"I admit that I have read this report and from my opinion that it is suffice from aspect of scope and quality for a purpose of awarding Bachelor of Mechanical Engineering (Thermal-Fluid)"

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Date : **MAY 2006**

THE DEVELOPMENT OF A HYDRAULIC FLOW METER

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"I admit that this report was done all by me except the summary and passage that I have clearly stated the source on each of them"

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ABSTRACT

Study of flow meter has become essential, either for liquid or for gases, to determine its conditions. Necessity to acquire flow rate will help engineers to recognize, estimate and carry out the task that involve getting an optimum results. This situation needs an instrument device that fit the purpose. Turbine- type flow meter is one of the instruments that can do such a thing. Based on the principal that rotation of the blade is proportional to volumetric rate, this device is the best and practical choice. In this study, turbine- type flow meter will be develop and been tested to be calibrate to become acceptance device for flow meter. From the basic theory to the principal of construction, this study will observe the appropriate and relevant methodology to be used to make this device is one of the reliability devices for flow meter measurement.

ABSTRAK

Kajian mengenai kadar alir amat penting dalam menentukan sesuatu keadaan bendalir sama ada dalam bentuk cecair atau gas. Kepentingan mengetahui kadar alir akan dapat membantu jurutera mengenalpasti, menilai serta melaksanakan sesuatu operasi yang berkaitan dengan mudah dan mendapat hasil yang optimimum. Keadaan sebegini memerlukan suatu instrumen atau alat pengukuran yang sesuai dan mampu memenuhi kehendak tersebut. Meter kadar alir jenis turbin merupakan salah satu instrument yang mampu melakukan tugas tersebut. Berdasarkan kepada prinsip kadar putaran bilah yang berkadar terus dengan kadar alir bendalir, sememangnya instrumen ini merupakan pilihan yang tepat dan praktikal untuk digunakan dalam menentukan kadar alir bendalir. Dalam kajian ini, meter kadar alir jenis turbin akan dibangunkan serta dijalankan ujian pengukuran supaya dapat menjadi alat pengukuran yang boleh diterima pakai. Bermula dengan teori hinggalah kepada prinsip pembinaannya, kajian ini turut menjalankan permerhatian terhadap methodologi yang sesuai agar alat ini menjadi sejitu yang mungkin untuk digunapakai kelak.

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SYMBOL	DEFINITION
P	Pressure
Q	Flow rate
C_v	Flow coefficient
S_g	Specific gravity
g	Gravity acceleration
ν	Velocity
f	Friction loss
A	Cross section area
T	Temperature
μ	Coefficient of dynamic viscosity
v	Kinematic viscosity
k	constant
Δ	Differences
ρ	Density
Σ	Total

Chapter 1

Introduction of project

1.1 Definition of Flow Meter:

Three types of flow meter are commonly used to measure flow rates in fluid system: orifice flow meters, rotameters, and turbine flow meters.

An orifice flow meter is operates on the principle of differential pressure; which is the pressure drop across an orifice is proportional to the flow through it. The flow rate determine from pressure drop, ΔP

$$\Delta P = P_1 - P_2$$

where; P_2 = pressure is read before the orifice

P_2 = pressure is read after the orifice

The relationship between the flow rate and the pressure drop through an orifice is describe by the flow coefficient, C_v .

$$Q = C_v \, (\Delta P \,/\, S_g)^{1/2}$$

A rotameter is operating on the principle of variable area. A float in the device is allowed to move freely inside a vertically mounted, tapered tube. The flowing fluid enters from tube and tends to lift the float because of the *flow force*, which is created by fluid drag as the fluid flows around the float. At the same time, the force of gravity opposes this motion. As the float moves up, the tube diameter increase, causing the flow force on the float to decrease as it moves up because of the larger flow area. The float will stop at a position where the flow force balances the force of gravity. The faster the flow rate, the greater the flow force on the float and the higher it will raise. The height of the float that indicated the flow rate can be read directly through a transparent sight glass. However, a float type rotameter must be vertically mounted because it depends on gravity for its operation.

