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DESIGN AND MANUFACTURING OF EXPERIMENTAL EQUIPMENT FOR PUMPS AND HYDRAULICS STUDY

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ABSTRACT

The project "Design and Manufacturing of Experimental Equipment for Pumps and Hydraulics Study" was developed to provide Mekong University students with a practical tool for research and training. The system includes a centrifugal pump connected to three pipes of different sizes, together with valves, a flow meter, an orifice, and a Venturi tube. Water circulates from a lower tank through these devices to an upper tank and back. There are suitable instruments to measure voltage, current, vacuum, pressure, and hydraulic losses. The equipment enables students to study pump performance and pressure losses in pipes and fittings. Two experimental lessons were also prepared for student practice.

Keywords: *Design, manufacture, experiment, pump, hydraulics, pipes, valves, orifice.*

1. Introduction

Pumps and hydraulic systems are indispensable components in industry and agriculture, transportation, as well as in everyday life. They provide energy to fluids, creating flow with the required flow rate and pressure to perform a wide variety of tasks: liquid transporting, compression, power transmission, irrigation, washing, misting, landscape creation, etc. If a hydraulic system is viewed as a living organism, the pump is its heart, and the pipelines are the blood vessels that transmit energy to all functioning parts of the body.

Although there are many types of pumps, based on operating principles they can be divided into two main groups: positive displacement pumps and dynamic pumps. Among dynamic pumps, the centrifugal pump is the most commonly used because of its simple structure, ease of installation and operation, and its ability to generate medium-level pressure and flow suitable for many practical applications [1], [5]. However, the pressure and efficiency of a centrifugal pump depend on the flow rate. Moreover, not all centrifugal pumps have the same characteristics; each type operates efficiently only within a specific range of pressure and flow.

Aside from pumps, hydraulic systems also include various types of pipes and fittings (valves, tees, elbows, etc.) differing in material, shape, and size. These pipes and fittings significantly affect the hydraulic system's performance, including flow rate, head, and transport efficiency. Therefore, understanding the characteristics of pumps, pipes, and fittings is essential for designing a fluid transport system that meets technical requirements and ensures economic efficiency. For that purpose, this project has developed an experimental model for fluid transport to support investigation and research on hydraulic parameters related to pumps, pipelines, and fittings.

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2.1. Structure and working principles of centrifugal pumps

The structure of a centrifugal pump is quite simple (Figure 1). Its main components include the impeller, the volute casing, and the drive mechanism. A centrifugal pump operates based on dynamic principles, using the centrifugal force generated as the fluid rotates with the impeller to create head (Figure 2).

For the centrifugal pump to function, the pump casing must be completely filled with liquid; the suction pipe must be connected to the fluid source (the suction tank), and the discharge pipe must lead to the point of use (the discharge tank). The centrifugal force pushes the liquid along the impeller's channels, increasing the pressure from the inside outward while simultaneously creating a vacuum at the pump's center, allowing fluid to be drawn in.

The fluid leaving the impeller possesses high kinetic energy, part of which is converted into pressure that drives the liquid through the pipeline. In this way, the liquid is continuously pumped from the suction tank to the discharge tank, with its pressure rising from suction pressure to discharge pressure.

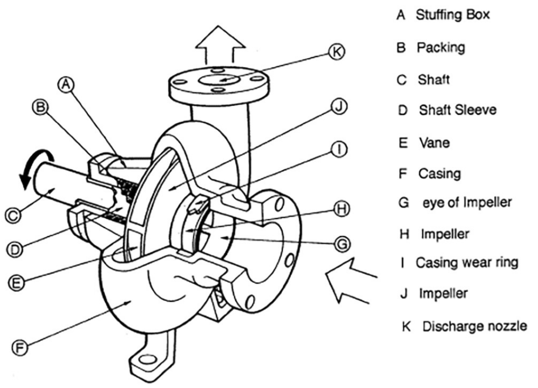

Fig. 1 - Structure of a centrifugal pump [6]

