

## Virtual Laboratory Work in the Course of Hydromechanics «The Parametric Tests of Centrifugal Pump»

### PRINCIPLES OF INTERACTION WITH THE VIRTUAL MODEL OF THE LABORATORY EQUIPMENT

The simulation model of the laboratory equipment is an interactive geometric structure placed in a virtual three-dimensional space. Observation of objects is carried out using a virtual camera. In the basic (free) mode, the camera can rotate around the focus point (Figure 1). The focus point of the camera can move in the vertical frontal plane. In addition, the camera can distance itself relative to the focus point for an arbitrary distance bounded by the dimensions of the work space of 3D scene.

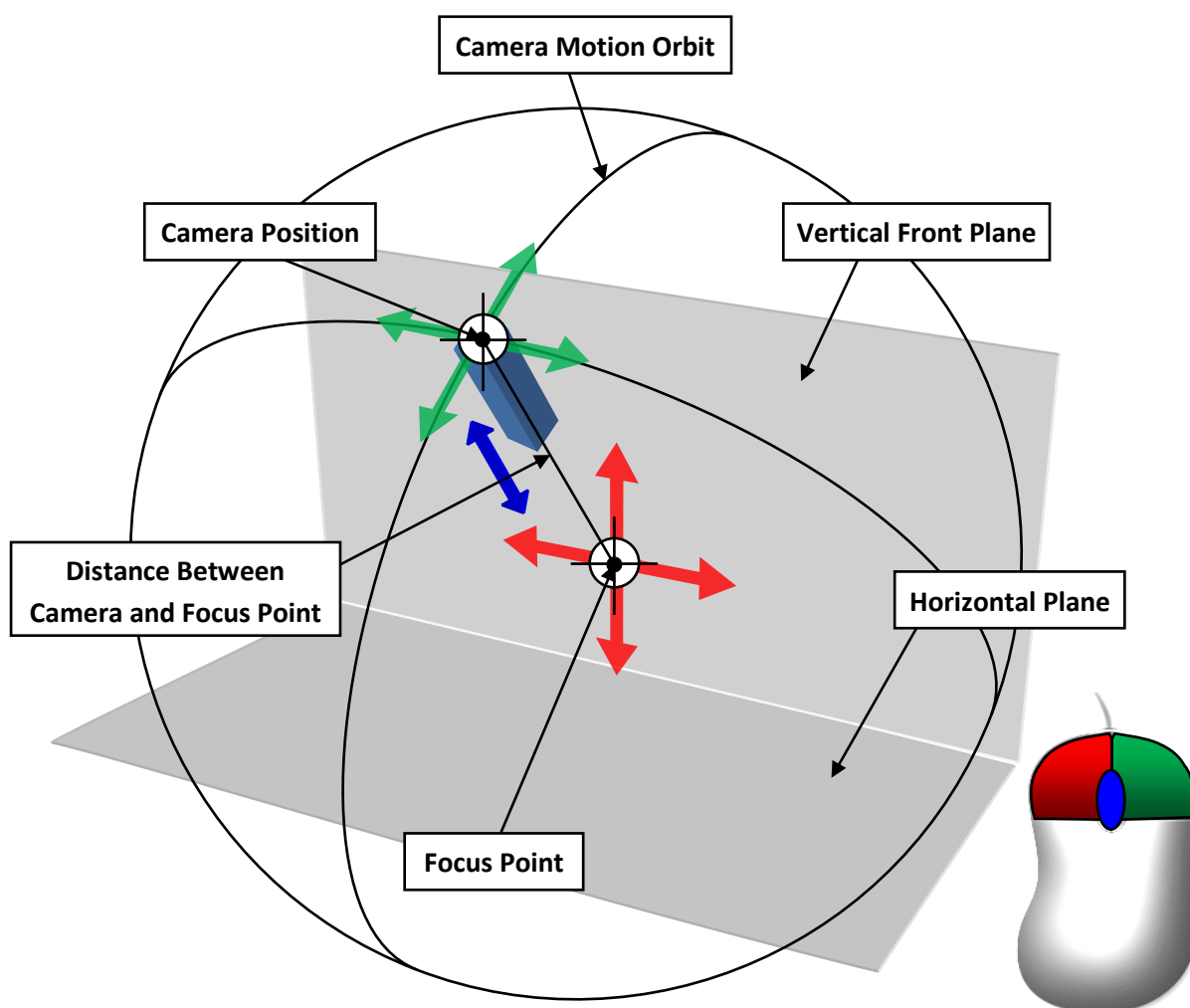


Figure 1 – Principle of the Camera Control in Free Mode

Basic manipulations with the camera in a free mode are carried out using a computer mouse. Herewith pressing and holding the left mouse button with the accompanying movement of the mouse moves the focus point of the camera in the frontal plane of work space. Clicking and holding the right mouse button while moving the mouse causes the camera to rotate relative to the focus point. The angles of rotation (azimuth and elevation) of the camera are limited by the dimensions of the 3D work space. The distance between camera and focus point is changing by rotating the mouse scroll wheel in the forward and reverse directions.

