

Virtual Laboratory Work in the Course of Hydromechanics
«Experimental Determination of the Terms of D. Bernoulli's Equation
at Steady Non-Uniform Motion of the Liquid»

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.

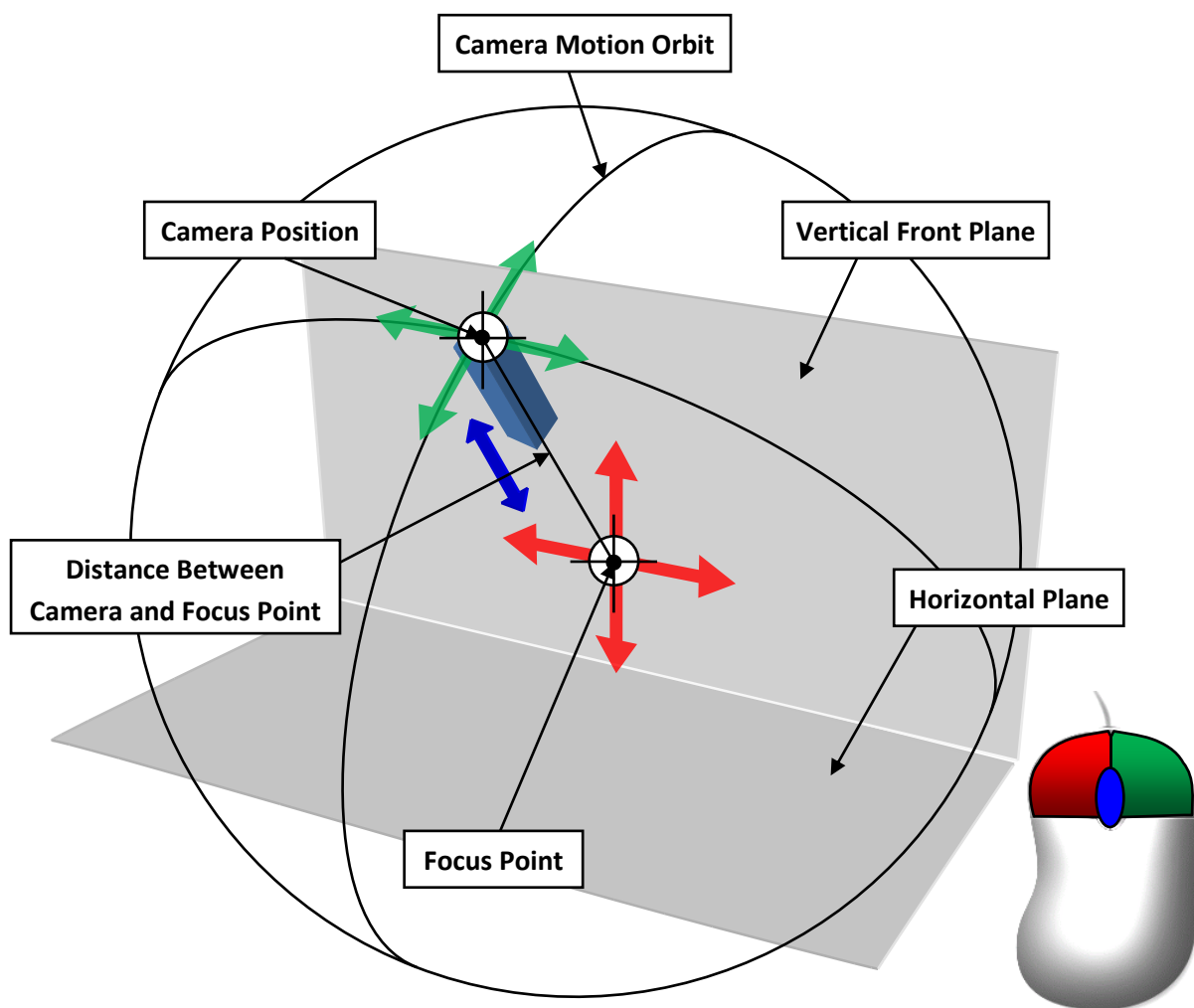


Figure 1 – Principle of the Camera Control in Free Mode

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 variable cross-section pipeline (1) with a pressure tank (2), in which water is supplied through the supply pipeline by opening the valve (3). The pressure tank is equipped with an overflow device to maintain the water level at a constant elevation in order to ensure steady flow of fluid in a variable cross-section pipeline. Piezometers and velocity tubes (4) are connected to crossections $I-I$ and $II-II$ of a variable cross-section pipeline for measuring the values of

$z + \frac{p}{\rho g}$ and $z + \frac{p}{\rho g} + \frac{v^2}{2g}$. The measuring piezometric tubes are fixed on a special stand (5).