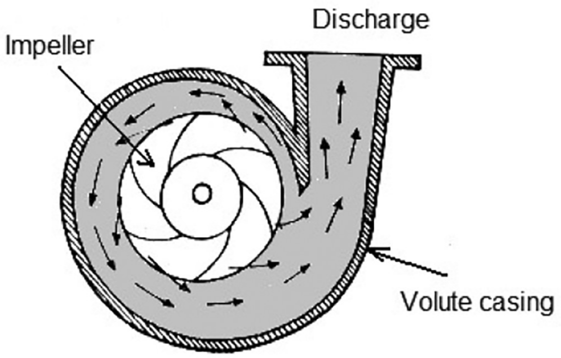

Fig. 2 - Centrifugal pump working principle [6]

Centrifugal pumps have been invented several centuries ago and widely used in practice currently [2]. There are many brands from well-known pump manufacturers such as Pentax, Embara, Wilo, Franklin, and others available on the Vietnamese market. However, not many companies provide the full performance data of their products to the customers.

2.2. Pipes for fluid conveying

Fluid-conveying pipes are generally divided into two groups: metal pipes and non-metal pipes (plastic, rubber, ceramic…). Metal pipes have high rigidity and heat conductivity, can withstand high pressure and temperature but they are difficult to process and expensive. Galvanized steel pipes are no longer used for domestic water supply because they rust easily. Copper and stainless-steel pipes are costly and are only used in special cases. Today, plastic pipes are the main type used in daily life as well as in industry. There are many different kinds of plastics, but for fluid transport, three common types of plastic pipes are typically used:

1) PPR pipes (Polypropylene Random Copolymer)

2) HDPE pipes (High-Density Polyethylene)

UPVC pipes (Unplasticized Polyvinyl Chloride)

Among those types, PPR pipes can withstand high temperatures and high pressure, making them suitable for both hot and cold water. HDPE pipes have high durability and are highly resistant to pressure and impact. However, these two types are more expensive and thus less common than UPVC pipes. UPVC pipes are now widely used in residential, industrial, and agricultural water supply and drainage systems due to their reasonable cost, ease of use, and good durability. UPVC pipes are typically manufactured in gray or white. Their nominal outside diameter (OD), according to international standards ISO 1452, TCVN 6151, and TCVN 8491, ranges from Φ21 mm to Φ315 mm or larger (D21, D27, D34, D42, D49, D60, D75, D90, D110...). The working pressure (PN) depends on pipe-wall thickness, commonly ranging from 5 bar to 16 bar. Standard pipe lengths are 4 meters or 6 meters per section.

In Vietnam, there are many companies manufacturing and supplying plastic pipes. The most notable brands include Bình Minh, Hoa Sen, Tiền Phong, and Dekko [7]. The informations about material, dimensions, pressure and temperature resistance of their products are available, except the information on pipe wall roughness. Therefore, determining the friction coefficient or resistance coefficient of the pipe can only be done through experimentation.

2.3. Review of experimental equipment for studying pump and hydraulic systems

A number of pumps and hydraulic devices have been introduced in the public media. A typical example is the experimental apparatus manufactured and supplied by Chemical and Environmental Equipment Joint Stock Company (JSC). The pump testing equipment (Figure 3) produced by JSC allows the study of changes in head and energy consumption with respect to flow rate, as well as the influence of rotational speed on the pump's operating parameters.

JSC also offers experimental equipment for determining hydraulic flow regimes based on Reynolds' experimental model. The main components of this apparatus include a system of tanks and fluid-conveying pipes, with a glass pipe section containing a colored dye capillary tube at its center for observing the fluid's flow state.

Figure 3: Experimental apparatus for pump of JSC [8]

Foreign-made experimental equipment for pumps and hydraulic systems has also been introduced to research institutions in Vietnam. Dinh-Bach-Ma Trading & Service Co., Ltd. offers an experimental system combining two centrifugal pumps that is branded TecQuipment from the United Kingdom (Figure 4).