**Note: in some virtlabs, the focus point may move in a horizontal plane!**

In addition to the free mode, the camera can switch to individual elements of the laboratory equipment. Switching the camera to the individual object is performed by hovering the mouse over the object with a subsequent single click of the left mouse button. In this case, the camera can take a static position or be able to move in a vertical plane by hovering the mouse pointer to the edges of the screen or using the keyboard arrow keys. The clicking on an arbitrary area of the screen is return of the camera to basic mode.

The interaction with the control elements of the simulational laboratory equipment is carried out by hovering the mouse over the object and then pressing (or a single click) the left (or right) mouse button. Specific of the control for different elements may vary. For example, continuously regulating elements (flow control valves, etc.) require holding the left or right mouse button to change their state. Elements of discrete action (gates or latches) require a single click of the left mouse button.

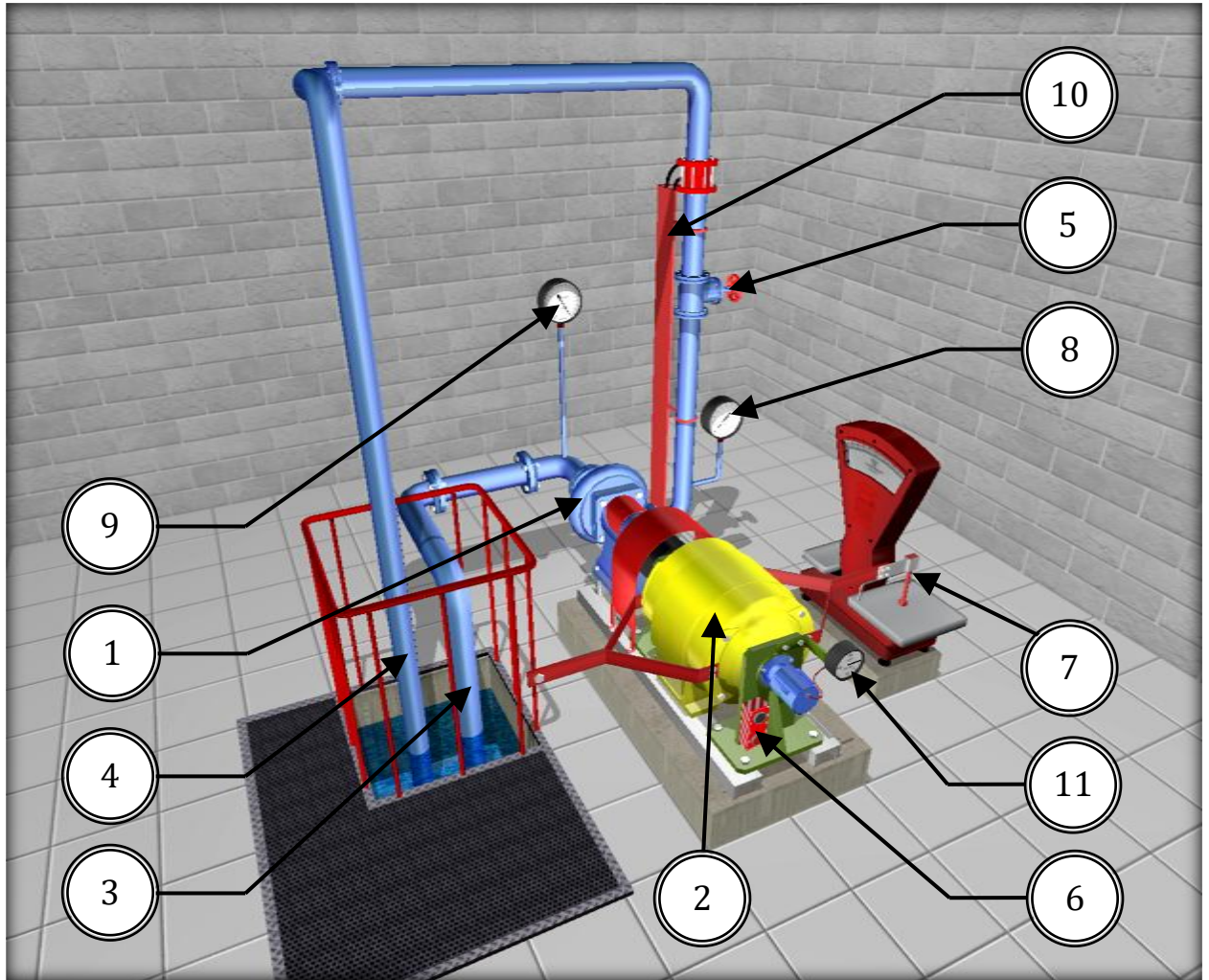
At the moment of hovering the mouse pointer over the object, manipulations with the camera are temporarily unavailable. Similarly, when manipulating the camera, it is not possible to perform actions on the controls elements of the lab equipment.