The value of water flow in a variable cross-section pipeline is regulated by a valve (6). A measuring tank (7), an overflow device (8), a piezometric tube with a scale (9) and a stopwatch are available for measuring the flow of water.

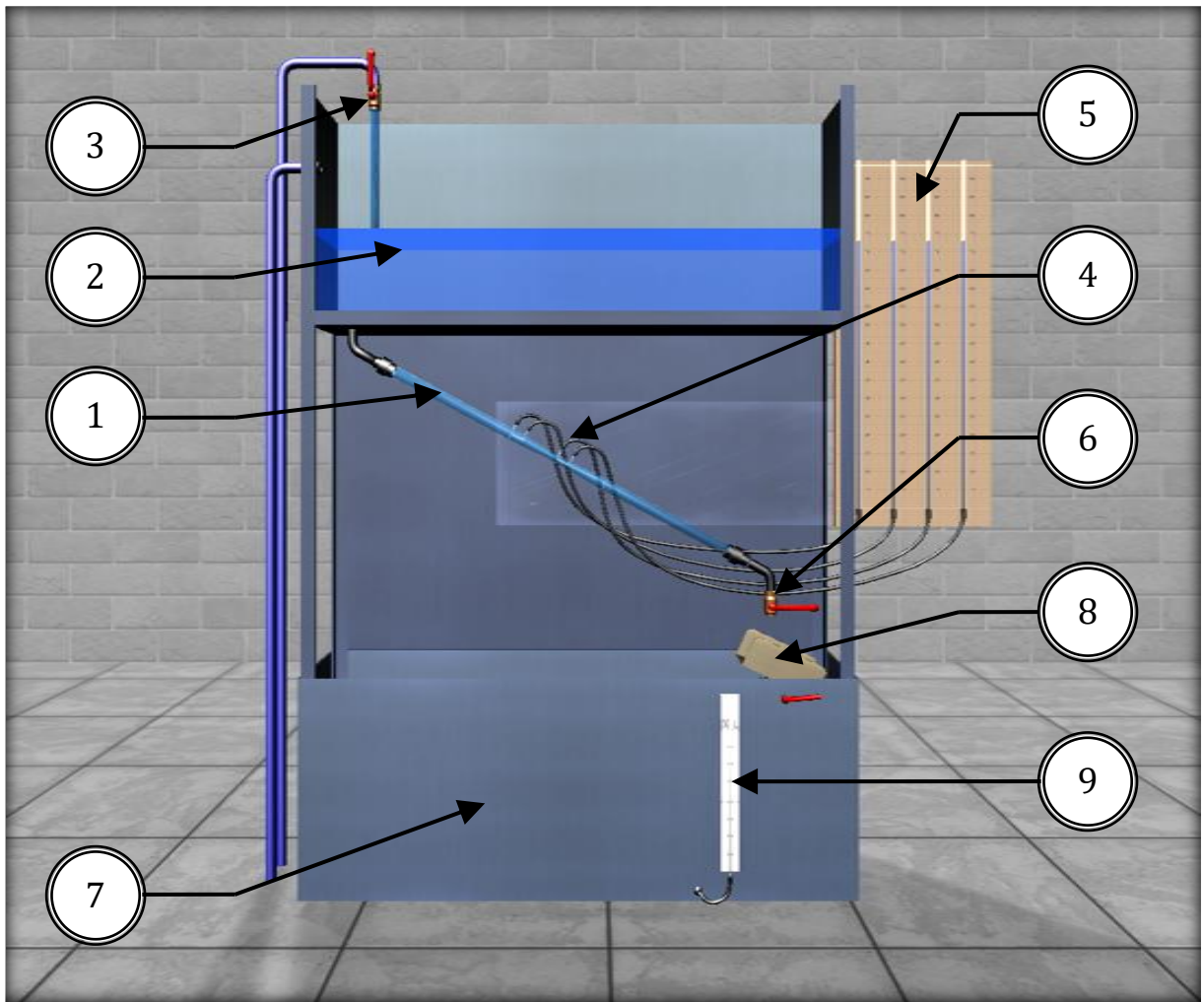


Figure 2 – Image of a Simulation Laboratory Equipment for Experimental Determination of the Terms of D. Bernoulli's Equation at Steady Non-Uniform Motion of the Liquid

PHYSICAL PROCESS DESCRIPTION

For two arbitrarily selected living cross-sections *I-I* and *II-II* of the real liquid stream at steady motion (Figure 3), the D. Bernoulli equation has the form

