3" (satisfactory) The student completed all the practical and laboratory work during the semester. All practical and laboratory works are protected with a mark not lower than "satisfactory". "4" (good) The student completed all the practical and laboratory work during the semester. More than 75% of all practical and laboratory works are protected with a "good" rating, and the remaining 25% are not lower than a "satisfactory" rating
"5" (excellent) The student completed all the practical and laboratory work during the semester. More than 75% of all practical and laboratory works are protected with an "excellent" rating, and the remaining 25% are not lower than a "good" rating

6. EDUCATIONAL AND INFORMATION SUPPORT				
6.1. Recommended reading				
6.1.1. Main literature				
	Authors, compilers	Title	Library	Publisher, year
L1.1	Gudilin N. S., Krivenko E. M., Makhovikov B. S., etc., Pastoev I. L.	Hydraulics and hydraulic drive: textbook. allowance for students. universities, education for example "Mining" and special.	MISiS Library	M.: Mining book, 2007

6.1.2. additional literature				
	Authors, compilers	Title	Library	Publisher, year
L2.1	Krestin E. A.	Hydraulics: Tutorial	E-library	Samara: Samara State University of Architecture and Civil Engineering, 2010
L2.2	Malashkina V. A.	Hydraulics: Tutorial	E-library	Moscow: Moscow State Mining University, 2012
6.1.3. Methodological developments				
	Authors, compilers	Title	Library	Publisher, year
L3.1	Ivanov S. A., Chichenev N. A.	Hydraulics: lab. workshop	E-library	M.: MISiS Publishing House, 2008
L3.2	Malashkina V. A.	Hydraulics: textbook. allowance for the practice. occupations and independent. work stud.	MISiS Library	Moscow: MGGU, 2006
L3.3	Koval P.V.	Hydraulics and hydraulic drive of mining machines: textbook. for stud. universities, education	MISiS Library	M.: Mashinostroenie, 1979

6.2. List of resources of the information and telecommunications network "Internet"		
E1	Federal portal Russian education. Single window of access to information resources. Section "Hydraulics".	URL: http://window.edu.ru/catalog/resources?p_str=hydraulics
E2	Federal Portal Open Education	URL: https://openedu.ru/
E3	Scientific and Technical Library of NUST	URL: http://lib.misis.ru/

6.3 Software list	
P.1	Windows Server CAL ALNG LicSAPk MVL DvcCAL, WinEDUA3 ALNG SubsVL MVL PerUsr and PerUsr software licenses
P.2	Kaspersky Endpoint Security Software
P.3	Win Pro 10 32-bit/64-bit AIILng PK Lic Online DwnLd NR
P.4	Autodesk AutoCAD
P.5	MATCAD
P.6	MATLAB
P.7	Microsoft Word
P.8	Microsoft Excel
P.9	Microsoft PowerPoint

6.4. List of information reference systems and professional databases	
I.1	ScienceDirect is a database of full-text scientific journals and books published by Elsevier.
AND 2	Scopus is the world's largest unified abstract database of scientific publications.

7. LOGISTICS		
Aud.	Purpose	Equipment
L-117	Classroom/Laboratory of hydraulic drive:	"training stand "Volumetric hydraulic machines and hydraulic devices" SGU-IGM-08, training stand "Hydraulic

