SCUPI

Sichuan University - Pittsburgh Institute

ME 1042

Thermal Fluids Lab

Fluid Mechanics

Revised

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Mechanical Engineering Department

Goal: To explore the basic principles of the fluid mechanics of: 1) The difference between laminar flow and turbulent flow in circular pipe through Reynolds experiment, and measure the corresponding Reynolds number; 2) The fluid velocity measurement in the circular pipe through the Pitot tube; 3) The head loss measurement due to the contraction at the inlet and the expansion at the outlet.

Equipment Needed:

DYT001 Multifunctional Fluid Mechanics Test Platform

Beaker

Timer

1. Introduction and Basic Theory

Fluid mechanics is the study of fluids at rest or in motion. It has traditionally been applied in such areas as the design of canal, levee, and dam systems; the design of pumps, compressors, and piping and ducting used in the water and air conditioning systems of homes and businesses, as well as the piping systems needed in chemical plants; the aerodynamics of automobiles and sub- and supersonic airplanes; and the development of many different flow measurement devices such as gas pump meters.

The assumptions inherent to a fluid mechanical treatment of a physical system can be expressed in terms of mathematical equations. Fundamentally, every fluid mechanical system is assumed to obey: 1) Conservation of mass; 2) Conservation of energy; 3) Conservation of momentum.

1.1 Service Module

The experimental platform is shown in Figure 1. The device is composed of a table, a water supply system, pipelines and water tanks.

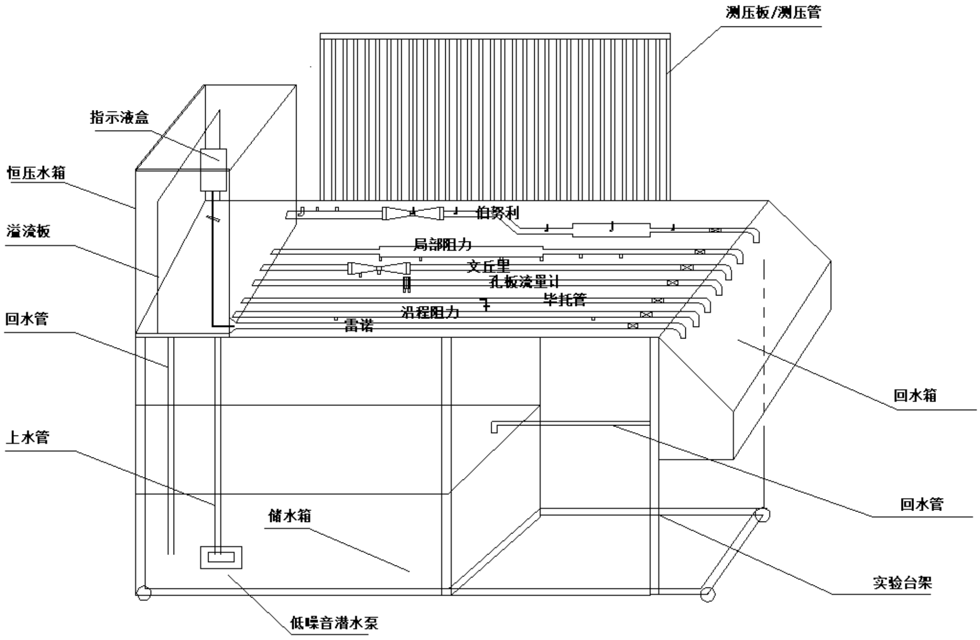


Figure 1 DYT001 multifunctional fluid mechanics test platform

Among them, there are two pressure measuring holes in the experimental tubes, and a piezometer is installed. The distance between the pressure measuring holes are L=800mm, and the inner diameter of the tubes is 14mm.

1.2 Reynolds Experiment

The actual fluid flow will show two different patterns: laminar flow and turbulent flow. The difference between them lies in whether mixing occurs between fluid layers during the flow. In turbulent flow, there is a randomly varying amount of pulsation, but in laminar flow, there is not, as shown in Figure 2.