Figure 4: Experimental apparatus for pumps conection of TecQuipment [8]

TecQuipment's system includes a liquid storage tank, two centrifugal pumps, and a system of valves and pipelines that allow switching between different pump configurations. A notable feature of this system is that the pumps have transparent windows, enabling observation of the impeller shape, the flow through the pump and cavitation phenomena inside the pump. This experimental apparatus is used to study changes in pump system characteristics when two pumps are connected in parallel or in series.

Several technical training institutions in Vietnam have also equipped themselves with pump and hydraulic experimental systems for educational purposes. The Industrial University of Ho Chi Minh City (IUH) has pump-connection experimental equipment as shown in Figure 5. The system is designed similarly to TecQuipment's model, but it is made using materials available in Vietnam. The system is used for students to study and investigate the performance of fluid transport systems when two pumps are connected together.

Figure 5. Pump-connection experimental equipment of IUH [1]

Ton Duc Thang University (TDTU) has also used a pump and fluid-circuit experimental system since 2010 for its training, which was designed and manufactured domestically [4]. The structural diagram of TDTU's equipment system is shown in Figure 6.

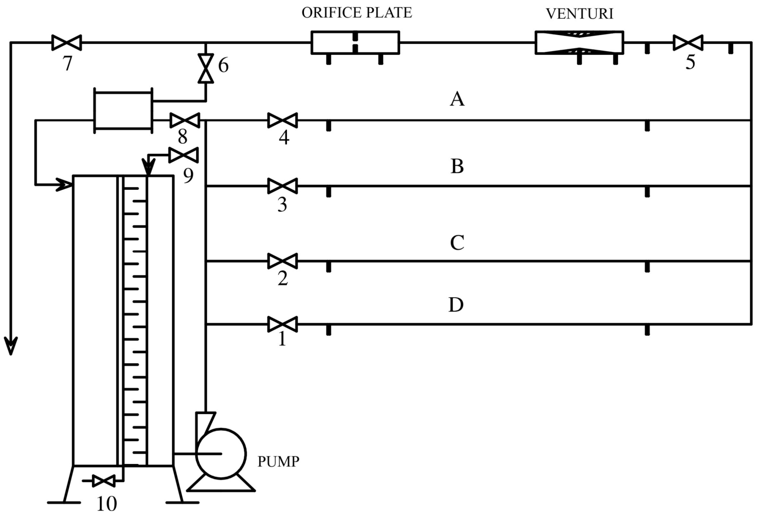

Figure 6: Pump and fluid-circuit experimental system of TDTU [4]
(1, 2, 3, 4: gate valves; 5: regulator valve; 6, 8: return valves; 7, 10: drain valve;
9: supply valve)

The pump and fluid-circuit system of TDTU is used to determine the friction coefficient of flow in different pipelines (A, B, C, D), the flow coefficient of the Venturi meter or orifice plate, and the local loss coefficient of valves.

3. Design and manufacturing methods

3.1. Survey and investigation method

Before designing the experimental equipment large information which was published in mass media had been collected. Some direct visits to training institutions and equipment suppliers were made to study the operating principles, features, and applications of existing pump and hydraulic experimental systems both domestically and abroad. This serves as the reference for the design process.

3.2. Method for designing the equipment system

Based on the project's objectives and scope, the advantages and limitations of the surveyed equipment were analyzed to design a pump and hydraulic system suitable for the engineering training programs at Cuu Long University. AutoCAD software was used to produce technical drawings. Knowledge from the courses *Pumps, Fans & Compressors* and *Fluid Mechanics*, along with specialized references, provided the design foundation. Excel and MATLAB software were used as computational tools for determining parameters of the experimental model.