### VIRTUAL MODEL OF THE LABORATORY EQUIPMENT

A simulation model of a laboratory equipment (Figure 2) includes a centrifugal pump (1) with an electric motor (2), a suction pipe (3) with a non-return valve, pressure pipe (4) with a flow rate change valve (5), power switch (6), and instrumentation: scales (7), manometer (8), vacuum gauge (9), differential manometer (10) and tachometer (11).

Instrumentation serves to measure the flow rate (diaphragm and mercury differential manometer), pressure at the pump outlet (manometer), vacuum at the pump inlet (vacuum gauge), torque on the pump shaft (balancing motor with lever and scales) and motor shaft velocity (tachometer).

To fill the pump and suction pipe with water on the current physical model, the latter is connected to a vacuum pump, which creates the necessary vacuum in the suction pipe before starting the pump. Under the pressure difference on the free surface of the water in the inlet tank and in the suction pipe, the valve opens and the water fills the pipe and pump.



**Figure 2** – Image of a Simulation Laboratory Equipment for the Parametric Tests of Centrifugal Pump

### PHYSICAL PROCESS DESCRIPTION

Parametric tests are conducted to determine the technical indicators (parameters) and characteristics of the pumps.

The operation of the pump is characterized by the following main technical indicators: supply, pressure, power, efficiency coefficient, rotation velocity and permissible cavitation reserve.

1. Pump flow  $Q$  – the volume of fluid pumped by the pump per unit time ( $\text{m}^3/\text{s}$ ,  $\text{L}/\text{s}$ ,  $\text{m}^3/\text{h}$ ).

Mass pump flow  $G$  – mass of fluid pumped by the pump per unit time ( $\text{kg}/\text{s}$ ,  $\text{kg}/\text{h}$ ). Mass flow through the fluid density  $\rho$  [ $\text{kg}/\text{m}^3$ ] is associated with the volumetric dependence:

$$G = \rho \cdot Q \quad (1)$$

The ideal (theoretical) pump flow  $Q_t$  – the sum of the pump flow  $Q$  and volumetric losses  $\Delta Q$

$$Q_t = Q + \Delta Q, \quad (2)$$

Volumetric losses occur as a result of fluid overflow (leakage) under the action of a pressure drop from the pressure cavity to the suction and change, all other things being equal, almost directly proportional to the pressure drop  $\Delta p$ :

$$\Delta Q = \alpha \cdot \Delta p, \quad (3)$$

where  $\alpha$  – the coefficient of proportionality.

2. Pump head  $H$  – the increment of the total specific energy of the fluid passing through the pump (m). For a working pump, the pressure can be determined by the readings of the manometer and vacuum gauge:

$$H = \frac{p_M \pm p_V}{\rho g} + z_M + \frac{v_P^2 + v_S^2}{2g}, \quad (4)$$

where  $p_M$  and  $p_V$  – the readings of the manometer and vacuum gauge located, respectively, on the pressure and suction pipelines of the pump, Pa;  $z_M$  – excess of the rotation axis of the manometer needle over the connection point of the vacuum gauge, m;  $v_P$  and  $v_S$  – the average fluid velocities in the pressure and suction pipelines, respectively, m/s.

The minus sign in formula (4) is preceded by  $p_V$  in the case when there is excess pressure at the pump inlet, that is, the pump works «in a backwater».