8. METHODOLOGICAL INSTRUCTIONS FOR STUDENTS

Preparation for lectures. Preparation for a lecture session includes the implementation of all types of tasks recommended for each lecture, i.e. assignments are completed even before the lecture on the relevant topic. In the course of lectures, it is necessary to take notes of educational material, pay attention to categories, formulations that reveal the content of certain phenomena and processes, scientific conclusions and practical recommendations. If necessary, ask the teacher clarifying questions. When working on lecture notes, you should always use not only the textbook, but also the literature that the lecturer additionally recommended. It is precisely such a serious, painstaking work with lecture material that will allow one to deeply master the theoretical material. Preparation for practical or laboratory classes You should start preparing for each practical or laboratory lesson by familiarizing yourself with the plan of the practical or laboratory lesson, which reflects the content of the proposed topic. Careful thinking and study of the issues of the plan is based on the study of the current lecture material, and then the study of the mandatory and additional literature recommended for this topic. All new concepts on the topic under study must be learned by heart and included in the glossary, which is advisable to keep from the very beginning of the course. In the process of preparing for practical or laboratory classes, you need to pay special attention to self-study of the recommended literature. With all the completeness of the notes of the lecture, it is impossible to present all the material in it due to the limit of classroom hours. Therefore, independent work with textbooks, teaching aids, scientific, reference literature, materials of periodicals and the Internet is the most effective method of obtaining additional knowledge, allows you to significantly intensify the process of mastering information, contributes to a deeper assimilation of the studied material, forms your attitude to a specific problem. Your independent work can be carried out in classroom and extracurricular forms. Independent work in the classroom includes: 1 Independent work on a theoretical course: classroom independent work at lectures, work with lecture material after a lecture, performing additional individual tasks in practical classes and laboratory work. Independent work at the lecture is carried out at the end of each lecture and consists in solving a small problem set by the teacher based on the material of the lecture. Each student has a checklist, which indicates the last name, first name, patronymic, group, lecture number, date, task and answer (solution) of the problem. After classes, the teacher checks the correctness of the tasks and, if necessary, gives an additional task at the next lesson or at the consultation to correct the mistakes made. The analysis of checklists allows the teacher to assess the assimilation of the material of each lecture by each student and, in parallel, to take into account the attendance of lectures. The student must hand over the material of the missed lecture to the teacher in writing during consultation hours. Working with a lecture includes supplementing the abstract with information from the recommended literature (with an indication of the source used). It is possible for students to speak at lectures on certain issues of the topic under discussion (worked out independently under the guidance of a teacher); messages take 7…10 minutes. Such speeches help to clearly express one's thoughts, to state and defend one's point of view when answering questions. Independent study of practical material is planned at the rate of 0.3 hours per 1 hour of lecture. Working with the material of the lecture, performed one or two days after listening to it, allows you to highlight unclear points that you need to either sort it out yourself, using the recommended literary sources, or discuss it with the teacher at the next consultation. Such self-control can be included in the scope of the student's independent work, provided for by the work program. 2. Classroom independent work in practical and laboratory classes according to the discipline program. They provide the acquisition of skills and abilities necessary in the study of this discipline, as well as necessary in subsequent training and work. In addition, they provide interactive communication between participants and provide an experience of joint participation in solving problems. 3. Extracurricular independent work.

Literature

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- completed and defended all laboratory work;
- completed and defended all practical work;
- the test was passed for a positive assessment ("satisfactory"; "good"; "excellent").

Criteria for grading an assessment with an assessment

"2" (unsatisfactory) "3" (satisfactory) The student did not complete and (or) did not defend all practical and laboratory work during the semester.

"3" (satisfactory) The student completed all the practical and laboratory work during the semester. All practical and laboratory works are protected with a mark not lower than "satisfactory".

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"5" (excellent) The student completed all the practical and laboratory work during the semester. More than 75% of all practical and laboratory works are protected with an "excellent" rating, and the remaining 25% are not lower than a "good" rating

ABOUT TOPICS

1. Surface forces acting on a liquid. The concept of pressure in a liquid. Basic units of measurement and their dimensions

2. The phenomenon of cavitation in a liquid. The physical essence of the phenomenon, conditions of occurrence, consequences, methods of combating cavitation

3. Basic equation of hydrostatics. Its conclusion and special cases

4. The concept of pressure in a liquid. Units of measurement, their ratio in various systems of units, indicate the dimension

5. Euler's total differential pressure. Mathematical expression, application in fluid mechanics

6. Property of liquid viscosity. Petrov formula. Dynamic viscosity coefficient μ, its physical meaning and dimension

7. Bernoulli's equation for an elementary stream of an ideal liquid. mathematical expression. The physical meaning of the terms of the equation, their dimension. What parameters of a moving stream are mathematically linked by this equation?