A turbine flow meter measures the velocity of the fluid stream and determines the flow rate from this measurement. It measures the fluid velocity by passing the flow through a turbine. The rotational speed of turbine is proportional to the flow rate.

1.2 Definition of Turbine Type Flow Meter:

A turbine meter consist a multi-bladed rotor suspended in the fluid stream on a free-running bearing. The axis of rotation of the rotor is perpendicular to the flow direction and the rotor blade sweep out virtually to the full bore of the meter. The fluid impinging on the rotor blades cause the rotor to revolve. Within the linear flow range of the meter, the angular speed of rotation is directly proportional to the volumetric flow rate.

1.3 Problem Statement

In our lab, there are no flow meters that can be used to determine the flow rate of the fluids, especially when conducting experiments.

1.4 Rational of Project

There is an urgency to have an educational flow meter to be compared with other technique in calculating the flow rate of the fluids. The new and reliable equipment must be developing to replace the conventional methods.

1.5 Objectives of Project

The main objectives of this project are:

a. To develop a hydraulic flow meter for educational and research purpose.

b. To study the overall performance of hydraulic flow meter.

c. To obtain efficiency data based on different parameters.

d. To compare theoretical and experimental results.

1.6 Scope

The scope of this project is:

a. To built an educational turbine-type hydraulic flow meter.

b. To conduct experiments on the flow meter efficiencies and other performance based on different parameters such as hydraulic oil, fitting and arrangements.

Chapter 2

Literature review

2.1 Introduction

Flow measurement is critical to determine the amount of material purchased and sold, and in these applications, very accurate flow measurement is required. In addition, flows throughout the process should the regulated near their desired values with small variability; in these applications, good reproducibility is usually sufficient. Flowing systems require energy, typically provided by pumps and compressors, to produce a pressure difference as the driving force, and flow sensors should introduce a small flow resistance, increasing the process energy consumption as little as possible. Most flow sensors require straight sections of piping before and after the sensor; this requirement places restrictions on acceptable process designs, which can be partially compensated by straightening vanes placed in the piping. The sensors discussed in this subsection are for clean fluids flowing in a pipe; special considerations are required for concentrated slurries, flow in an open conduit, and other process situations.

2.2 Theory

Several sensors rely on the **pressure drop or head** occurring as a fluid flows by a resistance; an example is given in Figure 2.1. The relationship between flow rate and pressure difference is determined by the Bernoulli equation, assuming that changes in elevation, work and heat transfer are negligible.

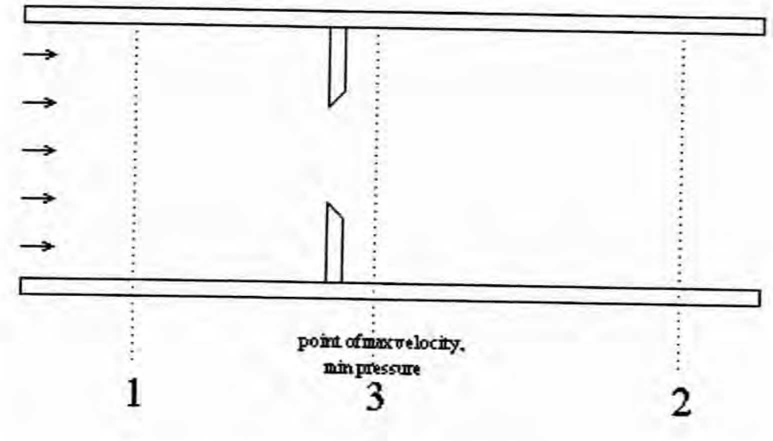

Figure 2.1: Orifice flow meter

Bernoulli's equation

$$\frac{P_1}{\rho g}+\frac{1}{2g}v_1^2=\frac{P_3}{\rho g}+\frac{1}{2g}v_3^2+\Sigma f \qquad \textbf{(2)}$$

where Σf represents the total friction loss that is usually assumed negligible. This equation can be simplified and rearranged to give (Foust et. al, 1981; Janna, 1993)

general head meter equation

$$F_1 = A_1V_1 = C_{meter}YA_3\sqrt{\frac{2(P_1-P_3)}{\rho(1-A_3^2/A_1^2)}} \qquad \textbf{(3)}$$

