

THESIS

ROBERT COLLEGE GRADUATE SCHOOL
BEBEK, ISTANBUL

PAGE 1

FOR REFERENCE

NOT TO BE TAKEN FROM THIS ROOM

MECHANICAL ENGINEERING

FLUID MECHANICS and HYDRAULICS EXPERIMENTATION

AND

LABORATORY DESIGN FOR ROBERT COLLEGE

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BY

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Bebek - Istanbul
1955

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TO MY MOTHER

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PREFACE

The material presented in this thesis describes one part of mechanical engineering experimentation, namely experimentation in the field of "Fluid Mechanics and Hydraulics".

Since an engineer without practical capability in application can not be visualized, it then becomes a necessary task to determine the kind and form of the experimentation program to be given to an engineering student during his years in undergraduate education.

The first basic outlines for constructing an up-to date Mechanical Engineering Laboratory at Robert College were given in the thesis written by Mehmet Yeyinmen (M.E-Graduate-1964).

In this thesis the "Fluid Mechanics and Hydraulics" laboratory construction is considered in detail. The author hopes that this work will be a guide to those who actually will construct the modern laboratory, and those who will do further study in this area.

Türkey ERATAMAN

Bs in ME

Bebek - Istanbul

June, 1965

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INTRODUCTION

Fluid mechanics is that branch of engineering sciences, which is concerned with the behavior of fluids at rest and in motion.

Fluid mechanics does not stand isolated in engineering curriculum. It is directly related to other divisions of the engineering sciences. Fundamental laws describing the motion and deformation of fluid particles and fluid elements are exactly the same as those for solid particles and solid elements. In as much as moving fluids possess and transport mass, heat and momentum, basic concepts and principles developed in fluid mechanics are also fundamental to engineering problems in transfer and rate processes. Thermodynamics must also be considered when the fluid involved is readily compressible. When electric - magnetic fields affect the flow of a fluid, then still more laws of basic physics must be used. These electro-magnetic problems in fluid flow give rise to a specialized subject known as "Magneto-Fluid Mechanics".

Fluid mechanics as it is known today evolves from two bodies of scientific knowledge, empirical hydraulics and classical hydrodynamics.

Hydraulics, as defined in dictionaries, is "the application of the laws governing liquid behavior at rest and in motion. This definition stems from the Greek origin of the word "Hydor" (water) and "Aulos" (pipe) so originally it referred to laws describing liquid motion in pipes. However the scope of hydraulics is now considerably wider, and the meaning has become as, "The laws governing liquid behavior at rest and in motion, and the application of these laws", leaving the original definition of the word of historical significance only.

The main subject of engineering hydraulics is to establish the laws of liquid equilibrium and liquid motion and to devise methods for solving the practical problems encountered in the various branches of technology.

Modern hydraulics, being mainly concerned with the motion of water, is based on the laws of physics, theoretical mechanics and mathematics. It is an applied science consisting of an enormous quantity of practical experiences which have been accumulated during many centuries of human activities.

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The hydraulician relies heavily on field observations and laboratory tests. The data thus obtained are usually reduced to empirical formulas for use in technical applications.

Hydrodynamics is essentially a mathematical science. The advent of mathematical hydrodynamics can be put at the end of the seventeenth century when mathematics had attained a state of broad applicability in both manipulative technique and graphical relation to physical phenomena, and when mechanics had also provided the fundamental laws of momentum and energy. Mathematical physicist of the eighteenth and nineteenth centuries formulated the correct equations of motion for a viscous fluid. Unfortunately mathematical complexities in solving these equations forced them to adopt many simplifications, such as a fluid without either fluid viscosity or fluid compressibility.

Thus the two sciences developed separately with little collaboration, until the appearance of Ludwig Prandtl (1875 - 1953), who is today hailed as the founder of modern fluid mechanics. He recognized the significance of explaining the behavior of fluid motion in a physical basis rather than purely mathematical or purely empirical.

Modern fluid mechanics combines basic physical principles of hydrodynamics and experimental technique of hydraulics. Experimental data are used merely to verify theories or to supplement missing information in the fundamental analysis. Complicated fluid flow problems are studied by examining the affect of fluid properties on the motion of the fluid. Dimensional homogeneity of physical equations is strictly observed.

It is clear from the above that, intelligent experimentation is absolutely essential in present day fluid mechanics. On the one hand theory of fluid mechanics leads to equations which are too complex to be solved. On the other hand experimentation without regard to theory often leads to great quantities of data, without correlation or general usefulness.

Laboratory work in engineering schools has then the purpose of providing the necessary applications for the improvement of the technical and experimental knowledge of the student engineer.

The construction of a laboratory is not an easy task, sometimes requiring many years. Therefore it is at least very useful to state the objectives and the aims expected from a laboratory course, so that the laboratory construction can be accomplished accordingly.

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The author suggests that the aims of a laboratory course should be:

- 1) To give the student an opportunity to apply the theory thought in the class room.
- 2) To familiarize the student with the construction and technique of using or operating instruments or machines.
- 3) To teach the student a logical method of approach to experimental work.
- 4) To give the student an experience in obtaining and recording data, making computations, and analyzing and interpreting results.
- 5) To teach the student how to write reports.

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PART I

PRESENT STANDING OF THE R.C
MECHANICAL ENGINEERING
LABORATORY

(in 1965)

The present standing of the M.E Laboratory : (1965)

Many years ago fluid mechanics experiments were carried out as a part of the mechanical engineering laboratory. These experiments dealt mostly with hydraulic machinery. Individual experiments for the demonstration of fluid-laws were not present.

During the presidency of Dr. Black, there were laboratory experts who possessed degrees in mechanical engineering, employed in the laboratory. Problem sessions were held after the performance of the experiments. The apparatus used was of the classical type, suitable for undergraduate study.

Later laboratories lost their importance and functioning, until it is now felt that the reconstruction is necessary.

The apparatus of the old laboratory is, however, suitable for the performance of certain experiments. The old apparatus was repaired and the author has performed these experiments, and presented the technical reports, written according to the form suggested by the ASME Power Codes.

The experiments are:

1. Measurement of water rates by means of venturi, orifice and weir.
2. Determination of orifice discharge coefficient
3. Pipe flow experiment
4. Determination of Reynold's number in laminar flow
5. Test of an air compressor
6. Test of a triplex pump
7. Test of radial fan with forwardly curved blades.

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MEASUREMENT OF WATER RATES BY MEANS OF VENTURI, ORIFICE, and WEIR

Experiment No: Fk.OI

Object: The object of this experiment is to measure the water rate passing through measuring devices, such as: Venturi, orifice, weir, and thus determine the coefficients of discharge of each device.

Procedure:

- 1) Start the pump.
- 2) Take readings of manometers located at the venturi and orifice.
- 3) Measure the average height of water at a convenient distance from the weir.
- 4) Record time required for a measured increase of water in the tank.
- 5) Take dimensions of tank, pipes, orifice throat and venturi throat.
- 6) Stop the pump and empty the apparatus.