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

The terms in equation (1) can be interpreted from a geometric and energetic point of view. From a geometric point of view, the terms of equation (1) are heights (heads):

z – geometric height (head), i.e., exceeding the center of gravity of the considered cross section of the stream above the reference plane 0-0, chosen arbitrarily;

$\frac{p}{\rho g}$ – piezometric height, i.e. the height of the fluid in the piezometer connected to the center of gravity of the considered section of the stream, corresponding to the hydrodynamic pressure p at this point;

$\frac{v^2}{2g}$ – velocity height (head) corresponding to the local velocity v , i.e. the velocity at the center of gravity of the section;

$z + \frac{p}{\rho g}$ – hydrostatic head;

$z + \frac{p}{\rho g} + \frac{v^2}{2g} = H$ – total head in the considered cross-section of the stream;

$h_{w_{1-2}} = H_1 - H_2$ – total head loss, i.e. part of total head, spent on overcoming hydraulic resistances on the way between cross-sections $I-I$ and $II-II$.

From the energy point of view, the terms of equation (1) are varieties of specific energy, namely:

z – the specific potential energy of the position of the liquid in the stream cross-section under consideration;

$\frac{p}{\rho g}$ – specific potential energy of pressure;

$z + \frac{p}{\rho g}$ – specific potential energy of a fluid;

$\frac{v^2}{2g}$ – specific kinetic energy of fluid motion;

$z + \frac{p}{\rho g} + \frac{v^2}{2g}$ – total specific energy;

$h_{w_{1-2}}$ – loss of the total specific energy of the stream, i.e. parts of it, spent on overcoming the work of internal friction forces caused by the viscosity of the fluid.

Specific energy is the energy per unit weight of a liquid.

The values of the terms of equation (1) can be determined empirically as follows:

z – geometric leveling or measurement with a ruler;

$\frac{p}{\rho g}$ – using a piezometer;

$\frac{v^2}{2g}$ – by the difference of the level marks of the liquid in the velocity and piezometric tubes connected to the considered point of the living cross-section of the stream;

$h_{w_{1-2}}$ – by the difference of the water level marks in the velocity tubes connected to the cross-sections $I-I$ and $II-II$ of the real liquid stream.