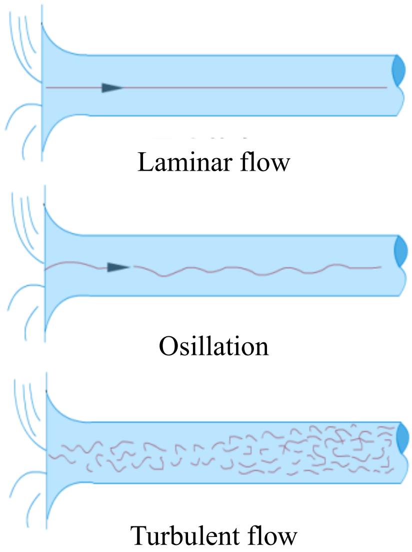


Figure 2 Schematic diagram of three flow patterns

The transition of the flow pattern in a tube depends on the Reynolds number. Based on large amounts of experimental data, the factors that affect the fluid flow state are summarized into a dimensionless number, called the Reynolds number with the symbol, Re. The Reynolds number is used as a criterion for determing the fluid flow pattern.

$$\mathrm{Re} = \frac{4Q}{\pi D \upsilon}$$

where $Q\ (L/s)$ is cross-sectioanl flow rate, $D\ (mm)$ is the test tube diatmeter, $\upsilon\ (m^2/s)$ is the flow kinematic viscocity.

In this experiment, the fluid is water. The relationship between the kinematic viscosity of water $\upsilon\ (m^2/s)$ and temperature $T\ (°C)$ can be calculated with an empirical formula:

$$\upsilon = 0.01775 \times 10^{-4} \Big/ 1 + 0.0337T + 0.000221T^2;$$

The critical factor for judging the state of fluid flow is the critical velocity. The critical speed varies with the viscosity and density of the fluid and the size of the flow channel. The velocity of the fluid transit from laminar flow to turbulent flow is called the upper critical flow velocity, and the velocity at the transition from turbulent flow to laminar flow is the lower critical flow velocity.

The Reynolds number corresponding to the transformation of the steady flow in the tube is called the critical Reynolds number, and the Reynolds number corresponding to the upper and lower critical speeds is called the upper critical Reynolds number and the lower critical Reynolds number. The upper critical Reynolds number indicates that the flow exceeding this Reynolds number must be turbulent, which is very uncertain and spans a larger value range. And it is extremely unstable, as long as there is a slight disturbance, the flow pattern will change. The upper critical Reynolds number often varies with the experimental environment and the initial state of the flow. Therefore, the upper critical Reynolds number has no practical significance in engineering technology. What is of practical significance is the lower critical Reynolds number, which means that the flow has the Reynolds below this number must be laminar and has a definite value. It is usually used as the criterion for judging the flow state, namely

$\mathrm{Re} < 2320$, laminar flow

$\mathrm{Re} > 2320$, turbulent flow

This value is the value of a round smooth tube or nearly a smooth tube, and $\mathrm{Re} = 2000$ is generally adopted in engineering practice.

The reason why the actual fluid flow presents two different patterns is the result of the balance between the disturbance factor and the viscous stabilization effect. In view of the steady flow in a circular pipe, it is easy to understand: reducing $D\ (mm)$, reducing $D\ (mm)$ and increasing the flow velocity are all three ways that are conducive to stablize the flow. Taken together, the flow with small Reynolds number tends to be stable, while the flow of large Reynolds number has poor stability and turbulence is prone to occur. Since the flow field structure and dynamic characteristics of the two flow patterns are quite different, it is necessary to distinguish them and discuss them separately. When the steady flow in the tube is laminar, the head loss along the way is proportional to the average velocity, and when turbulent, it is proportional to the 1.75 to 2.0 power of the average velocity of, as shown in Figure 3.