Requirements:

- I. Calculate:
 - a) Coefficient of discharge for the venturi
 - b) Coefficient of discharge for the orifice
 - c) Coefficient of discharge for the weir

2. Plot: C_w , C_v , C_o versus discharge rate (ft^3/sec)

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M.E FLUID MECHANICS and HYDRAULICS LABORATORY REPORT

MEASUREMENT OF WATER RATES BY MEANS OF VENTURI
ORIFICE
WEIR

Experiment No : FM . 01

Date of experiment: _____

Date of Report: _____

Submitted by: _____

Submitted to: _____

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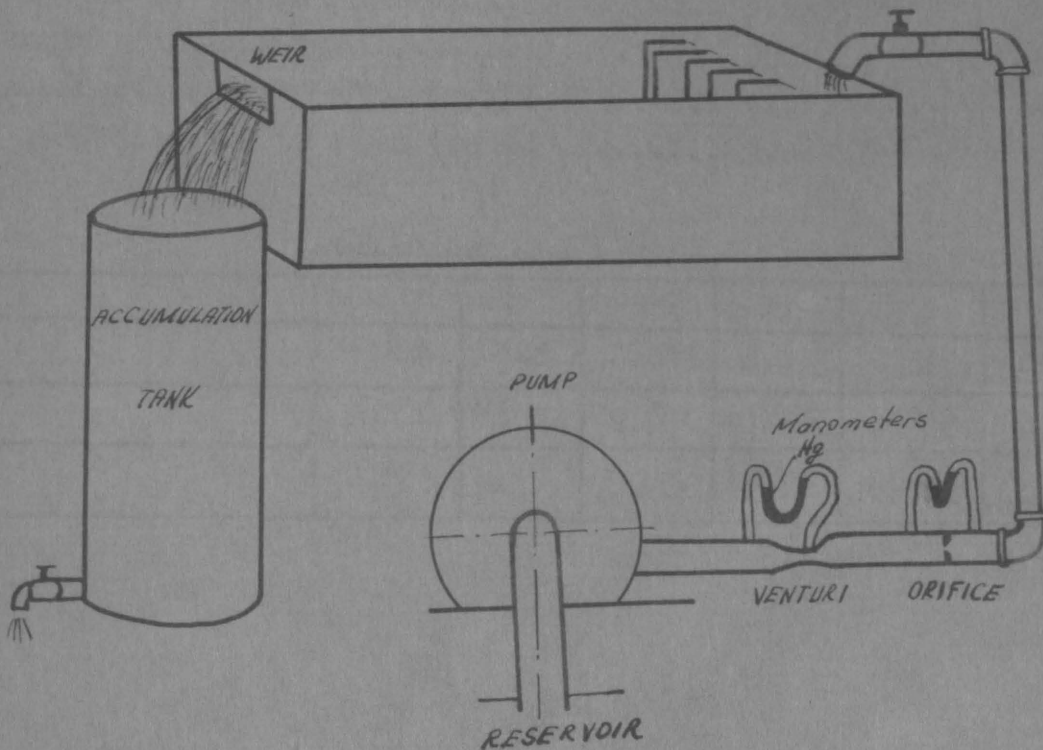
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Object: The object of this experiment is to measure the water rate passing through various measuring devices such as: venturi, orifice and weir, and thus determine the coefficients of discharge of each measuring device.

Procedure:

The various measuring devices were set up as seen on the sketch. The pump was started and readings of the manometers situated at the venturi, and orifice were taken. The average height of the water above the weir was also measured at a convenient distance from the weir. The discharge rate was measured by means of a tank in which water was accumulated and the time spent for a definite increase of height was recorded. The dimensions of the tank, of the pipes as well as that of the orifice and venturi throat were also recorded.

Sketch of test set-up:



DATA

Run	1	2	3	4	5
Pressure (ft. of water)	17.5	19.0	20.0	22.3	22.5
H_v (ft. of Hg over ft. of H_2O)	0.38	0.25	0.33	0.14	0.09
H_o (same as H_v)	0.63	0.36	0.46	0.22	0.13
H_w (cm. of water)	12.3	11.0	11.0	9.10	8.0
H_q (sec/138 cm)	43.5	53.0	53.2	68.5	68.0

Where:

- H_v = The difference in levels of venturi manometer
- H_o = " " " " " " " orifice " " "
- H_w = The height of liquid above the bottom of the weir
- H_q = The height of the liquid in the tank

Other data:

- Orifice diameter 3.8125"
- Diameter of venturi throat 3.34375"
- Length of weir crest 38cm. = 1.248'
- Inside diameter of pipe (orifice)..... 6.065"
- Inside diameter of pipe (venturi)..... 5.0625"

TABULATED RESULTS

Run	1	2	3	4	5	Average
C_v	0.860	0.83	0.865	0.898	0.89	0.8686
C_o	0.528	0.574	0.566	0.566	0.586	0.5520
C_w	0.813	0.79	0.786	0.81	0.783	0.7964

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SAMPLE CALCULATIONS

All calculations are based on the first run.

I. Coefficient of discharge for the venturi:

The discharge is given by: $Q = C_v \cdot A_p \cdot A_t \sqrt{\frac{2 \rho H_v}{\rho_p - \rho_t}}$

Where: C_v = The discharge coefficient

A_p = Cross sectional area of the pipe

A_t = Cross sectional area of the venturi throat

In the first run: $H_v = 0.38 (13.6 - 1) = 4.78$ ft. of water

$$A_p = \frac{\pi(5.065)^2}{4(12)^2} = 0.14 \text{ ft}^2 \quad \text{and} \quad A_p^2 = 0.0196$$

$$A_t = \frac{\pi(3.34)^2}{4(12)^2} = 0.061 \text{ ft}^2 \quad A_t^2 = 0.00375$$

Therefore:

$$C_v = \frac{Q}{0.14 \times 0.061 \sqrt{\frac{2 \times 32.2 \times 4.78}{0.0196 - 0.00375}}} = 0.836 Q$$

But Q is found as follows:

Rate of change in height of water is: $138/43.5 = 3.17$ cm/sec, or
0.104 ft/sec.

Since the diameter of the tank was: 108 cm. or 3.54 ft, the area is:

$$A = \pi(3.54)^2/4 = 9.9 \text{ ft}^2$$

Hence the discharge is equal to: $9.9 \times 0.104 = 1.030 \text{ ft}^3/\text{sec}$

Accordingly: $C_v = 0.836 \times 1.030 = \underline{0.860}$

II. Coefficient of discharge for the orifice:

The formula for the discharge in an orifice meter is:

$$Q = C_o \cdot A_o \sqrt{\frac{2 \rho H_o}{1 - \beta^4}}$$

Where: C_o = Coefficient of discharge of the orifice
 A_o = Cross-sectional area of the orifice
 β = Ratio between the diameter of the orifice and the diameter of the pipe.