8. Bernoulli equation for real fluid flow. The physical meaning of each term of the equation and their dimension. The practical meaning of the equation

9. Devices for measuring pressure in a liquid. Types, scope, accuracy class, measurement error. Pressure gauge selection rules

10. Geometry of fluid flows. Concepts: open section, wetted perimeter, hydraulic radius, fluid flow. Mathematical expression, dimension

11. Coefficient of hydraulic resistance λ. What does it depend on. Graphs by Nikuradze-Mukhin.

12. Interaction of a liquid with an inclined solid wall

13. Toricelli's formula as a consequence of Bernoulli's equation

14. Hydraulic resistance. The concept of linear pressure losses. Darcy formula, hydraulic resistance coefficient λ, its expression for hydraulically smooth pipes

15. Turbulent regime of fluid motion. Plot of fluid particle velocities over the flow cross section. Coriolis coefficient

16. Turbulent regime of fluid motion. The concept of hydraulically smooth and hydraulically rough pipes. Where are these terms used?

17. The outflow of liquid from the holes. The concept of a hole in a thin wall. Perfect and imperfect compression of the jet, the phenomenon of jet inversion. Fluid flow in the hole

18. Water hammer in a pipe. physical entity. Impact phases. shock wave speed. Formula N.E. Zhukovsky. The concepts of complete and incomplete hydraulic shock. Methods of dealing with water hammer

19. Local hydraulic head loss. Weisbach formula. The main types of local resistance. Equivalent length of local losses. The concept of short pipelines

20. Property of liquid compressibility. Mathematical expression, evaluation criteria. What is the property of compressibility of liquid in hydraulic systems of machines?

QUESTIONS TO CONTROL

QUESTIONS
for the final examination
in the discipline "HYDRAULICS"
1 - OPTION

1. Basic properties of liquids.
2. Pascal's law and its practical application.

Keywords

Liquid; fluidity; drip; gaseous; viscosity; continuum; free surface; friction. Pressure; absolute pressure; hydraulic accumulators; specific gravity; piston; cylinder; strength; pressure; free surface. Mechanical energy, fluid movement energy; hydraulic energy; bladed; volume; centrifugal; piston; rotary.

QUESTIONS
for the final examination
discipline "HYDRAULICS"
OPTION 2

1. Laminar and turbulent motion of fluids.
2. Devices and methods for measuring pressure.
3. Efficiency of vane hydraulic machines.

Keywords

Laminate; particle; speed; pressure; Reynolds number; ; intersection trajectory; transition from one flow regime to another. Piezometer; pressure; free surface; basic equation of hydrostatics; overpressure; U-shaped manometer; differential pressure gauge; vacuum gauge.

Compiled by:

QUESTIONS
for the final examination
in the discipline "HYDRAULICS"
3 - OPTION

1. Dynamic and kinematic viscosity of a liquid and measuring instruments.
2. Law of Archimedes. Swimming tel.
3. Vane pumps.

Keywords

Real liquid; particle; tangential friction forces; energy loss; Newton's hypothesis; forces of internal friction; velocity gradient; viscosity coefficient; ship theory; buoyancy force; liquid weight; specific body weight; specific gravity of the liquid. Storage tank; valve; injection; filter; suction height; discharge height; statistical height.

QUESTIONS
for the final examination
in the discipline "HYDRAULICS"
4 - OPTION

1. Surface tension of a liquid. Free liquid surface and pressure on the wall.
2. Basic equation of hydrostatics.
3. Dynamic pumps.

Keywords

Voltage; Laplace formula. Kinematic energy; pressure diagrams; Working wheel; working chamber; vacuum; centrifugal force; diffuser; water hammer; piston pump; vane pump.

QUESTIONS
for the final examination
in the discipline "HYDRAULICS"
5 - OPTION

1. Methods for measuring flow and speed.
2. Absolute, gauge, vacuum and atmospheric pressure of a liquid and their units of measurement.

Keywords

Volumetric method; consumption; live section; weight method; liquid weight; weight consumption; specific gravity; liquid volume; strength; surface; mercury column; water. pillar. Euler equation; Working wheel; blade; theoretical pressure; rotational speed; absolute speed; amount of rotation.

QUESTIONS
for the final examination
in the discipline "HYDRAULICS"
5 - OPTION

1. Saturated vapor pressure of a liquid. The concept of cavitation.
2. Fluid outflow from a hole in a thin wall.
3. The phenomenon of cavitation and the prevention of its occurrence.