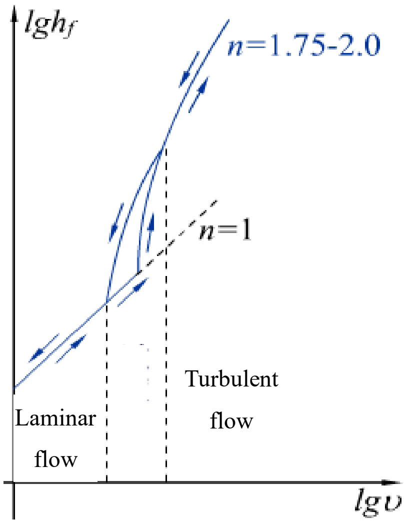


Figure 3 The relationship between the head loss and the average velocity

By comparing the cross-sectional velocity distribution of laminar flow and turbulent flow in a circular pipe at the same flow rate, it can be seen that the laminar flow velocity distribution is a paraboloid of revolution, while the turbulent flow velocity distribution is relatively uniform. The wall velocity gradient and shear stress are larger than laminar flow.

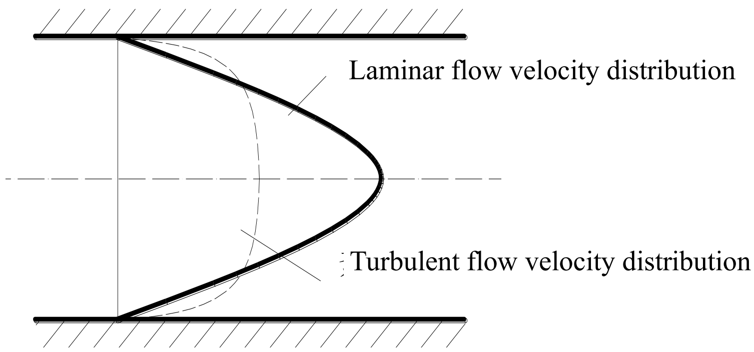


Figure 4 Flow velocity distribution

1.3 Pitot Tube Experiment

The structure of the pitot tube is shown in Figure 5

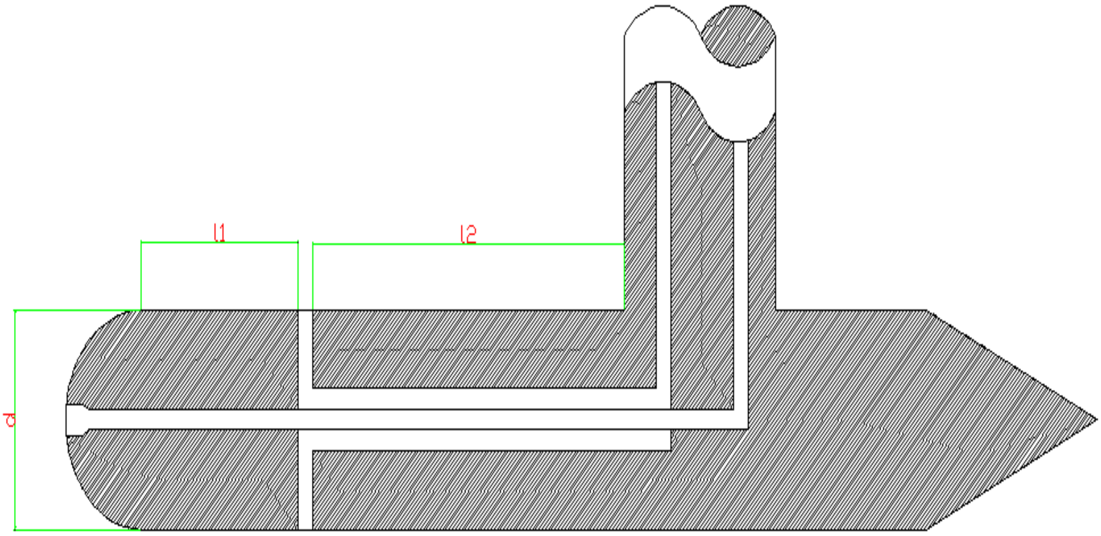


Figure 5 Pitot tube structure

Pitot tube has the advantages of simple structure, convenient use, high measurement accuracy, and good stability. The measuring range of the Pitot tube is 0.2～2m/s for water flow and 1～60m/s for airflow.