3.3. Method for manufacturing and installing the equipment system

The project took priority for using available materials and components on the local market whose features and quality met the project's requirements. Special parts were fabricated at the Mechanical Workshop of Cuu Long University following the detailed drawings. System installation followed the assembly drawings and consisted of three components: the pump, the piping–valve system, and the measurement instruments.

3.4. Method for experimentation and determining major parameters of the system

Before conducting experiments, the measuring instruments must be inspected and calibrated as follows:

- A multimeter certified by QUATEST 3 was used to check the accuracy of the voltmeter and ammeter. The inspection was carried out directly by the suppliers. The pressure gauge was checked by the supplier using a dead weight tester. The meters must have the level of error less than 5%.

- The flowmeter was verified by directly measuring the volume of water when the system was in operation. By opening valve V4, the amount of water entering tank BC2 was measured using a stopwatch and compared with the flowmeter reading to determine the error, which was then used to compensate during flowrate calculations.

Experiment 1: Determining pump characteristics

A vacuum gauge and pressure gauge were used to determine the pump head according to formula (3). A float-type flowmeter was used to measure the flow corresponding to different valve openings on the discharge pipeline. From this, the relationship between pump head and flowrate was established, forming the basis for plotting the pump characteristic curves. Changing the impeller speed gives data to draw the overall characteristic graph of the pump.

The actual power of the pump was determined from the electrical energy consumed by the motor (powered by a single-phase grid) during operation, calculated using the formula:

$$\text{Nmotor} = \text{U.I.}\cos\varphi \quad (1)$$

where:

U is the voltage and *I* is the current, measured by the voltmeter and ammeter;

The power factor (*cos φ*) is determined using a power meter; typically, **cos φ = 0.85**.

On the other hand, the actual power of the pump can be determined using the formula:

$$N_t = \frac{\rho g H Q}{\eta} \quad (2)$$

In this formula, the pump head (H) is calculated as follows: $H = \frac{P_{ak}+P_{ck}}{\rho g}$ (3)

Q is the pump flow rate (measured by a flow meter); ρ is the density of water (kg/m^3); Pck is the vacuum pressure at the suction port, and Pak is the pressure at the discharge port of the pump. From this, the pump efficiency η can be determined.

Experiment 2: Determining hydraulic loss of the flowing fluid

To determine the hydraulic loss along a pipe section, a U-tube manometer (also called a differential manometer) is used to measure the head difference Δh between the two ends of the pipe while adjusting different flow rates through the pipe. From this, the head loss and the friction coefficient of the fluid flow in the pipe can be determined. Similarly, the resistance coefficient across a valve at different opening levels and the flow coefficient through an orifice plate can also be determined.

Using the Darcy equation [6]::

$$\boldsymbol{\Delta h_{ms} = f\frac{L}{D}\frac{V^2}{2g}} \quad (4)$$

Where: L is the pipe length; D is the internal diameter of the pipe; V is the flow velocity (in SI units); f is the friction factor between the fluid and the pipe; and g is the gravitational acceleration (m/s^2). Δh_{ms} is the head loss when the fluid flows through the pipe (the difference in liquid height between the two columns of the U-tube manometer measuring pressure at both ends of the pipe).

From this, the friction factor of the fluid flowing inside the pipe can be determined.

$$f = \frac{2Dg}{LV^2}\Delta h_{ms} \qquad (5)$$

The degree of hydraulic loss at valves and other local points is represented by the local resistance coefficient (Kcb). When fluid flows through these local points, the energy loss of the flow is determined by the formula:

$$\Delta hcb = Kcb\frac{V^2}{2g} \quad \text{Then:} \quad Kcb = \frac{2g\Delta h_{cb}}{V^2} \qquad (6)$$

Where: Kcb is the local resistance coefficient. For a valve, the local resistance coefficient (K_v) depends on the valve's opening; Δhcb is the head loss when the fluid passes through the local point (the difference in liquid height in the two branches of the differential manometer).