Keywords

Free evaporation; a state of equilibrium; cavitation; boiling temperature; solution; light component. Free surface; perfect holes; local energy losses; formula of Torricelli; theoretical expense. State of aggregation; local narrowing; water hammer; valve.

QUESTIONS
for the final examination
in the discipline "HYDRAULICS"
7 - OPTION

1. Flow rate and average flow velocity in laminar fluid flow.

2. Pressure on flat surfaces.
3. Operation of the centrifugal pump on the pipeline.

Keywords

Viscosity; pressure force; parabolic law; cylindrical pipe; speed; consumption; average speed; maximum height. Pipeline; centrifugal pump; pressure; pressure; pipeline characteristics; pump characteristic; optimal mode; performance; engine energy.

QUESTIONS
for the final examination
in the discipline "HYDRAULICS"
8 - OPTION

1. Turbulent regime of fluid motion.
2. Basic problems of hydrodynamics.
3. Series connection of pumps. General characteristics of centrifugal pumps.

Keywords

Turbulence; trajectory; randomness; layer; transverse movement; quantitative similarity. Speed; the law of fluid motion; compressibility; movement indicators; time; established; unsteady; storage tank. Nozzle; consumption; total pressure; general power; efficiency.

QUESTIONS
for the final examination
in the discipline "HYDRAULICS"
9 - OPTION

1. Ideal gas (Basic laws of Boyle-Mariotte and Gay-Lussac, Claperon's equations).
2. Hydraulic flow elements flow line.
3. Positive displacement pumps and their classification.

Keywords

Mass of gas; velocity vector; broken line; transverse section; impenetrable surface. Liquid; volume; strength; potential energy; injection; efficiency; shift mechanism; piston; pressure; reciprocating; rotor; rotary pumps.

QUESTIONS
for the final examination
in the discipline "HYDRAULICS"
10 - OPTION

1. Velocity pulsation in a turbulent flow and average velocity over time.
2. Liquid pressure on curved surfaces.
3. Efficiency of pumps.

Keywords

. Ripple; time; oscillatory movement; balanced speed (speed over time). sy; energy loss; mechanical; volume; hydraulic; theoretical consumption; actual expense; local vacuum gauge; discharge pipe; volumetric efficiency; discharge pressure; friction; manometer; volume.

TEST QUESTIONS BY DISCIPLINE

"HYDRAULICS»

What is the height to which a liquid rises in a piezometer called?	*Piezometric height	geometric height	hydraulic height	All answers are correct
What is called non-pressure movement?	*Movement of a fluid in a flow with a free surface	The movement of a fluid in a flow without a free surface	Movement, flow is limited on all sides by solid walls	All answers are correct
Name the motion in which all the particles of the liquid are moving in a randomly chaotic manner?	*Turbulent driving mode	Laminar fluid motion	Transient fluid motion	All answers are correct
Movement, in which speeds, accelerations, pressures, depths change, over time are ...	* Relentless movement	steady motion	uniform movement	uneven movement
What instrument is used to measure hydrostatic pressure?	*piezometer	thermometer	micrometer	pitot tube
What is the free surface of a liquid?	* surface adjacent to the gaseous medium	walled surface	fluid in equilibrium	liquid in vacuum
Under what conditions does a vacuum occur?	*if the pressure is less than atmospheric	if the pressure is greater than atmospheric	if atmospheric pressure	when overpressure
Choose the basic equation of hydrostatics	* $p = p_0 + \gamma \hbar$	$p_0 = \gamma_h - gh$	$p_0 =$	$p_0 = p + pgh$
The pressure equal to the difference between the total hydrostatic pressure and atmospheric pressure is ...	* Gauge pressure	absolute pressure	hydrostatic pressure	external pressure
Define an instrument for measuring subatmospheric pressure?	*vacuum gauge	pitot tube	venturi water meter	stopwatch
Meaning of Pascal's Law: When pressure is applied to a fluid...	*pressure is transmitted in all directions lonely	pressure is transmitted in all directions not alone	pressure only acts on the bottom of the vessel	All answers are correct
Find the formulation of the hydrostatic paradox from the listed formulas.	*Hydrostatic pressure depends on the area, depth and does not depend on the shape of the vessel	Hydrostatic pressure depends only on the shape of the vessel	Hydrostatic pressure does not depend on the area of the bottom of the vessel	Hydrostatic pressure depends on the depth and shape of the vessel
Which of the scientists established that: “The absolute pressure at the points of the liquid at different depths is different. However, the pressure on a liquid enclosed in a closed vessel is transmitted to all its particles without change?	*Pascal	Archimedes	Euler	Bernoulli
What hydraulic machine is used to obtain large compressive forces?	*Hydraulic Press	hydraulic accumulator	Hydraulic pump	hydraulic motor