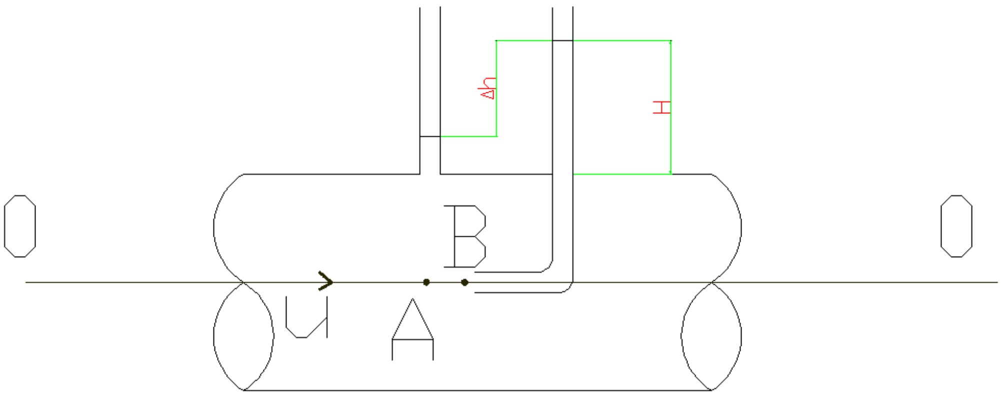


Figure 6 Pitot tube speed measurement principle

The Pitot tube speed measurement principle is shown in the Figure 6. It consists of a 90-degree curved tube with two openings. Point A is at the place where the Pitot tube is not disturbed, and the flow velocity is u. Point B is at the stagnation point of the Pitot tube and the flow velocity is zero. The fluid particle flows from point A to point B, and its kinetic energy is converted into potential energy, which raises the liquid level of the vertical pipe and exceeds the static pressure by $\triangle h$ water column height. List the Bernoulli equation along the streamline, ignoring the energy loss between A and B, there are

$$0 + P_1/\rho g + u^2/2g = 0 + P_2/\rho g + 0$$
$$P_2/\rho g - P_1/\rho g = \triangle h$$
$$u = \sqrt{2g \triangle h}$$

Considering the head loss and the manufacturing error of the Pitot tube, the flow velocity obtained from the above formula must be corrected

$$u = c\sqrt{2g \triangle h} = k\sqrt{\triangle h}$$

$$k = c\sqrt{2g}$$

where u is the flow velocty, c is correction coeffcient, also known as Pitot tube coefficient, $\triangle h$ is the difference between the total pressure head of the pitot tube and the static pressure head.

1.4 Local Resistance Coefficient Measurement

In the actual pipe flow, due to the change of pipe diameter or the sudden change of the structure, the flow structure is re-adjusted, and vortexes are generated, which causes energy loss, such as sudden expansion or reduction of pipe diameter, sharp bends, forks, etc. It can be seen from the energy equation that the local head loss caused by the sudden expansion of pipe flow is the head loss from crosssection 1-1 to crosssection 2-2 in the Figure 7.

$$h_j^{measurement} = \left(z_1 + \frac{p_1}{\rho g} + \frac{\alpha_1 v_1^2}{2g} \right) - \left(z_2 + \frac{p_2}{\rho g} + \frac{\alpha_2 v_2^2}{2g} \right)$$

where $\alpha_1 = \alpha_2 = 1$, $(z_1 + \frac{p_1}{\rho g})$、$(z_2 + \frac{p_2}{\rho g})$ can be measured using the piezometer. The flow velocity head $\frac{\alpha_1 v_1^2}{2g}$、$\frac{\alpha_2 v_2^2}{2g}$, is obtained by calculating the flow velocity v_1、v_2 according to the flow rate Q measured and the pipe diameters d_1 and d_2.

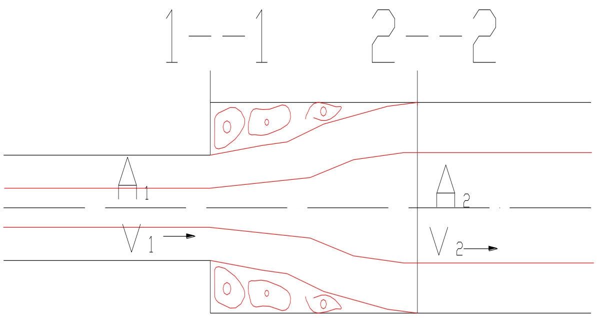


Figure 7 Sudden expansion of pipe flow

The theoretical formula for the sudden expansion of pipe flow and local head loss:

$$h_j^{theortical} = (1-\frac{A_1}{A_2})^2 \frac{v_1^2}{2g} = [1-(\frac{d_1}{d_2})^2]^2 \frac{v_1^2}{2g}$$

$$\zeta^{theortical} = (1-\frac{A_1}{A_2})^2 = [1-(\frac{d_1}{d_2})^2]^2$$

It can be seen from the energy equation that the local head loss caused by the sudden shrinkage of the pipeline is the energy loss from the crosssection 1-1 to crosssection 2-2 in the Figure 8.

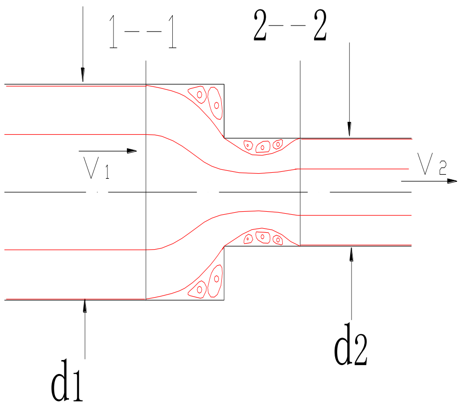


Figure 8 Sudden shrinkage of pipe flow

$$h_j^{measurement} = (z_1 + \frac{p_1}{\rho g} + \frac{\alpha_1 v_1^2}{2g}) - (z_2 + \frac{p_2}{\rho g} + \frac{\alpha_2 v_2^2}{2g})$$

where $\alpha_1=\alpha_2=1$, $(z_1+\frac{p_1}{\rho g})$、$(z_2+\frac{p_2}{\rho g})$ can be measured using the piezometer. The flow velocity head $\frac{\alpha_1 v_1^2}{2g}$、$\frac{\alpha_2 v_2^2}{2g}$, is obtained by calculating the flow velocity v_1、v_2 according to the flow rate Q measured and the pipe diameters d_1 and d_2. The emprical formula is

$$h_j=\zeta\frac{v_2^2}{2g}$$

$$\zeta=0.5(1-\frac{A_2}{A_1})$$

where ζ is the head loss coefficient.

2. Experimental Procedures

2.1. Reynolds Experiment

Requirement:

Observe the flow state of the water flow in a circular pipe, including laminar flow, turbulent flow and flow state transition phenomena, and determine the critical Reynolds number.

Work through the following procedure:

1.1. Turn on the power supply, start the water pump, and add red ink to the indicating container of the Reynolds test tube.

1.2. When the water in the water tank starts to overflow, gently open the control valve to make the water flow in the Reynolds test tube.

1.3. Open and close the control valve of the test tube repeatedly to eliminate air bubbles.

1.4. Turn on the indicator switch slightly to make red ink flow into the test tube.

1.5. Slowly reduce the flow rate and observe laminar flow, transition phenomena and turbulent flow (a stable straight color line, curved and intermittent color lines and completely spread out color lines).

1.6. Use a beaker to collect the water flowing from the tube and determine the flow rate with a timer.

1.7. Calculate the critical Reynolds number.

1.8. After the experiment, turn off the indicator switch and the water pump, and clean up the experimental bench.

Table 1 Data table for Reynolds experiment

(Tube diameter=1.4 cm, water temperature= C)

Item	Flow rate Q (10^{-6}m^3/s)	Flow velocity v (10^{-2}m/s)	Reynolds number R_e	Color line state	Remark

Attention

- The opening of the indicator switch should be appropriate, neither too large nor too small
- Do not shake the test tube during the experiment
- In order to judge the critical flow state, adjust the flow rate slowly in one direction

2.2. Pitot Tube Experiment

Requirement:

Understand the working principle of pitot tube and measure the flow velocity using a pitot tube.

Pitot tube

Figure 9 Pitot tube

2.1 Turn on the water pump and adjust the opening of the flow control valve to the maximum. Eliminate air bubbles in the pitot tube and the piezometers.