Using Bernoulli's law [5], the flow-rate coefficient CM of the orifice plate (or Venturi tube) can be determined by the formula:

$$Q = C_M S\sqrt{2g\Delta h}$$

Therefore

$$C_M = \frac{Q}{S\sqrt{2g\Delta h}} \qquad (7)$$

Where: Q is the flow rate through the orifice plate (or Venturi tube); S is the cross-sectional area of the flow; and Δh is the head loss when the fluid passes through the valve (the difference in liquid height in the two branches of the U-tube manometer).

4. Results and discussion

4.1. Results of design

The experimental pump and hydraulic equipment is designed according to the diagram shown in Figure 7. Water is drawn from storage tank 1 (TC1) by pump 4 and then discharged into the distribution pipe 10 then it is distributed through a system of valves (V01, V02, V04) into branch pipes O1, O2, and O4, through the flowmeter 11 (LK1), and through pipe O3 to conduct experiments on head loss in pipes and fittings (valve Vt and orifice of membrane M).

Afterward, the liquid flows through valve V3 up to the high-level storage tank (TC2) and then returns to storage tank 1 (TC1). In some cases when water is needed to flow directly from the pump to TC2, valve V2 is opened and the distribution valves (V01, V02, V04) are closed.

The flow rate can be measured using the flowmeter or using manually calibrated tank TC3 (volumetric tank). Valve V4 is opened only when the mannual measurement of the flow rate through the system is required. Valve V1 is used to supply water in order to maintain a stable water level in TC1. During operation, the suction valve (Vh) is always kept open to prevent pump cavitation.

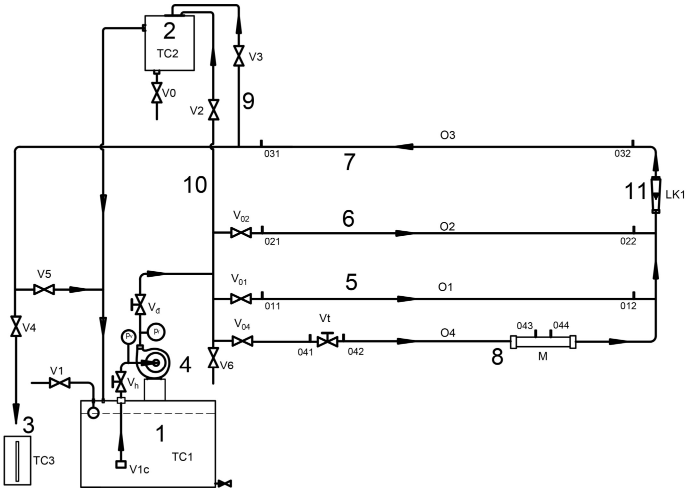

Figure 7: Schematic design drawing of the experimental equipment system

The main specifications of the equipment are as follows:

1) Power supply: 220 V, single-phase.

2) Centrifugal pump: Rated power P = 750 W, voltage 220 V, equipped with an inverter for speed control and phase conversion.

3) Pipes for the experiments: Plastic pipes with three diameter sizes Φ21, Φ27, and Φ34, with wall thickness ranging from 1.5 to 2 mm. All pipes have the same length: L = 2 m.

4) Valves in the system:

- Flow control valves (Vh, Vđ, Vt): Brass valves, Φ34.
- Other valves: Plastic globe valves.

5. Measuring instruments:

- Vacuum gauge: Measures vacuum in the range 0–760 mmHg.
- Pressure gauge: Measures pressure in the range 0–5 kG/cm².
- Ammeter: Measures electrical current in the range 0–5 A.
- Voltmeter: Measures electrical voltage below 400 V.
- Flowmeter: Measures water flow rate from 10 L/min to 100 L/min.

4.2. Results of the equipment manufacturing and installation

4.2.1. Manufacturing of special parts

Several special components (not available commercially in suitable forms) must be designed and fabricated, including the equipment frame, control cabinet, diaphragm plate, and Venturi tube. Figures 8 and 9 illustrate the drawings of the orifice plate (membrane) and the Venturi tube.