Formulate the law of Archimedes:	* A body immersed in a liquid is subjected to a buoyant force equal to F $_T$ in this body	A body immersed in a liquid is only affected by the force of gravity.	A body immersed in a liquid is subjected to a force equal to the weight of the body.	No force acts on a body immersed in a liquid.
What hydraulic machine is used to store energy?	*Hydraulic accumulator	hydraulic motor	Hydraulic pump	Hydraulic Press
Choose the equilibrium condition of the floating body, where G is the force of gravity, P is the buoyancy force.	$*G = P$	$G \angle P$	$G \rangle P$	$G \geq P$
One of the equilibrium conditions for a floating body:	*The centers of gravity of the body and pressure lie on the same vertical	The center of gravity of the body and pressure do not lie on the same vertical	The center of pressure and the center of application of force do not lie on the same vertical	All answers are correct
Volumetric interaction is?	*Volume of fluid displaced by the body	Floating body volume	The volume of fluid in which the body is	All answers are correct
What is the graphical representation of hydrostatic pressure called?	*Plot	Coordinate system	Scheme	Ellipse
What law characterizes the buoyancy of a body immersed in it?	*Power of Archimedes	Gravity	Friction force	Elastic force
What is the name of the state when a part of the body is immersed in a liquid?	*Body floats	The body is sinking	body pop up	The body is at rest
Flow is...?	*A set of elementary streams of liquid	The totality of fluid layers	The set of elementary fluid streams only in laminar flow	Collectio n of colored streams of liquid
Fluid flow is the amount of fluid...	* passing through per unit of time	passing through the living section	passing through a small hole	Passing through a large hole
Movement, in which speeds, accelerations, pressures, depths do not change, over time are ...	*Steady motion	Unsteady motion	uniform movement	uneven movement
What is hydrodynamics	*Section of hydraulics, which studies the laws of motion of fluids	branch of hydraulics that studies the laws of fluids at rest or equilibrium	This is an applied technical science that studies dropping liquids at rest or in equilibrium.	It is a science in which strictly mathematical methods are applied.
What is a push movement?	*Movement of a fluid in a stream without a free surface	The movement of a fluid in a flow with a free surface	Movement when the flow is not limited on all sides by solid walls	All answers are correct
What is the name of the line, at each point of which at a given moment the fluid velocity vector coincides with the direction of the tangent to this line?	*Stream line	pressure line	flow line	Fluid line
What is the movement in which all particles of the fluid move along parallel trajectories?	*Laminar jet movement	Turbulent driving mode	Movement of an ideal fluid	All answers are correct