Therefore,

$$\beta = 0.065 / 3.8125 = 0.0275 \quad \text{and} \quad \beta^4 = 0.146$$

$$A_o = \frac{\pi (3.8125)^2}{4 (12)^2} = 0.0795 \text{ ft}^2$$

$$H_o = 0.63 (13.6 - 1) = 7.95 \text{ ft. of water}$$

Finally:

$$C_o = \frac{1.030}{0.0795 \sqrt{\frac{2 \times 32.2 \times 7.95}{1 - 0.146}}} = 0.528$$

III. Coefficient of discharge for the rectangular weir:

Fluid Mechanics, Germano and Cox, give the following formula for the discharge over a rectangular weir:

$$Q = C_w \cdot \frac{2}{3} \cdot L \cdot \sqrt{2g} (0.74 H_w^{3/2})$$

Where: L = Length of weir crest = 1.248 ft.

H_w = Head of water above the weir crest.

$$\text{Here, } H_w = 12.3 \times 0.0328 = 0.404 \text{ ft.} \quad \text{and} \quad H_w^{3/2} = 0.2568$$

Therefore:

$$C_w = \frac{1.030}{\frac{2}{3} \times 1.248 \sqrt{2 \times 32.2} (0.74 \times 0.2568)} = 0.813$$

DISCUSSION and EXPLANATIONS

1) The triangular weir is suited for low discharge rates as well as high rates because in any case the head produced over the weir is higher than the one that would be produced over a rectangular weir, and therefore, more accurate results could be obtained with the triangular. The results with the rectangular weir are fairly good. It should be believed that the small errors involved are not of great importance, because all the values are within 1 % correct.

2) Derivation of the coefficient for Venturi:

Writing the Bernoulli's equation for positions 1 and 2, we have:

$$\frac{P_1}{w} + z_1 + \frac{V_1^2}{2g} = \frac{P_2}{w} + z_2 + \frac{V_2^2}{2g}$$

Transposing,

$$\frac{V_2^2 - V_1^2}{2g} = \frac{P_1 - P_2}{w} + z_1 - z_2$$

Considering the manometer attached to the meter, and letting the datum plane to be taken at the lower end of the gage fluid, we have:

$$\frac{P_1}{w} + z_1 - R(S.G) - (z_2 - R) = \frac{P_2}{w}$$

Where S.G is the specific gravity of the gage fluid with reference to the medium flowing through the meter. Rearranging terms we get :

$$\frac{P_1 - P_2}{w} + z_1 - z_2 = R(S.G - 1) = h$$

It is now evident that the right hand side of the equation is equal to the head on the meter and that the manometer will indicate the correct head regardless the value of the elevation terms.

Eliminating V_1 with the equation of continuity, $\pi d_1^2 V_1 / 4 = \pi d_2^2 V_2 / 4$ we get:

$$\frac{V_2^2}{2g} \left[1 - \left(\frac{d_2}{d_1} \right)^4 \right] = h$$

Solving for V_2 ,

$$V_2 = \frac{1}{\sqrt{1 - \left(\frac{d_2}{d_1} \right)^4}} \cdot \sqrt{2gh}$$

Due to the fact that flow can not exist without loss, a coefficient is introduced,

$$V_2 = \frac{C_v}{\sqrt{1 - \left(\frac{d_2}{d_1} \right)^4}} \cdot \sqrt{2gh}$$

Substituting areas to diameters,

$$Q = \frac{C_v \cdot A_1 \cdot A_2}{\sqrt{A_1^2 - A_2^2}} \cdot \sqrt{2gh}$$

3) Derivation of discharge equation for Rectangular Weir:

Using the nomenclature on the

figure we have:

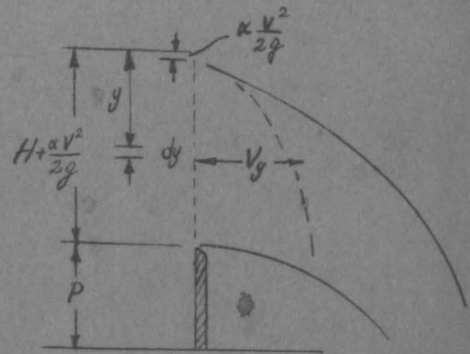
$$V_y = \sqrt{2gy}$$

$$dQ = C_w \cdot V_y \cdot dA = C_w \cdot V_y \cdot L \cdot dy = C_w \cdot L \cdot \sqrt{2g} \cdot y^{1/2} dy$$

$$Q = C_w \cdot L \cdot \sqrt{2g} \int_{\frac{\alpha V^2}{2g}}^{H + \frac{\alpha V^2}{2g}} y^{1/2} dy = C_w \cdot \frac{2}{3} \cdot L \cdot \sqrt{2g} \left[y^{3/2} \right]_{\frac{\alpha V^2}{2g}}^{H + \frac{\alpha V^2}{2g}}$$

Therefore,

$$Q = C_w \cdot \frac{2}{3} \cdot L \cdot \sqrt{2g} \left[\left(H + \frac{\alpha V^2}{2g} \right)^{3/2} - \left(\frac{\alpha V^2}{2g} \right)^{3/2} \right]$$



In the above derivation:

Q = Discharge in cfs .

H = Head on the weir in ft.

α = Coefficient for obtaining effective velocity of approach head.

V = Mean velocity in the approach channel in ft/sec.

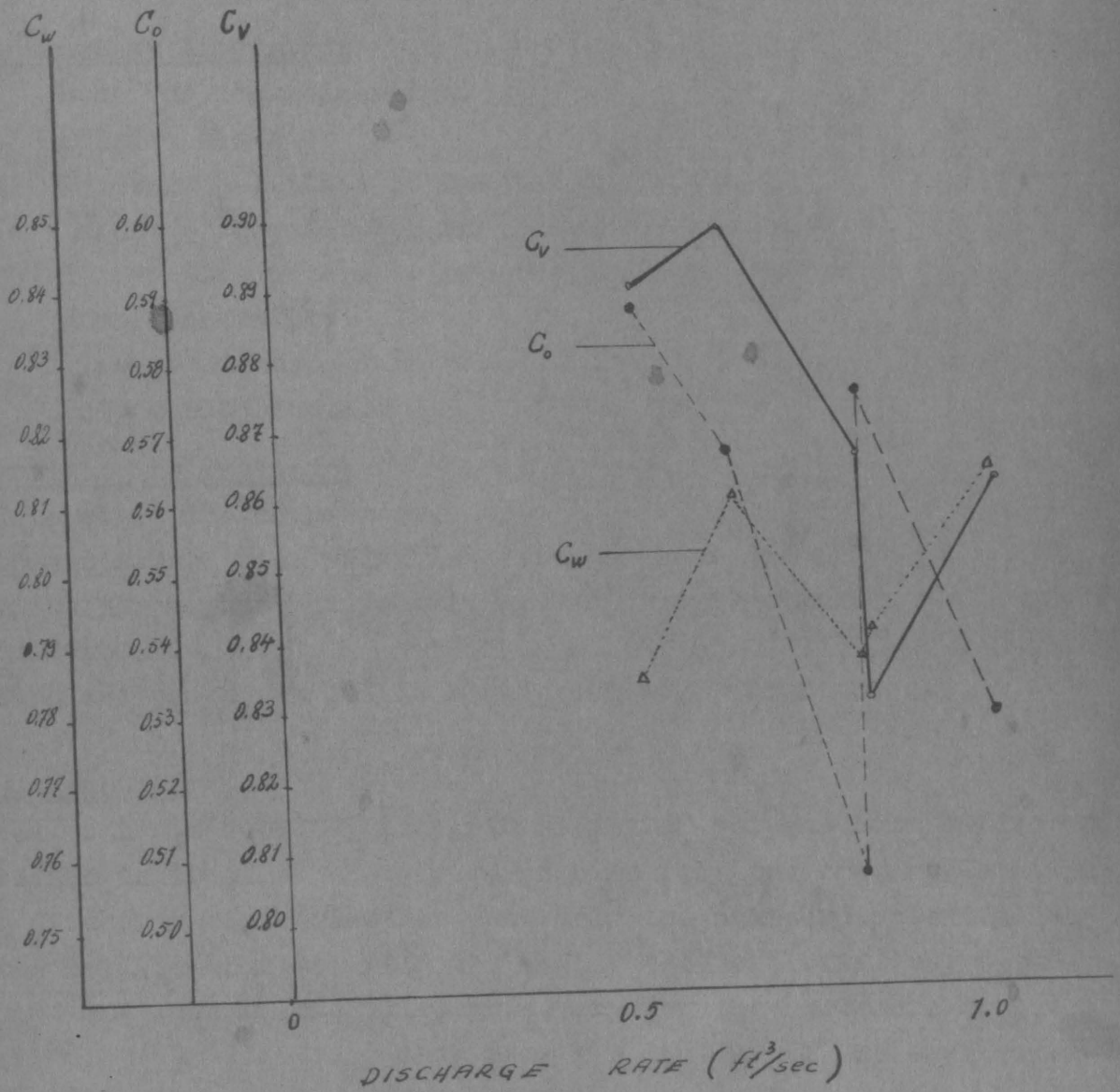
C_w = Coefficient of discharge for the weir