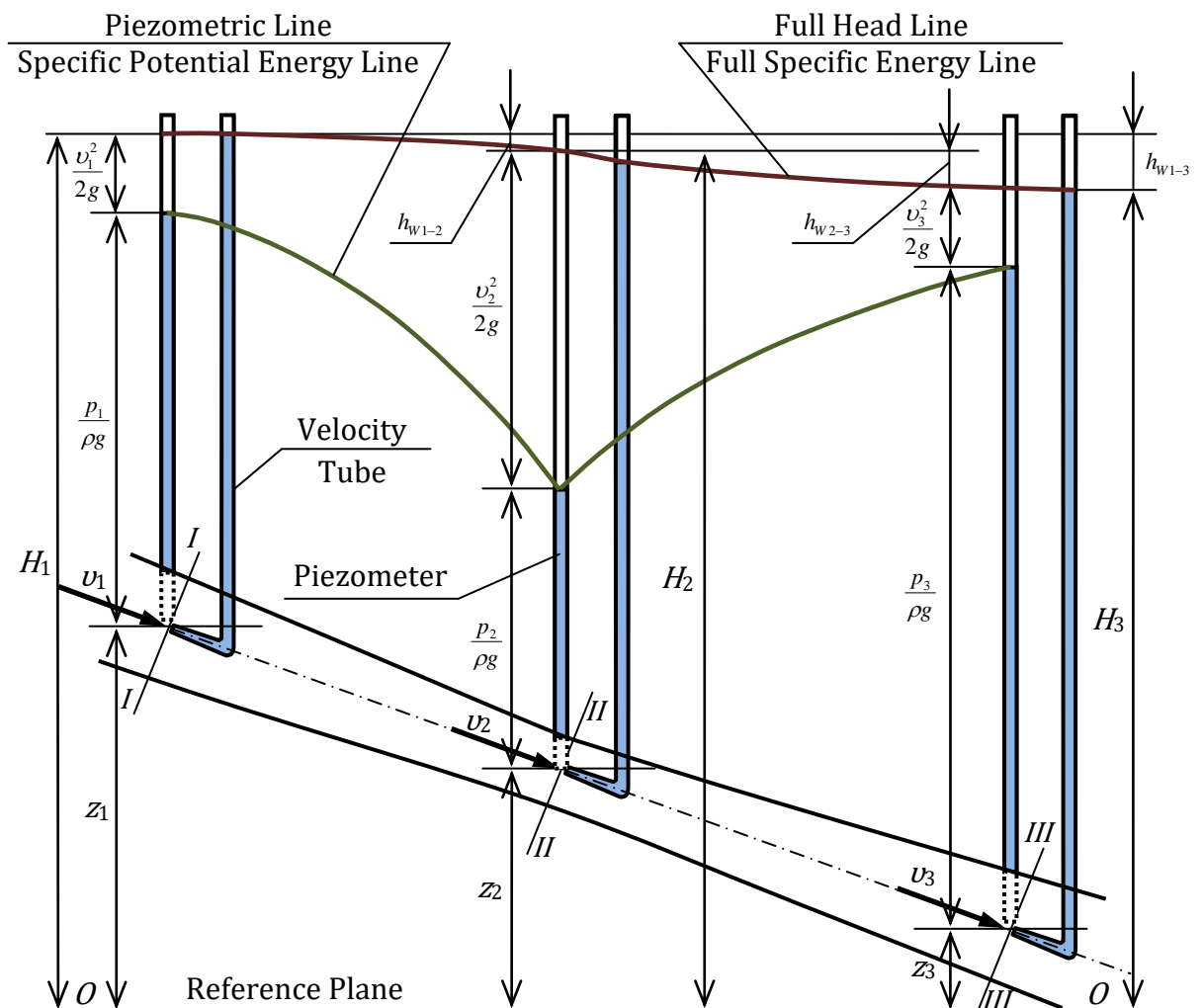


Figure 3 – D. Bernoulli's Equation Diagram for Stream of Real Fluid

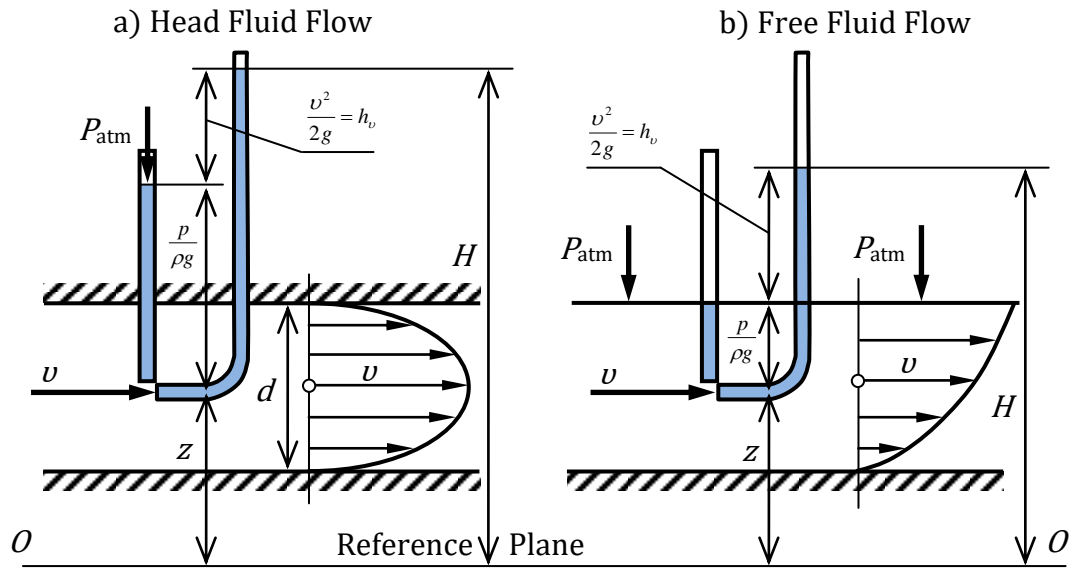


Figure 4 – Measurement of Velocity Head $v^2/2g$

The velocity tube (Figure 4) is a tube, the upper end of which is open to the atmosphere, and the lower end is bent to meet the velocity v at the considered point of fluid flow. Due to this, at the entrance to the curved end of the velocity tube, the kinetic energy of the fluid particle is converted into the potential energy of the pressure of the liquid column with height $h_v = \frac{v^2}{2g}$.

Since the cut of the lower end of the speed tube is perpendicular to the velocity vector, and the cut of the lower end of the piezometer is parallel, the liquid level in the velocity tube is always higher than in the piezometer by $h_v = \frac{v^2}{2g}$.

A device that combines piezometric and velocity tubes structurally is called a Pitot tube and is widely used to measure the velocity of a fluid: $v = \sqrt{2gh_v}$.