3. Pump power  $N$  – power consumed by the pump:

$$N = M \cdot \omega, \quad (5)$$

where  $M$  and  $\omega$  – shaft torque and pump shaft angular velocity.

Net power  $N_{\text{pump}}$  – the power supplied by the pump of the pumped fluid and determined by the dependence

$$N_{\text{pump}} = p \cdot Q = \rho \cdot g \cdot H \cdot Q, \quad (6)$$

The pump power  $N$  is greater than the net power  $N_{\text{pump}}$  by the amount of energy loss taken into account efficiency.

4. Pump efficiency  $\eta$  – ratio of net power and pump power:

$$\eta = N_{\text{pump}} / N, \quad (7)$$

The efficiency of the pump takes into account all types of energy losses associated with the transfer of its pumped fluid. The energy loss in the pump consists of mechanical, hydraulic and volumetric.

Mechanical losses – friction losses in bearings, oil seals, piston against cylinder walls, etc.

Hydraulic losses – losses associated with overcoming hydraulic resistance in the working bodies of the pump.

Volumetric losses – losses due to leakage of fluid from the pressure cavity of the pump to the suction through gaps. In this regard, it is necessary to distinguish between mechanical, hydraulic and volumetric efficiency.

The mechanical efficiency of the pump  $\eta_M$  – a value that expresses the relative share of mechanical energy losses in the pump:

$$\eta_M = \frac{N - \Delta N_M}{N} = \frac{N_t}{N}, \quad (8)$$

where  $\Delta N_M$  – the power of mechanical losses;  $N_t$  – the pump power minus the power of mechanical losses (theoretical power).

The hydraulic efficiency of the pump  $\eta_H$  – the ratio of the pump's net power to the sum of the net power and the power spent to overcome the hydraulic resistance in the pump:

$$\eta_H = \frac{N_{\text{pump}}}{N_{\text{pump}} + \Delta N_H} = \frac{pQ}{pQ + \Delta p_H Q} = \frac{p}{p + \Delta p_H} = \frac{H}{H + \Delta H_H}, \quad (9)$$

where  $\Delta N_H$  – the power required to overcome the hydraulic resistance in the pump;  $\Delta p_H$ ,  $\Delta H_H$  – loss of pressure or pressure to overcome the hydraulic resistance in the working bodies of the pump.

The volumetric efficiency of the pump  $\eta_V$  – the ratio of the pump's net power to the sum of the net power and the power lost with leaks:

$$\eta_V = \frac{N_{\text{pump}}}{N_{\text{pump}} + \Delta N_{\text{outflow}}} = \frac{pQ}{pQ + p\Delta Q} = \frac{Q}{Q + \Delta Q} = \frac{Q}{Q_t}, \quad (10)$$

where  $\Delta N_{\text{outflow}}$  – power required for leakage.