L = Length of weir crest in ft.

But we must recognize the fact that the flow does not take place through an area LH, but through an area approximately 0.67 LH, which extends from 0.22H to 0.89 H. Therefore using this conception and neglecting the velocity of approach coefficient we obtain:

$$Q = C'_w \cdot L \cdot \sqrt{2g} \int_{0.22H}^{0.89H} y^{1/2} dy$$

$$Q = C'_w \cdot L \cdot \sqrt{2g} (0.74 H^{3/2})$$



C_w, C_o, C_v versus DISCHARGE RATE

DETERMINATION OF ORIFICE DISCHARGE
COEFFICIENT

Experiment No: FM 02

Object: To ascertain the discharge coefficient of a circular sharp edged thin plate orifice.

Description of machine to be tested:

7/8 " circular sharp edged thin plate orifice

Measurements necessary:

- Receiver tank dimensions
- Orifice diameter
- Pressure potential across the orifice
- Amount of air discharged (measure pressure drop)
- Temperature of air before the orifice
- Room temperature
- Time of discharge
- Barometric pressure

Operation instructions:

- A. To start the compressor,
1. Open cooling water valve to the compressor jacket.
 2. Close three phase knife switch. This brings power to the compressor switchboard.
 3. Turn switch on panel. This starts the compressor motor.

Requirements:

The tank has been filled with air at 60 psi. one hour before you arrive. This is to allow the air to come to room temperature. To measure the discharge coefficient we must hold the pressure potential across the orifice constant with the aid of the regulating valve, and at the same time measure the time necessary for the pressure to fall between two given limits. In this case the limits will be approximately 50psi and 10 psi.

Caution: Open the discharge valve slowly or you will blow the fluid from the manometer.

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As a check, this procedure is to be repeated twice. Therefore it will be necessary for you to refill the tank to 60 psi. and wait one hour before retesting.

$$Q = C \cdot A \cdot V = C \cdot A \sqrt{2g \cdot \Delta h} \quad (\text{flow equation})$$

Where:

A = Discharge area in ft².

C = Orifice coefficient.

Δh = Pressure in ft of air causing flow

$$\Delta h = \frac{\text{Inches of water}}{12} \times \frac{\text{Density of water} = 62.4}{\text{Density of air} = P/RT}$$

Where:

P = Barometric plus the static pressure across the orifice.

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M.E FLUID MECHANICS and HYDRAULICS LABORATORY REPORT

DETERMINATION OF THE ORIFICE DISCHARGE COEFFICIENT

Experiment No: FM. 02
Date of experiment: _____
Date of report: _____
Submitted by: _____
Submitted to: _____

Object: The object of this experiment is to ascertain the discharge coefficient of a circular, sharp edged $7/8$ " thin plate orifice.

Procedure: The water valve to the compressor jacket is opened, the start-switch being closed. The switch on the panel is turned on, which starts the compressor motor. Air is compressed in the tank and held at 60 psi. Then the compressed air is left to cool down to room temperature. After this condition is reached, the air is allowed through the check valve and hence to pass through the thin plate orifice.

Temperature measurements are taken at intervals of 15 minutes, at the orifice outlet. The pressure in the tank is left to drop from 50 psi to 10 psi, and the piezometer head is kept at a certain, fixed head. This procedure is repeated three times. Air is left to cool for 15 minutes in each trial.

Apperatus:

A) Induction Motor:

Model no: 460I9, Type: KT 750, 6-5, Cycles: 50, 3-phase
Voltage: 190, Speed at full load: 940 rpm.
Amperage: 17.2 , no: 4I32C23
HP: 5 , continious , 150°C
General Electric Co. N.P 24I33
Scheneectady New York - USA

B) Gardner - Rix Compressor:

No: 39969 , Size: 4 1/2 x 4 1/2
Maximum rpm : 500
Minimum rpm: 300
Maximum air pressure: 150 psi.
Quincy, Ill. -USA, The Gardner Governor Co.

C) Pressure Governor:

CR 2922 CAT I769I24 G6
Class 103/160 , Form: A
Pressure limits 30 - 130 lbs.
General Electric Co.
Scheneectady, New York - USA

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D) Magnetic switch:

CR 7006 - D4, CAT. I773589 G2
Voltage: 110 - 25 , 220 - 60
General Electric Co. USA.

Theory:

An orifice is an abrupt restriction to the fluid flow. It is interesting to know that the restriction section of flow does not occur at the orifice as it is in a nozzle, but down stream from it, owing to the formation of the vena-contracta. At the vena - contracta, the cross-section area of the flow contracts as the flow passes the orifice. The restriction effect, is a higher velocity and subsequently a lower pressure of the fluid.

By measuring the pressure we could easily calculate the quantity of fluid flowing through the orifice. Orifices are thus used to meter fluid flow.