For two cross-sections of real fluid flow, the D. Bernoulli's equation has the form:

$$z_1 + \frac{p_1}{\rho g} + \frac{\alpha_1 v_1^2}{2g} = z_2 + \frac{p_2}{\rho g} + \frac{\alpha_2 v_2^2}{2g} + h_{w_{1-2}}, \quad (2)$$

where $\frac{\alpha v^2}{2g}$ – velocity head corresponding to the average velocity $v = \frac{Q}{S}$ of the fluid flow in the considered living cross-section (here Q is the flow rate of the fluid; S is the area of the living cross-section of the flow); $h_{w_{1-2}}$ – loss of total head (total specific energy) to overcome the work of internal and external friction forces on the path between the living

cross-sections of the fluid flow *I-I* and *II-II*; α – Coriolis coefficient (correction of kinetic energy), taking into account the uneven distribution of local velocities v over the living cross-section of the flow, due to the viscosity of the liquid.

The value of α depends on the mode of fluid flow and type of movement. So, with a uniform motion for the laminar mode $\alpha = 2$, and for the turbulent one – $\alpha = 1.05 \dots 1.15$.

The components of equations (1) and (2) in various living cross-sections can be represented graphically in the form of a diagram of D. Bernoulli's equation, which gives a visual representation of the redistribution of potential and kinetic energy along the path of a fluid, as well as the nature of the decrease in total energy.

LABORATORY WORK DESCRIPTION

Laboratory Work Objectives:

1. Experimentally and using the calculation method, determine the terms z , $\frac{p}{\rho g}$, $\frac{v^2}{2g}$ of the D. Bernoulli equation for sections *I-I*, *II-II*, *III-III*, as well as the total head loss $h_{w_{1-3}}$ between sections *I-I* and *III-III*.

2. Calculate the average flow velocities v and corresponding velocity heads $\frac{v^2}{2g}$ for the indicated living cross-sections of the fluid flow.

3. build by the experimental data piezometric line and the full head line.

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

1. With the control valve closed, open the water supply valve to fill the head tank and the variable cross-section tube with water. It should pay attention to the water levels in the piezometric and velocity tubes. These levels in the absence of air in the system should be on one mark.

2. Open the regulating valve so that the variable cross-section tube works with a full cross-section, and the water level in the head tank is constant.

3. Measure the flow rate with a measuring tank and stopwatch. Then measure the geometric heights z of the centers of gravity of the cross-sections *I-I*, *II-II* and *III-III* relative to the reference plane 0-0, marked on the equipment.

4. Determine the water level marks in piezometers and velocity tubes in cross-sections *I-I* and *II-II* on scale. Record the results of all measurements in table 1.

5. Perform all calculations provided in table 1.

For cross-section *III-III*, the numerical values of the quantities (see rows 5 and 11...15) should be similar to the section *I-I*.

The total head loss $h_{w_{2-3}}$ (see row 6) between cross-sections *II-II* and *III-III* should be equal to the head loss $h_{w_{1-2}}$ between cross-sections *I-I* and *II-II*.

The remaining values for cross-section *III-III* (see rows 1...4) should be determined using the D. Bernoulli's equation and Figure 4.

6. Build to scale on the obtained data full head lines and piezometric line.

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

Table 1 – Results of Measurements and Calculations

№	Measured and Calculated Values	Units	Experimental Results		
			<i>I-I</i>	<i>II-II</i>	<i>III-III</i>
1	Geometric heights of the centers of gravity of cross-sections z	m			
2	The levels of water in piezometers tubes, i.e. hydrostatic heads $z + \frac{p}{\rho g}$	m			
3	he levels of water in velocity tubes, i.e. full heads $z + \frac{p}{\rho g} + \frac{v^2}{2g}$	m			
4	Piezometric heights $\left(z + \frac{p}{\rho g}\right) - z$	m			
5	Velocity heights $\frac{v^2}{2g} = H - \left(z + \frac{p}{\rho g}\right)$	m			
6	Loss of total head on the path between adjacent living cross-sections of streams $h_{w_{i-(i+1)}} = H_i - H_{i+1}$	m			
7	Total head loss $h_{w_{I-III}} = H_I - H_{III}$	m			
8	The volume of water in the measuring tank W	m ³			
9	Filling time of the measuring tank t	s			
10	Pipeline water flow $Q=W/t$	m ³ /s			
11	Diameter of cross-section d	m			
12	Cross-sectional area $S = \pi d^2/4$	m ²			
13	Average water velocity $v = Q/S$	m/s			
14	Velocity head corresponding to average velocity, $v^2/2g$	m			
15	Velocity head difference $\frac{v^2 - v^2}{v^2} \cdot 100$	%			

Note: tube diameters: $d_1=28$ mm, $d_2=19$ mm.