The meter coefficient, C_{meter}, accounts for all non-idealities, including friction losses, and depends on the type of meter, the ratio of cross sectional areas and the Reynolds number. The compressibility factor, Y, accounts for the expansion of compressible gases; it is 1.0 for incompressible fluids. These two factors can be estimated from correlations (ASME, 1959; Janna, 1993) or can be determined through calibration. Equation (3) is used for designing head flow meters for specific plant operating conditions.

When the process is operating, the meter parameters are fixed, and the pressure difference is measured. Then, the flow can be calculated from the meter equation, using the appropriate values for C_{meter} and Y. All constants are combined, leading to the following relationship.

relationship for installed head meter

$$F = C_0 \sqrt{\frac{(P_1 - P_3)}{\rho_0}} \quad (4)$$

In the usual situation in which only reproducibility is required, the fluid density is not measured and is assumed constant; the simplified calculation is where the density is assumed to be its design value of ρ_o. This is a good assumption for liquid and can provide acceptable accuracy for gases in some situations. Again, all constants can be combined (including ρ_o) into C_1 to give the following relationship.

relationship for installed head meter with constant density

$$F = C_0 \sqrt{P_1 - P_3} \quad (5)$$

If the density of a gas varies significantly because of variation in temperature and pressure (but not average molecular weight), correction is usually based on the ideal gas law using low cost sensors to measure T and P according to:

relationship for installed head meter, gas with constant MW, changing T and P

$$F = C_0 \sqrt{\frac{(P_1 - P_3)}{\rho_0}} \sqrt{\frac{P_0 T}{P T_0}} \quad (6)$$

where the density (assumed constant at ρ_o), temperature (T_o) and pressure (P_o) were the base case values used in determining C_o. If the density varies significantly due to composition changes and high accuracy is required, the real-time value of fluid density (ρ) can be measured by an on-stream analyzer for use as ρ_o in equation (4) (Clevett, 1985).

The flow is determined from equation (5) by taking the square root of the measured pressure difference, which can be measured by many methods. A U-tube manometer provides an excellent visual display for laboratory experiments but is not typically used industrially. For industrial practice a diaphragm is used for measuring the pressure drop; a diaphragm with one pressure on each side will deform according to the pressure difference.

Note that the pressure in the pipe increases after the vena contracta where the flow cross section returns to its original value, but because of the meter resistance, the pressure downstream of the meter (P_3) is **lower** than upstream pressure (P_1). This is the **"non-recoverable" pressure drop** of the meter that requires energy, e.g., compressor work, to overcome and increases the cost of plant operation. The non-recoverable pressure losses for three important head meters are given in Figure 5.

The low pressure at the point of highest velocity creates the possibility for the liquid to partially vaporize; it might remain partially vaporized after the sensor (called **flashing**) or it might return to a liquid as the pressure increases after the lowest pressure point (called **cavitation**). We want to avoid any vaporization to ensure proper sensor operation and to retain the relationship between pressure difference and flow. Vaporization can be prevented by maintaining the inlet pressure sufficiently high and the inlet temperature sufficiently low.

Some typical **head meters** are described briefly in the following.

***Orifice*:**

An orifice plate is a restriction with an opening smaller than the pipe diameter which is inserted in the pipe; the typical orifice plate has a concentric, sharp edged opening, as shown in Figure 1. Because of the smaller area the fluid velocity increases, causing a corresponding decrease in pressure. The flow rate can be calculated from the measured pressure drop across the orifice plate, P_1-P_3. The orifice plate is the most commonly used flow sensor, but it creates a rather large non-recoverable pressure due to the turbulence around the plate, leading to high energy consumption (Foust, 1981).