Data:

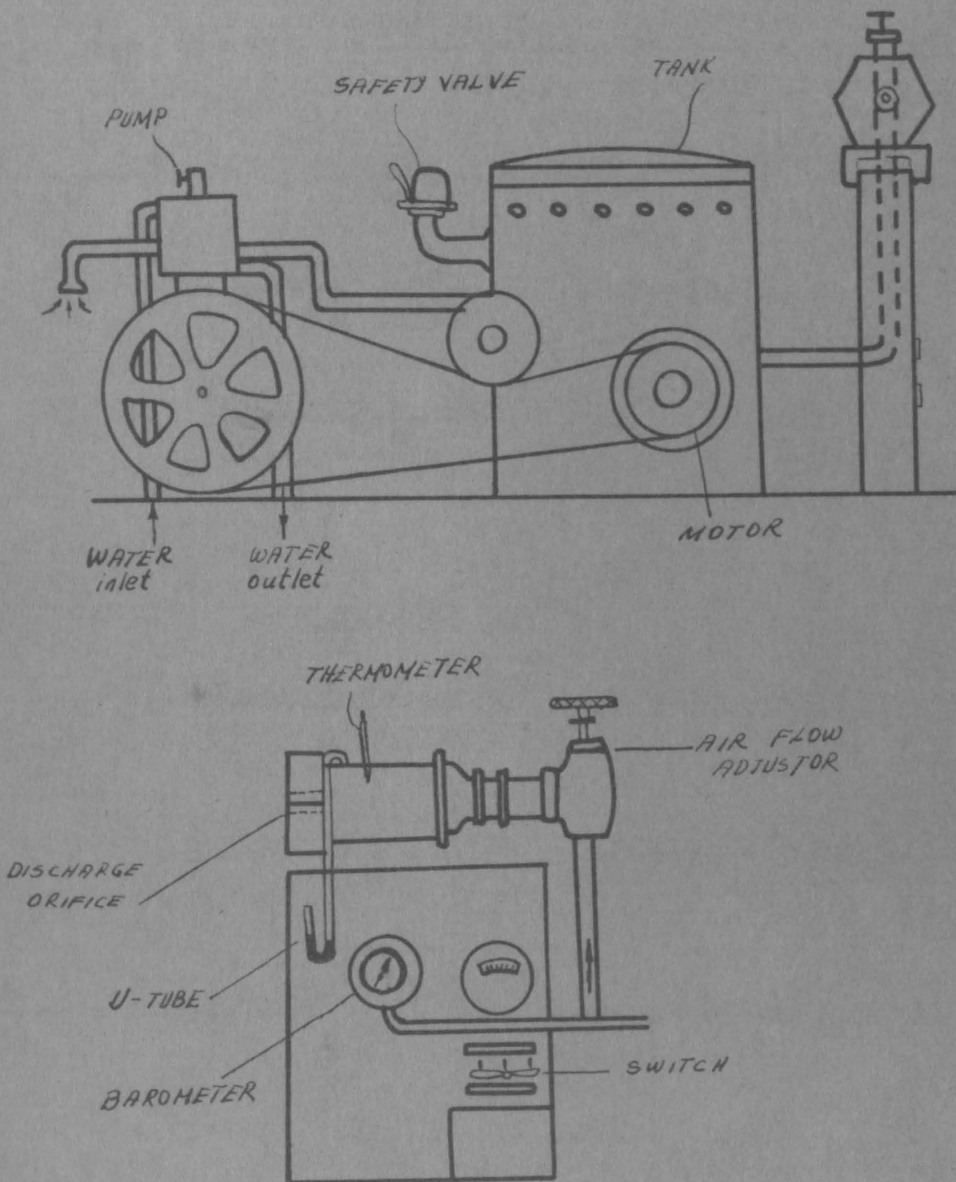
RUN I			RUN II			RUN III		
Temp.	Press.	Time	Temp.	Press.	Time	Temp.	Press.	Time
^o C	mm.	sec.						
21.25	8	185	21	52	85	21	51	80
21.21			20.8			20.8		
21			20.5			20.2		
21			20			19.9		
21			19.6			19.5		
21			19.2			19		
20.8								
20.8								
20.6								
20.6								
20.5								

Receiver tank dimensions: $h = 97$, $D = 63$ cm.
Barometric pressure : 29.92 in. Hg. , Atmospheric temperature: 70°F.
Orifice diameter: 7/8 " , Inner dimensions: $h = 95$ cm. , $d = 60$ cm.

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EXPERIMENT.FM:02-SET-UP of APPARATUS

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Calculations:

RUN I

$$Q = C.A.V = C.A\sqrt{2g\Delta h}$$

$$\text{Discharge area: } A = \frac{\pi D^2}{4} = \frac{\pi(7/8)^2}{4 \times 144} = \frac{49\pi}{4 \times 144 \times 64} = 0.00417 \text{ ft}^2$$

$$h = \frac{\text{inches of water}}{12} \times \frac{\text{Density of water}}{\text{Density of air}}$$

$$P/RT = \frac{14.71 \times 144}{53.3 \times 530.25} = 0.0748 \text{ lb/ft}^3$$

$$h = \frac{0.8/2.54 \times 62.4}{12 \times 0.0748} = 21.9 \text{ ' of air}$$

Therefore: $Q = w.A.V$, $w = P/RT$
 $Q = \frac{\Delta P.V}{\ell}$

$$Q = \frac{40 \times 144 \times 9.46 / 0.0748}{53.3 \times 518.8 \times 190} = 0.066 \times 0.00417$$

$$C = Q/A = 0.066 / 0.0748 \times 0.00417 = 0.88 = 88 \%$$

RUN II

$$A = \frac{\pi D^2}{4} = 0.00417 \text{ ft}^2 \quad (\text{from previous calculation})$$

$$P/RT = 14.77 \times 144 / 53.3 \times 5.28 = 0.0754$$

$$h = \frac{5.2/2.54}{12} \times \frac{62.4}{0.0754} = 141 \text{ ' of air}$$

$$Q = \frac{\Delta P}{RT} \times \frac{V}{t} = \frac{40 \times 144}{53.3 \times 529.8} \times \frac{9.46}{85} = 0.0227 \text{ lb/sec}$$

$$C = \frac{Q/P}{RT \sqrt{A \sqrt{2g h}}} = \frac{0.0227 / 0.0754}{0.00417 \sqrt{64.4 \times 144}} = 0.758 = 75.8 \%$$

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RUN III

$$A = 0.00417 \text{ ft}^2$$

$$h = \frac{5.1/2.54}{12} \times \frac{62.4}{\frac{14.77 \times 144}{53.3 \times 528}} = 138.5' \text{ of air}$$

$$Q = \frac{4P.V}{R.T.t} = \frac{40 \times 144 \times 9.46}{53.3 \times 529.8 \times 8} = 0.0241 \text{ lb/sec}$$

$$C = \frac{Q/\text{Den. a.}}{A \cdot \sqrt{2gh}} = \frac{0.0241/0.0752}{0.00417 \sqrt{64.4 \times 138.5}} = 81 \%$$

SUPPLEMENTARY RUN

$$A = 0.00417 \text{ ft}^2$$

$$h = 74.16$$

$$Q = 0.016 \text{ lb/sec}$$

$$C = 73.5 \%$$

Conclusion:

The results of the experiment can be considered as unsatisfactory due to certain inaccuracies in measurements and more important due to shortage of time .

The coefficient of discharge should have been between the values of 62 and 66 %,but instead we have reached to an average value of our determinations of 79%,which is rather high.