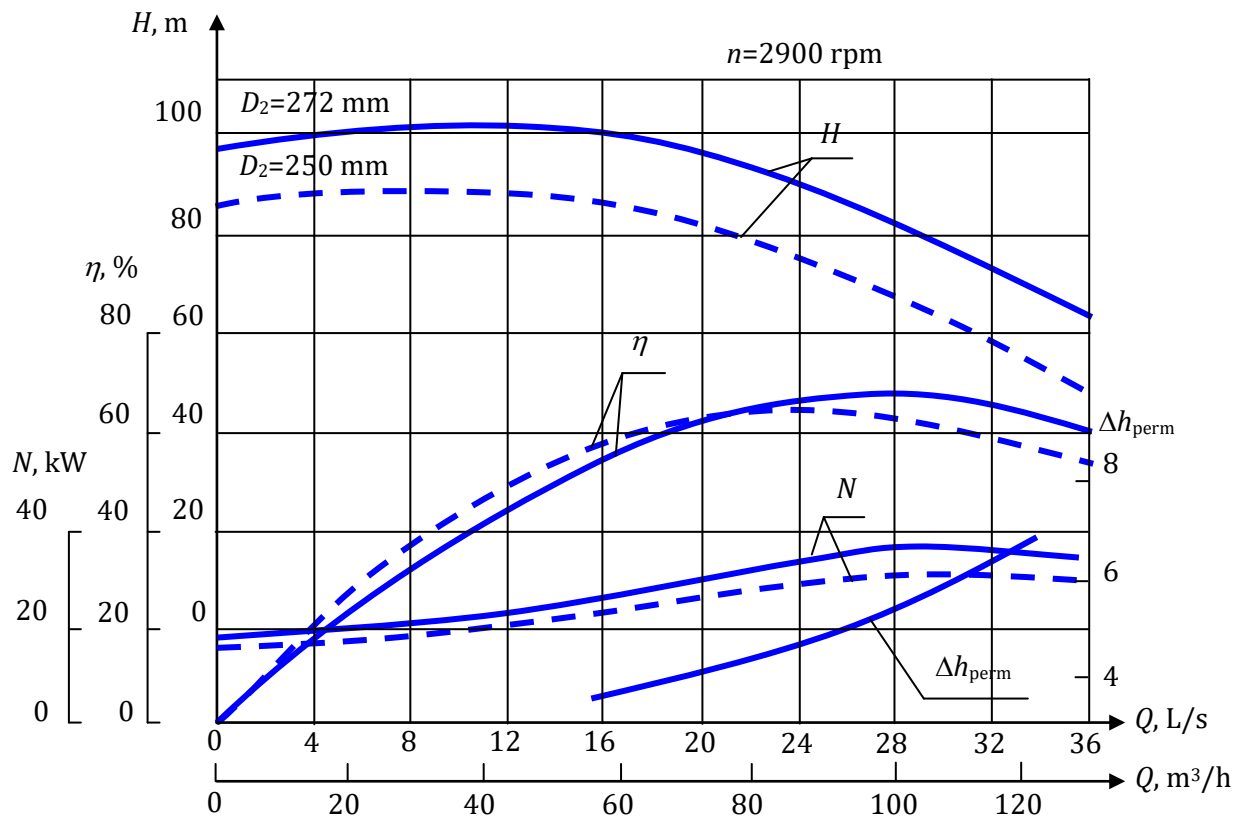
The relationship between the efficiency of the pump and other partial efficiency can be represented as:

$$\eta = \frac{N_{\text{pump}}}{N} = \frac{N_t N_{\text{pump}}}{N \cdot N_t} = \eta_M \frac{pQ}{(p + \Delta p_H)(Q + \Delta Q)} = \eta_M \eta_H \eta_V, \quad (11)$$

5. Permissible cavitation reserve  $\Delta h_{\text{perm}}$  – cavitation reserve that ensures the operation of the pump without changing the main technical indicators (without cavitation).

For the correct operation of the pumps and their selection, it is necessary to know how the basic technical characteristics of the pump ( $H$ ,  $N$ ,  $\eta$ ,  $\Delta h_{\text{perm}}$ ) change when changing its flow rate  $Q$ , i.e., know its characteristics.

A characteristic of a centrifugal pump is a graphical dependence of the head  $H$ , power  $N$ , efficiency  $\eta$  and the permissible cavitation reserve  $\Delta h_{\text{perm}}$  (or allowable vacuum) on the flow rate  $Q$  at constant values of the impeller rotation velocity, viscosity, and fluid density at the pump inlet. It includes three characteristics: pressure head  $H=f(Q)$ , energy (two curves) –  $N=f(Q)$ ;  $\eta=f(Q)$  and cavitation –  $\Delta h_{\text{perm}}=f(Q)$ . Characteristics are obtained as a result of parametric tests of pumps at manufacturers and placed in catalogs. Figure 3 shows the characteristics of the pump K90/85 (4K-6) at  $n=2900$  rpm for the impeller with diameters  $D_2=272$  mm and  $D_2=250$  mm (turned). For the latter, the curves are shown in dotted lines.



**Рисунок 3** – Characteristic of the Pump K90/85 (4K-6)

On the pressure characteristics, the wavy lines show the recommended area of application of the pump for supply and pressure (pump field  $Q-H$ ), obtained by changing the rotation velocity or turning the impeller along the outer diameter. Within the limits of the pump field, the efficiency has a maximum value, or less than no more than 10%.

### LABORATORY WORK DESCRIPTION

#### Laboratory Work Objectives:

1. To study the operation of the pumping unit with a centrifugal pump.
2. Master the method of parametric testing of a centrifugal pump.
3. Get the characteristic of a centrifugal pump.