Venturi Tube:

The venturi tube shown in Figure 2.2 is similar to an orifice meter, but it is designed to nearly eliminate boundary layer separation, and thus form drag. The change in cross-sectional area in the venturi tube causes a pressure change between the convergent section and the throat, and the flow rate can be determined from this pressure drop. Although more expensive that an orifice plate; the venturi tube introduces substantially lower non-recoverable pressure drops (Foust, 1981).

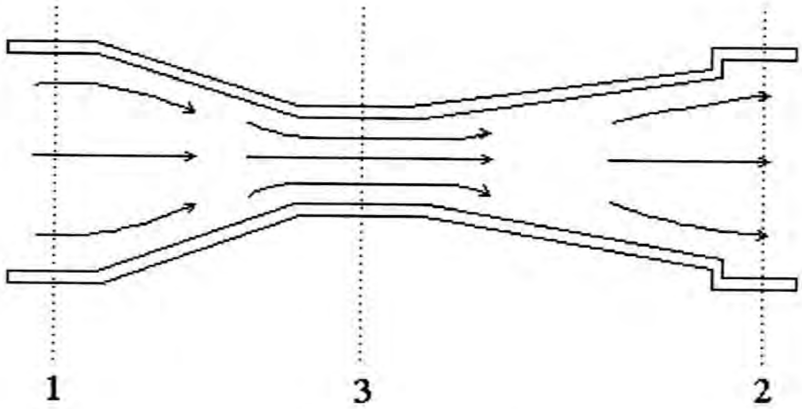

Figure 2.2. Venturi flow meter

***Flow Nozzle*:**

A flow nozzle consists of a restriction with an elliptical contour approach section that terminates in a cylindrical throat section. Pressure drop between the locations one pipe diameter upstream and one-half pipe diameter downstream is measured. Flow nozzles provide an intermediate pressure drop between orifice plates and venturi tubes; also, they are applicable to some slurry systems.

***Elbow meter*:**

A differential pressure exists when a flowing fluid changes direction due to a pipe turn or elbow, as shown in Figure 2.3 below. The pressure difference results from the centrifugal force. Since pipe elbows exist in plants, the cost for these meters is very low. However, the accuracy is very poor; there are only applied when reproducibility is sufficient and other flow measurements would be very costly.

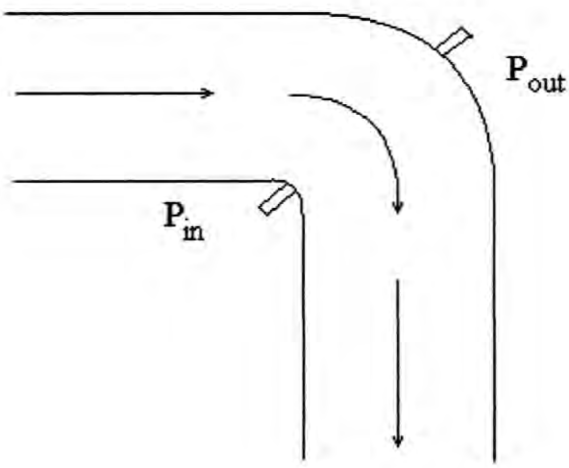

Figure 2.3. Elbow flow meter.

Pitot tube and annubar:

The pitot tube, shown in Figure 2.4 below, measures the static and dynamic pressures of the fluid at **one point** in the pipe. The flow rate can be determined from the difference between the static and dynamic pressures which is the velocity head of the fluid flow. An annubar consists of several pitot tubes placed across a pipe to provide an approximation to the **velocity profile**, and the total flow can be determined based on the multiple measurements. Both the pitot tube and annubar contribute very small pressure drops, but they are not physically strong and should be used only with clean fluids.