A much better value for the coefficient of discharge could be achieved by performing the experiment with runs of greater duration and then graphing the results of all runs and approximating these results by a proper curve. The average value can then be determined from the graph. This will certainly give a better value for the coefficient of discharge.

Chief sources of error are:

- a) Inaccuracy in measurements
- b) The old and dirty condition of the system
- c) Variation of certain quantities where they should be constant.
- d) The most significant error is caused by the Bourdon gage.
- e) Calibration error

A small inaccuracy in the pressure reading effects Q highly and consequently the value of the discharge coefficient is effected very largely.

Suggestion for improvement:

Renewal of all pipes and connections by the installation of clean galvanized pipes and brand new valves, etc. plus a pressure regulator.

PIPE FLOW

Experiment no: FM. 03

Object:

- 1) To find the friction factor, (f), for various lengths of pipe at three different discharge rates.
- 2) To find the friction factor, (K) for various pipe fittings, at the same three discharge rates.
- 3) To compare these values with values determined by the estimate method of the text book.
- 4) To plot the energy diagram for the pipe line.

Procedure:

See attached.

- a) Three rates of discharge are to be used, a complete set of data being taken at each rate. During each of these runs it will be necessary to measure, the discharge rate, water temperature, and the various pressure differences, at the different taps listed below.
- b) Plot the energy diagram without using experimental data.
- c) Plot the energy diagram, using the experimental data, to show discrepancies.

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M.E FLUID MECHANICS and HYDRAULICS LABORATORY REPORT

PIPE FLOW

Experiment No: FM. 03

Date of experiment:

Date of report:

Submitted by:

Submitted to:

Table of Contents:

1. Summary

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2. Scetch and description of test set-up

3. Methods of testing

4. Discussion of data and results

5. Table of results

6. Graphs

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9. Appendix

References

Instruction sheet

Object :

- 1) To find the friction factor (f), for various lengths of pipe at three different discharge rates.
- 2) To find the friction factor (K), for various pipe fittings, at these three different discharge rates.
- 3) To compare these values with the values determined from the text book.
- 4) To plot the energy diagram for the experimental and theoretical cases.

Conclusion:

There are large deviations between the experimental values and the theoretical values. The losses at the enlargement and contraction are fairly small and the losses at the bends are large. The large pipe loss is also very small and can be almost considered as negligible.

Results:

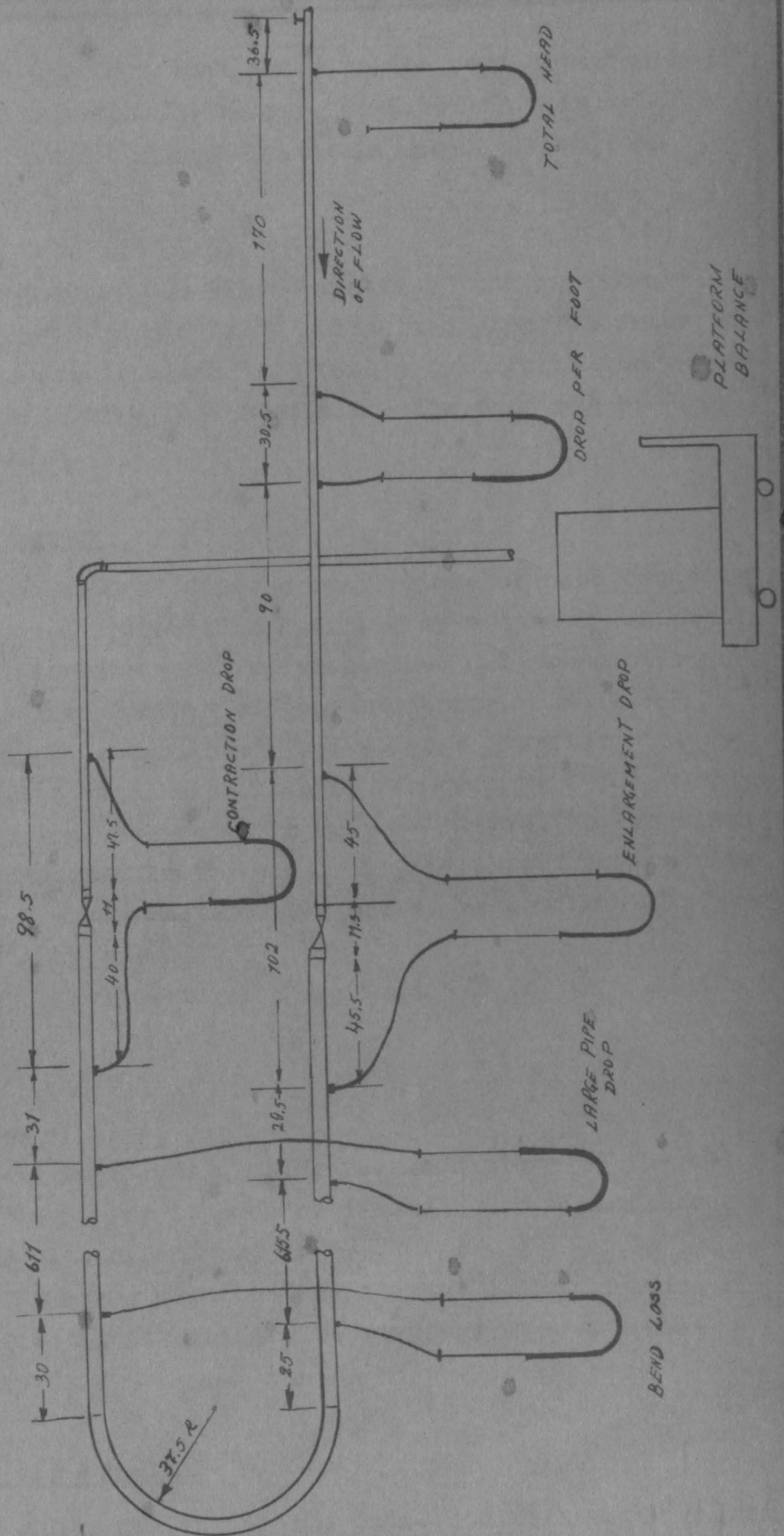
The results are presented on the graphs for theoretical and experimental cases. The values given in standard textbooks are seen to be

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SCETCH OF TEST SET - UP

FM EXP: 03



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more satisfactory due to the fact that, these values were obtained by using pipes in perfect condition. The values obtained by this experiment, indicate larger values for energy losses in actual pipes, than in perfectly clean pipes.

Recommendations:

It is recommended that the whole piping-system of the experiment set-up be changed. A new set should be of galvanized pipes in order to prevent corrosion and reduce friction loss due to rust formation on the inner sides of the piping system. Rust also clogs the taps and results in faulty pressure readings.

Description of test set-up:

The test set-up is composed of, first a small diameter pipe connected to the city water. The total pressure is measured by a mercury manometer connected to the pipe after the inlet valve. Another CCl_4 manometer measures the drop in pressure per foot of length of pipe.

The small diameter pipe is connected to the large diameter pipe by an enlargement fitting. The total pipe loss is measured by a CCl_4 manometer. The bend loss is also measured by a CCl_4 manometer. The large diameter pipe is again connected to the small pipe by a contraction fitting. The drop through the contraction is measured by another CCl_4 manometer.