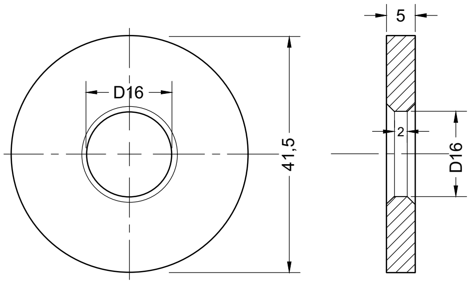

Figure 8. Orifice plate (membrane)

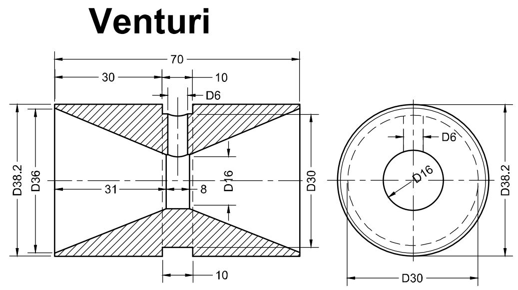

Figure 9. Core of the Venturi tube

4.2.2. System installation

Figure 10 illustrates the equipment system after installation at the Mechanical Workshop of Mekong University.

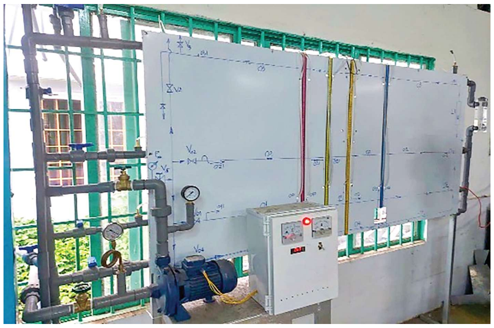

Figure10: The equipment system after installation

The pump and control cabinet are mounted on one support frame, while the pipe assembly is suspended on a separate frame. The Φ8 plastic tubes are attached to a panel with a scale for measuring differential head between the required measurement points.

4.3. Experimental results for determining the equipment parameters

4.3.1. Tests for preminimary determination of the pump performance

After testing the Pump–Hydraulic Experimental System according to the method described in Section 3.4, the readings from the measuring instruments were recorded in Table 1.

Table 1. Experimental data when adjusting the flow rate using the discharge valve $V_đ$

Valve open level (%)	Data recorded when pump speed at n = 2000 v/ph				
	P_{ck} (mmHg)	P_{ak} (kG/cm^2)	U (V)	I (A)	Q (lit/ph)
0	10	1.75	220	1.4	0
10	20	1.75	220	2.1	5
20	80	1.2	220	1.6	30
40	120	1.0	220	1.75	45
60	140	0.95	220	1.8	48
80	140	0.9	220	1.8	50
100	140	0.9	220	1.8	50

From the data in Table 1, and by applying formulas (1), (2), and (3) in Section 3.4, we obtain the main parameters of the pump as shown in Table 2.

Table 2. Results of preliminary determining basic parameters of the pump corresponding to the opening levels of valve $V_đ$

Valve open level (%)	Calculated results of pump working parameters				
	Q (l/ph)	H (m)	N_t (W)	N_i (W)	η
0	0	17.6	164.9	0	0
10	5	18.3	247.4	14.90	0.06
20	30	13.1	188.5	63.81	0.34
40	45	11.6	206.2	85.07	0.41
60	48	11.4	212.1	88.96	0.42
80	50	10.9	212.1	88.60	0.42
100	50	10.9	212.1	88.60	0.42

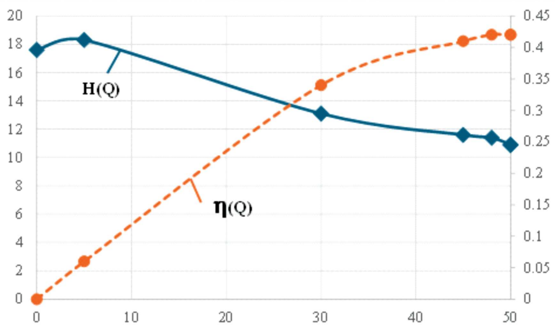

Figure 11: Chart of the pump basic perforemence at speed of 2000 rpm

From the calculated results (Table 2), the basic characteristic curve of the pump at a speed of 2000 rpm is obtained (Figure 11).