#### The Order of the Work and the Processing of Experimental Data:

1. With the valve for changing the flow rate closed, fill the suction pipe and pump with water, and then turn on the pump from the power control panel.
2. With the valve closed, the flow changes when ( $Q=0$ ) take the readings of the differential manometer, vacuum gauge, manometer, scales and tachometer.
3. Create at least eight different pump operating modes using a flow change valve, providing various flows up to  $Q_{max}$ . In each mode, take readings of the devices listed in paragraph 2. Record the measurement results in table 2.
4. Calculate the parameters necessary to build head and energy characteristics:



– pump flow rate  $Q_{\text{exp}}$  [L/s], according to the formula:

$$Q_{\text{exp}} = C\sqrt{h}, \quad (12)$$

where  $C$  – the constant of the diaphragm ( $C=0.7$ );  $h$  – the differential pressure across the differential manometer, mmHg. The resulting pump flow  $Q_{\text{exp}}$ , L/s, convert to  $Q_{\text{exp}}$ , m<sup>3</sup>/s;

– average fluid velocity  $v_s$  and  $v_p$  in the suction and pressure pipelines, m/s:

$$v_s = \frac{4Q_{\text{exp}}}{\pi d_s^2}, \quad (13)$$

$$v_p = \frac{4Q_{\text{exp}}}{\pi d_p^2}, \quad (14)$$

where  $Q_{\text{exp}}$  – pump flow, m<sup>3</sup>/s;  $d_s$  and  $d_p$  – are the diameters of the suction and pressure pipelines, respectively, m (selected depending on the type of pump used – Table 1);

– pump head  $H_{\text{exp}}$ , m, – according to formula (4), assuming that  $z_M = 0.34$  m;

– pump power  $N_{\text{exp}}$ , W – by the formula:

$$N_{\text{exp}} = M \cdot \omega = (F - F_0)L \frac{\pi \cdot n_{\text{exp}}}{30}, \quad (15)$$

where  $M$  – the torque on the pump shaft, N•m;  $\omega$  – the angular velocity of the pump shaft, rad/s;  $F$  – readings of scales, N;  $F_0$  – readings of the scales when the pump is off, N ( $F_0=0$ );  $L$  – the length of the lever arm, m ( $L=0.716$  m);  $n_{\text{exp}}$  – pump shaft rotation frequency, rpm.

Since at each operating mode the frequency  $n_{\text{exp}}$  may differ from the nominal  $n_{\text{nom}}$  ( $n_{\text{nom}}=2900$  rpm), the flow rate  $Q_{\text{exp}}$ , L/s, head  $H_{\text{exp}}$  and power  $N_{\text{exp}}$  must be reduced to  $n_{\text{nom}}$  by the similarity formulas:

$$Q = Q_{\text{exp}} \frac{n_{\text{nom}}}{n_{\text{exp}}}, \quad (16)$$

$$H = H_{\text{exp}} \left( \frac{n_{\text{nom}}}{n_{\text{exp}}} \right)^2, \quad (17)$$

$$N = N_{\text{exp}} \left( \frac{n_{\text{nom}}}{n_{\text{exp}}} \right)^3, \quad (18)$$

after which the values of  $Q$ , L/s should be converted to  $Q$ , m<sup>3</sup>/s.

Useful power  $N_{\text{pump}}$ , W and pump efficiency  $\eta$  are calculated using formulas (6) and (7), substituting  $Q$ , m<sup>3</sup>/s into formula (6).

The results of the calculations are written in table 2.

5. According to the table. 2 to build graphical dependencies  $H=f(Q)$ ,  $N=f(Q)$ ,  $\eta=f(Q)$ , taking for this the value of  $Q$  in L/s.

6. Give a conclusion of the results of the work.

**Table 1** – Diameters of the Suction and Pressure Pipelines in the Laboratory Equipment for the Parametric Tests of Centrifugal Pump

Pump Model	Suction Pipe Diameter $d_s$ , m	Pressure Pipe Diameter $d_p$ , m
K 18/8 (1.5K 6)	0.05	0.032
K 20/20 (2K 6)	0.065	0.05
K 20/18 (2K 9)		
K 45/55 (3K 6)	0.08	0.065
K 45/30 (3K 9)		
K90/85 (4K 6)	0.1	

**Table 2** – Results of Measurements and Calculations

Measured Values					Calculated Values												
$P_M$ , Pa	$P_V$ , Pa	$h$ , mmHg	$F$ , N	$n_{\text{exp}}$ , rpm	$Q_{\text{exp}}$ , L/s	$Q_{\text{exp}}$ , m³/s	$v_s$ , m/s	$v_p$ , m/s	$H_{\text{exp}}$ , m	$N_{\text{exp}}$ , W	$Q$ , L/s	$H$ , m	$N$ , W	$Q$ , m³/s	$N_{\text{pump}}$ , W	$\eta$	