2.2 Adjust the flow control valve to get an appropriate flow rate.

2.3 After the liquid level of the piezometer is stable, record its value. When reading, the line of sight should be level with the lowest part of the liquid level.

2.4 Use a beaker to collect the water flowing from the tube and determine the flow rate with a timer.

2.5 Reduce the opening of the control valve. Measure the pressure difference and the flow velocity again after the water flow is stable.

2.6 Repeat step 2.2 to step 2.5 under 4 different flow rates.

2.7 After the experiment, turn off the water pump and clean up the experimental bench.

Table 2 Data table for Reynolds experiment

(Tube diameter=1.4 cm)

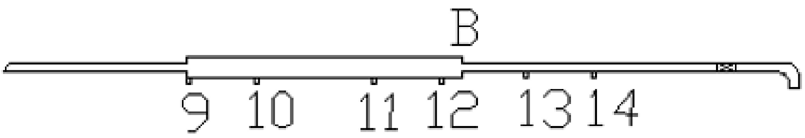
Item	Liquid level difference 10^{-2}m			Flow velocity calculated $u = \sqrt{2g\Delta h}$ 10^{-2}m/s	Real flow velocity (10^{-2}m/s)
	h_3	h_4	Δh		
1					

2					
3					
4					

2.3. Local Resistance Coefficient Measurement

Requirement:

Measure the local pressure loss due to the expansion at the inlet and the contraction at the outlet.



Local resistance coefficient measurement tube

Figure 10 Local resistance coefficient measurement tube

3.1 Eliminate air bubbles in the piezometers. (When the control valve is closed, the liquid level of the piezometers should be on the same level)

3.2 Switch the control valve to the maximum, then the liquid level difference of the pressure measuring tube is the largest.

3.3 After the water flow is stable, start to measure the flow rate and pressure difference.

3.4 Repeat step 3.2 to step 3.3 under 3 different flow rates and fill in the Table 3.

3.5 Refer to the formulas in Page 8 & 9 to calculate the parameters in Table 4. Turn off the water pump and clean the experimental bench.

Table 3 Data table for pressure measurement

Item	Flow rate $(10^{-6} m^3/s)$	Liquid level difference/10^{-2}m					
		9	10	11	12	13	14
1							
2							
3							

Table 4 Data table for local resistance coefficient measurement

(Thin tube diameter d1= 1.4 cm; thick tube diameter d2= 2.5cm)

Item		Flow rate $(10^{-6} m^3/s)$	Front entrance		Back entrance		h_j $(10^{-2} m)$	Experimental ζ	Theoretical ζ
			$\frac{v_1^2}{2g}$ $(10^{-2} m)$	$\frac{v_1^2}{2g}+(Z+\frac{p}{\rho \cdot g})$ $10^{-2} m)$	$\frac{v_2^2}{2g}$ $(10^{-2} m)$	$\frac{v_2^2}{2g}+(Z+\frac{p}{\rho \cdot g})$ $(10^{-2} m)$			

1	Expansion								
2									
3									
1	Contraction								
2									
3									

3. <u>For the Report</u>

Your discussion points will cover each of the 3 experimental investigations from laboratory. For each topic area use the following information to complete your reports. The form of the report is an extended memo. This should include

- Theory of fluid mechanics
- A brief introduction and explanation of experiments
- All the data tables
- Be sure to discuss the results in a separate discussion section and make your final conclusions in a separate conclusion section.

3.1 Reynolds Experiment

- Does the observed flow condition occur within the expected Reynold's number range for that condition?
- How is the flow pattern of each of the three states of flow (laminar, transitional, and turbulent) different?
- Descriptions, with **<u>illustrative photos</u>** of the flow characteristics of each experimental run.

3.2 Pitot Tube Experiment

Calculate the flow velocity using the measured flow rate and geometry dimensions obtained, such as tube diameter. Use the calculated flow velocity as the theoretical result and compare it with the flow velocity measured by the Pitot tube.

- Do those two quantities obtained agree well?
- Discuss all possible sources of errors.

3.3 Local Resistance Coefficient Measurement

Compare the experimental head loss coefficient with the theoretical head loss coefficient of the sudden expansion of the pipe and discuss all possible sources of errors.