At a rotational speed of 2000 rpm, the pump head reaches a maximum of 18.3 mH_2O when the valve is opened by 10%, corresponding to a flow rate of 5 L/min. The highest pump efficiency is 42% when the discharge valve opening is 60% or greater, with the pump delivering a flow rate of 50 lit/min.

4.3.2. Determination of hydraulic resistance in the pipeline

Using the method described in Section 3.4, the head loss in pipeline O1 (Φ21 pipe) is determined. The pump is operated at 1500 rpm to obtain the flow rate Q1 and the head difference Δh1. From these values, the friction factor is calculated using formula (6). The results are shown in Table 3.

Table 3. Calculated results of friction factor of the pipe O1 (**Φ**21)

Valve open level (%)	20	40	60	80	100
Flow rate Q1 (lpm)	16	26	29	30	30
Head loss Δh_1 (mm)	160	390	460	480	490
Friction fact of pipe O1	0,0257	0,0237	0,0235	0,0219	0,0224

As the results, the average friction factor of pipe O1 is **f1 = 0.0234**.

Based on the results, the Moody chart *f(Re, ε/D)* can be used to estimate the pipe wall roughness, which is one of the indicators for evaluating pipe quality. The friction factor of pipe O2 (Φ27) can also be determined using a similar procedure.

The resistance coefficient of valve Vt is determined using the method presented in Section 3.4 and formula (7), with the results listed in Table 4.

Table 4. Hydraulic resistance factor of valve Vt at different valve openings

Valve V_t open level (%)	20	40	60	80	100
Flow rate Q_4 (lpm)	20	35	38	39	39
Head loss (mm)	720	350	120	80	80
Resistant factor	63.4	10.1	2.9	1.9	1.9

Thus, the resistance coefficient decreases rapidly when the valve begins to open, and decreases more slowly as the opening becomes sufficiently large. The relationship between resistance (or flow rate) and valve opening level serves as the basis for automatic control of valve operation.

The values identified above are only preliminary results based on data obtained during the initial operation of the experimental system. Therefore, further study is needed to determine the optimal operating conditions for the pump and the transport system.

Conclusion

The pump and hydraulic experimental system has been fully designed and fabricated in accordance with the original objectives, providing a useful tool for students to practice after studying theoretical subjects related to fluid transport and fluid mechanics, while also helping develop skills in operating real pump systems. The equipment is user-friendly, easy to assemble and disassemble, and convenient for repair or functional expansion. The system is designed to perform experiments on pump characteristics, pipeline characteristics, and related components. This is a new design since no equivalent equipment would be found on the market or in existing published designs.

To clarify the novelty of this experimental system, it can be compared with similar systems used at TDTU and IUH. All three systems have the purpose of supporting learning and research on pumps and hydraulics. However, the system at TDTU is mainly used for practicing pipeline and fitting characteristics (fluid circuits). Meanwhile, the system at IUH focuses on practicing pump characteristics and analyzing changes in pump performance when connected in series or in parallel. The experimental system designed and manufactured at UCL can be used to investigate both pump operating characteristics at different speeds and the hydraulic parameters of pipelines, including accessories such as valves, orifice plates or Venturi tubes.

In addition, the system is designed for expansion to allow future experimental studies on flow regimes, pump installation in series or parallel, and the characteristics of other pump types. This is also the intended direction for further development of the project.

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