which means the suction height Hvs during the operation of the pumping system.	*Distance from the liquid level of the supply tank to the level of the installed pump	Distance from the liquid level of the receiving tank to the level of the installed pump	Distance from the liquid level of the supply tank to the liquid level of the receiving tank	All answers are correct
Who established the law of dynamic similarity in 1686?	*Newton	Reynolds	Archimedes	Pascal
What is the movement of liquids during turbulent motion?	*Chaotic	striated	Along the path of the pipe	All answers are correct
The Reynols number is determined by the formula?	* $\mathrm{Re} = vd/\vartheta$	$\mathrm{Re} = S/\vartheta$	$\mathrm{Re} = \omega R/\ \vartheta$	$\mathrm{Re} = \vartheta R/\ \ p\vartheta$
How many fluid regimes are there?	*2	one	3	four
What does the formula mean $\frac{h_w}{l} = i$	*Hydraulic slope	Piezometric slope	Fluid flow	Hydraulic radius
What are the losses in short pipelines?	*From local	From internal	From external	All answers are correct
What device shows excess pressure in the discharge line?	*Pressure gauge	Pitot tube	vacuum gauge	Micrometer
What instrument shows the amount of vacuum in the suction pipe?	*Vacuum gauge	Micrometer	Thermocouple	Thermometer
Choose the unit of measure for the roughness coefficient?	*Not measured in anything	Mm	sec	All answers are correct
Liquid is...?	* A physical body that easily changes its shape under the influence of the most insignificant forces	A physical body that does not change its shape under the influence of forces of any magnitude	A physical body that easily changes its shape without the action of forces	A physical body whose particles are in constant chaotic motion
What are the two types of liquids?	*Drip and gaseous	Ideal and drip	Drip and elastic	Elastic and gaseous
Choose a formula for determining the specific gravity of a liquid.	* $\gamma = G/V$	$\gamma = GV$	$\gamma = G + V$	$\gamma = G - V$
Viscosity is...?	*The property of a fluid to resist shear shear forces	The property of a fluid not to resist shear shear forces	The property of a liquid, characterized by a coefficient of volumetric compression	All answers are correct
What happens to the coefficient of thermal expansion for water as pressure increases?	*Increases	Decreases	Doesn't change	All answers are correct
What is called cavitation?	*Formation of cavities filled with air or steam	Formation of cavities filled with solids	Formation of cracks filled with water or steam	All answers are correct
what does the discharge height Hnag mean during the operation of the pumping system	*Distance from the liquid level of the receiving tank to the level of the installed pump	Distance from the liquid level of the supply tank to the level of the installed pump	Distance from the liquid level of the supply tank to the liquid level of the receiving tank	All answers are correct

Tension surface is...?	* The property of a liquid, which is due to the forces of mutual attraction that arise between the particles of the surface layer and cause its stressed state	The property of a fluid to resist shear shear forces	The property of a fluid to resist shear shear forces	All answers are correct
What is compressibility?	* The property of a liquid to change its volume with a change in pressure	The property of a liquid to maintain its volume when pressure changes	The property of a fluid to resist shear shear forces	All answers are correct
What are the easiest ways to measure fluid flow?	*Volume and weight	Measured aperture	Measuring Peto tube	Measured Water Meter Winture
When will fluid flow be free-flowing?	*Movement of liquid partially limited by walls	Fluid movement not limited by walls	Fluid movement not limited by walls	Fluid movement in a longitudinal section not limited by walls
What is a backward shock wave?	*Pressure reduction transmitted from layer to layer	Increasing pressure	pressure drop	All answers are correct
What causes local resistance?	*due to changes in flow shape	Due to change in flow rate	Due to the conservation of the flow rate	Due to the conservation of the flow shape
What type of head loss is defined as the arithmetic sum of all types of losses?	*Total loss of pressure	Not a complete loss of power	Partial head loss	Minimum head loss
Local resistances arise due to...	* Changes in flow shape	Save the flow shape	nozzles	Flow rate changes
Pipelines are divided into …?	*Simple and complex	small and large	With small and large holes	With nozzles and without them
Centrifugal pumps are divided into...	*Slow and high speed	Dioganal	Propeller	hazardous
What does the statistical height Hvt \u003d Hvs + Hnag mean	*Distance from the liquid level of the supply tank to the liquid level of the receiving tank	Distance from the liquid level of the receiving tank to the level of the installed pump	Distance from the liquid level of the supply tank to the level of the installed pump	All answers are correct
Water hammer occurs as a result of...?	*A sharp increase in pressure Fa	Time changes	Speed changes	Fluid Direction Changes
What is dangerous for the integrity of pipes during hydraulic shock?	*Great pressures that occur	Using pipes of the wrong diameter	Fluid flow rate	The resulting less pressure
what is the name of the installed tube on the walls of the container for the outflow of liquid	*nozzle	test tube	beaker	All answers are correct.
How can water hammer be reduced?	*Due to the slow closing of the pipeline	By opening the valve	Due to the abrupt activation of the pumps	Due to the abrupt shutdown of the pumps
Where does the liquid in the centrifugal pump go from the suction pipe?	*Impeller blades	Pump housing	To the external environment	All answers are correct

What causes an increase in pressure, propagating through the pipeline at high speed?	*Compression Fluid	Fluid expansion	Volume increase	Volume reduction

LITERATURE

Main literature				
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