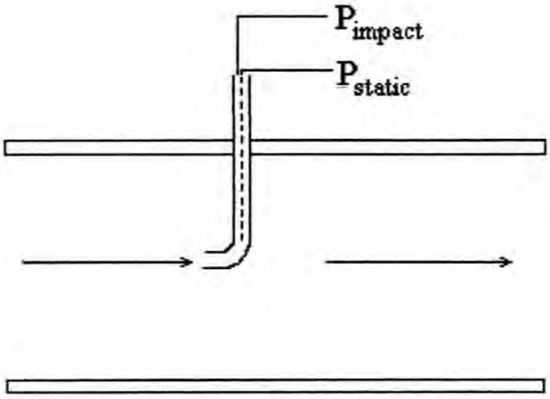

Figure 2.4. Pitot flow meter.

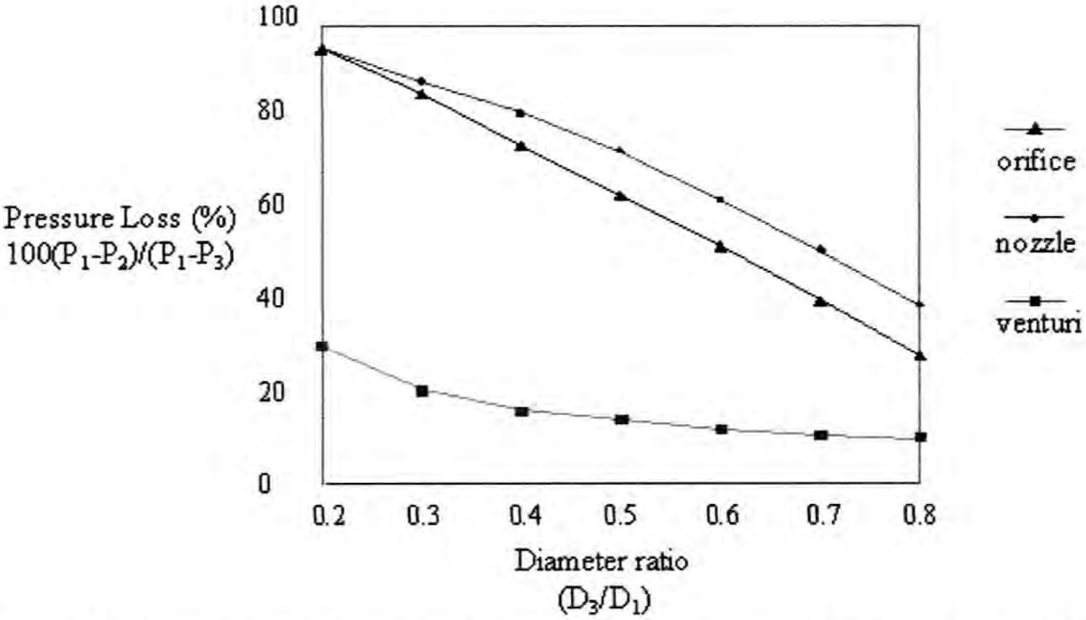

Figure 2.5. Flow meter non-recoverable pressure losses (Andrews and Williams, Vol 1, 1979)

The following flow sensors are based on physical principles other than head.

***Turbine*:**

As fluid flows through the turbine, it causes the turbine to rotate with an angular velocity that is proportional to the fluid flow rate. The frequency of rotation can be measured and used to determine flow. This sensor should not be used for slurries or systems experiencing large, rapid flow or pressure variation.

***Vortex shedding* :**

Fluid vortices are formed against the body introduced in the pipe. These vortices are produced from the downstream face in a oscillatory manner. The shedding is sensed using a thermistor and the frequency of shedding is proportional to volumetric flow rate.

***Positive displacement*:**

In these sensors, the fluid is separated into individual volumetric elements and the number of elements per unit time are measured. These sensors provide high accuracy over a large range. An example is a wet test meter.