The water discharge is collected in a tank and weighed on a platform balance.

Method of testing:

The experiment set-up is located in the ME. Laboratory of the old engineering building. The piping is hung on the wall. The manometers are freed of air before the experiment is

The inlet water temperature was constant at 54.5°F . The duration of one trial took four minutes at minimum. The readings were taken at appropriate time intervals.

Discussion of data and results:

A curve was plotted after collecting the data. From this curve values were selected, which were thought to be correct due to the fact that

they lied directly on the curve. Those points that fall off the curve were dropped. The data obtained in this manner was accepted to be fairly reliable.

The results were tabulated in a table. The theoretical values, so accepted for our experiment, were taken from textbooks.

In analyzing the results many discrepancies were noticed.

Losses at an enlargement should be more than the losses at a contraction. This fact came out to be true in the results found by using the estimate method of the book, but the results came out to be the opposite of this when the experimental values were used in the calculations.

In textbooks it is stated that the enlargement wall roughness factor, found by experiments is close to unity, and may be assumed to be so for most engineering problems. In this experiment the wall roughness factor for enlargement is found to be 0.041.

Textbook values for contraction wall roughness factors range from 0.02 to 0.5. In this experiment a value of 1.1 is found for the contraction wall roughness factor.

The friction factors came out to be fairly close to values found from graphs and those calculated on the estimate method of the reference book.

The velocity head in the large pipe is very close to the head in the line. The two curves lie very close to each other in the larger pipe section.

The ideal results on the basis of the estimate method of the book give low values for the bend loss, but a larger drop was encountered in the experimental case. The most probable reason for this deviation is the accumulation of rust and dirt on the bend walls, which increase the vortex action and turbulence of flow in the bend.

Table of results:

Using experimental data

Q	..... cfs.....	0.0272
V _{small}	.. fps.....	4.58
V _{large}	.. fps.....	1.18
P _T	...ft.of w....	8.7
h _{fsmall}	.. "".....	2.25
h _{flarge}	.. "".....	0.145
h _{fbend}	.. "".....	2.52
h _{fenl.}	.. "".....	0.0074
h _{fcont.}	.. "".....	0.3645
f _{small}	.....	0.055
f _{large}	.....	0.0515
K _e	.....	0.041
K _c	.....	1.1

Using textbook methods

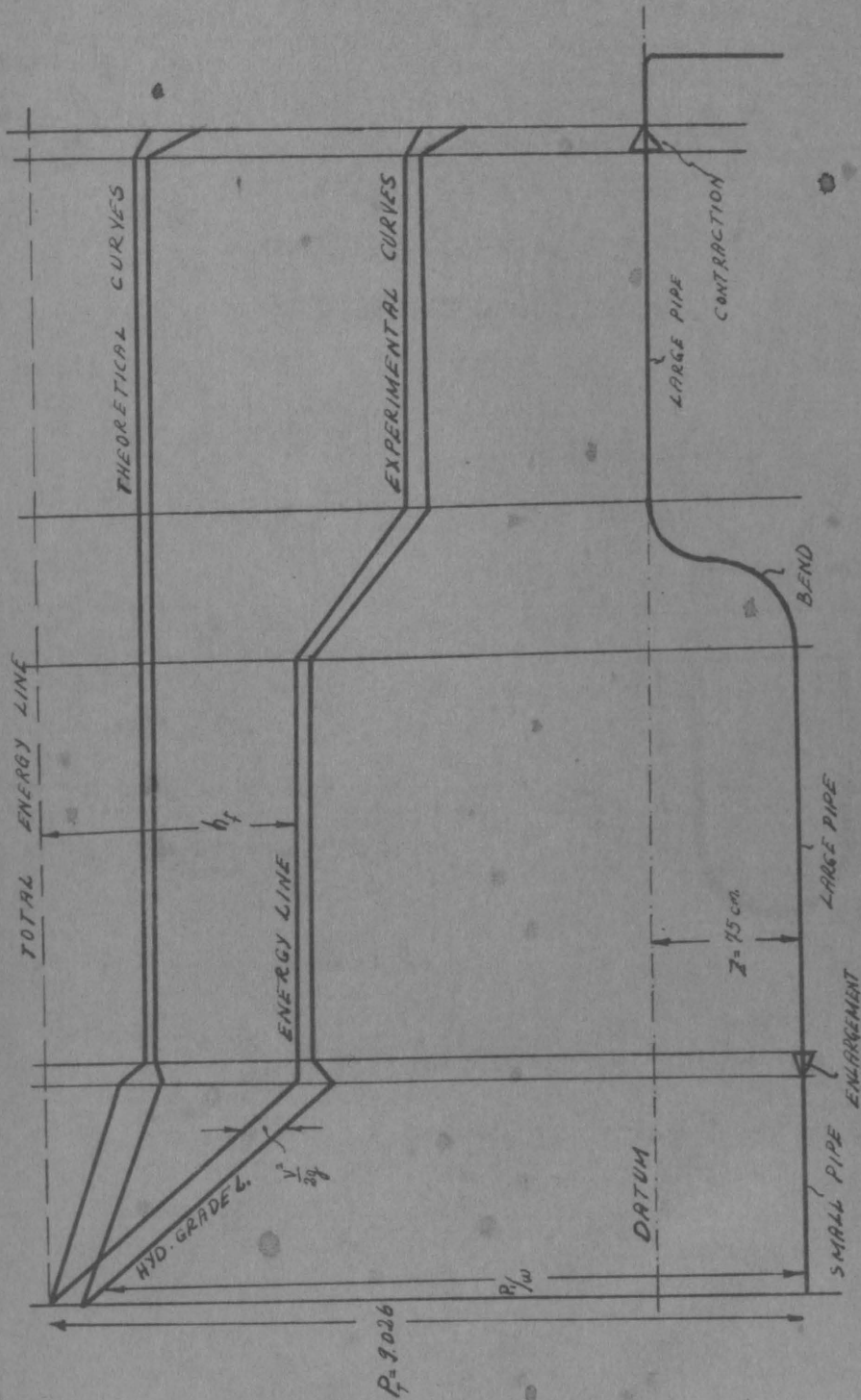
μ/ρ	.....ft ² /sec....	1.3 x 10 ⁻⁵
N _{Re small}	.....	30800
N _{Re large}	.....	15600
f _{small}	.....	0.028
f _{large}	.....	0.032
h _{fsmall}	.....	0.785
h _{flarge}	.....	0.113
h _{fenl.}	.....	0.18
h _{fcont.}	.....	0.126
h _{fbend.}	.....	0.0475

Table of data:

RUN	Discharge	P _T	Drop/ft	Sud.enl.	Sud.cont.	Pipe loss per foot	Bend loss
	kgs/4min.	cm Hg	cm CCl ₄	cm CCl ₄	cm CCl ₄	cm CCl ₄	cm CCl ₄
1	217.5	26.5	13.4	21.1	46.3	21.2	3.2
2	212	24.9	12.8	19.8	43.2	19.9	3.5
3	193	19.5	10.5	16.5	35.5	16.5	3.1
4	180	15.6	10.1	14.7	31	15.5	3.3
5	161	9.5	7.1	11	23.4	13.3	3.7
6	156	10.5	7.3	12.1	24.4	13.5	3.1
7	142	6.6	5.5	7.5	19.8	11.6	3.1
8	130	3.7	4.7	5.8	16	10	2.7
9	126	3.2	4.5	7.3	15	9.8	3.1
10	125	2.5	4.2	7.1	14.8	9.2	2.7

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FM. EXP. 03 ENERGY LINE

$\frac{1}{2} \text{ cm.} = 1 \text{ ft.}$

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Sample calculations:

Capacity: RUN : No. 3

$$Q = 193 \text{ Kg/4min.} = 48.2 \text{ Kg/min} = \frac{48.2 \times 2.2}{60 \times 62.4} = 0.0272 \text{ ft}^3/\text{sec}$$

Velocity:

$$V = Q/A$$

$$\text{Small pipe } A = 0.006 \text{ ft}^2$$

$$\text{Large pipe } A = 0.0232 \text{ ft}^2$$

$$V_{\text{small}} = 0.0272/0.006 = 4.58 \text{ fps.}$$

$$V_{\text{large}} = 0.0272/0.0232 = 1.18 \text{ fps.}$$

Total head:

$$P_T = h_T \times \frac{13.6}{30.5} \quad h_T = 19.5 \text{ cm.Hg.}$$

$$P_T = 19.5 \times \frac{13.6}{30.5} = 8.7 \text{ ft. water}$$

Small pipe loss:

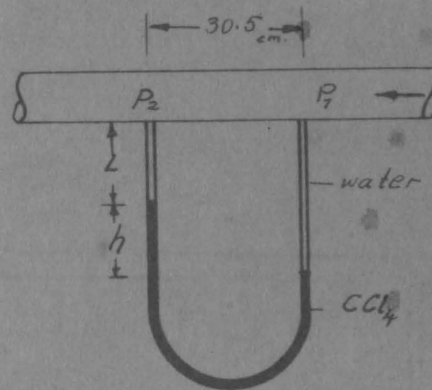
$$h_f = 0.595 h$$

$$h = 10.5 \text{ cm.CCl}_4/\text{ft.}$$

$$h_f = \frac{10.5}{30.5} \times 0.595 = 0.205$$

$$\text{Length of pipe: } \frac{355}{30.5} = 11 \text{ ft.}$$

$$\text{Total } h_f = 11 \times 0.205 = 2.25 \text{ ft.}$$



$$P_I + L(S.G_W) + h(S.G_W) = h(S.G_{CCl_4}) + L(S.G_{CCl_4}) + P_2$$

$$P_I - P_2 = h(S.G_{CCl_4} - S.G_W) = h(1.595 - 1)$$

$$P_I - P_2 = h(0.595)$$

Sudden enlargement:

$$h_f = 0.595 h$$

$$h = 16.5 \text{ cm CCl}_4$$

$$h_f = \frac{16.5}{30.5} (0.595) = 0.322$$

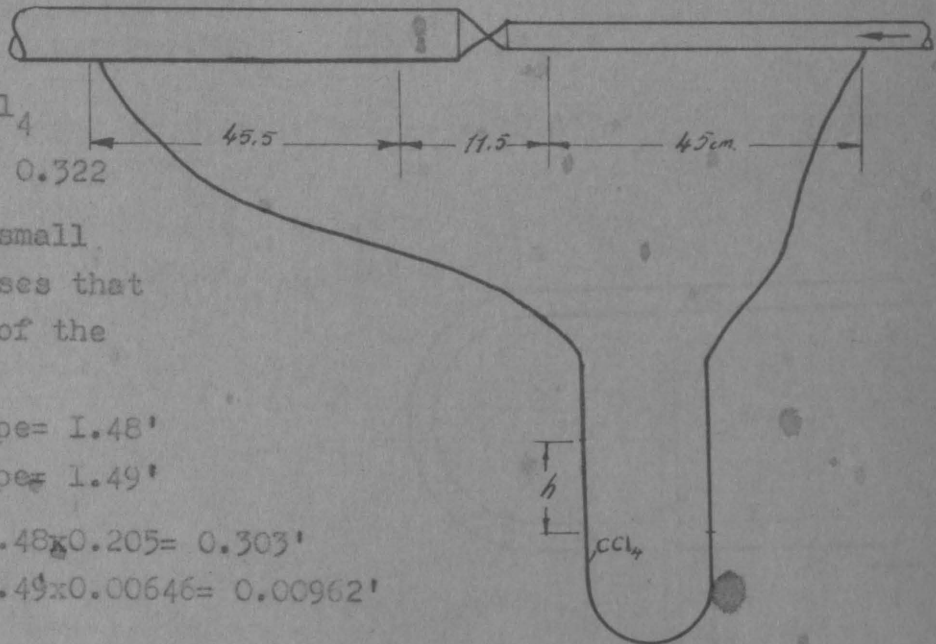
This includes the small and large pipe losses that are on both sides of the enlargement.

$$\text{Length of small pipe} = 1.48'$$

$$\text{Length of large pipe} = 1.49'$$

$$\text{Small pipe loss} = 1.48 \times 0.205 = 0.303'$$

$$\text{Large pipe loss} = 1.49 \times 0.00646 = 0.00962'$$



$$\begin{aligned} \text{Net enlargement loss} &= (\text{pipe losses} + \text{enlargement loss}) - \text{pipe losses} \\ &= 0.322 - (0.303 - 0.00962) = 0.0074' \end{aligned}$$

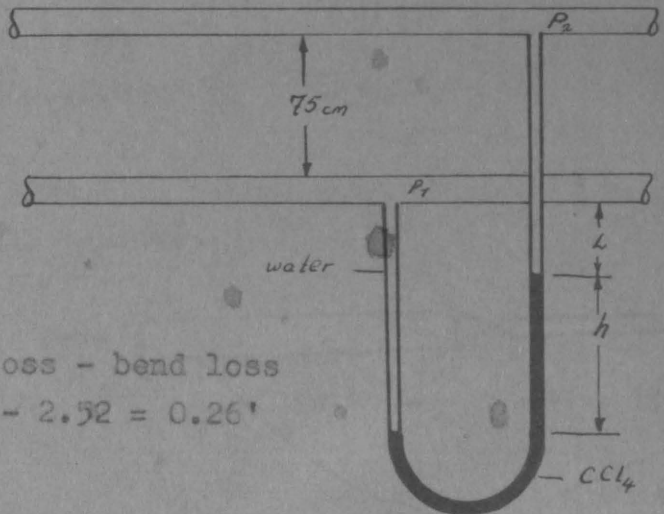
Large pipe loss:

$$P_1 + L(S.G_w) + h(S.G_w) - h(S.G_{CCl_4}) - L(S.G_w) - 75 - P_2 = 0$$

$$\begin{aligned} P_1 - P_2 &= 75 + h(S.G_{CCl_4} - S.G_w) \\ &= 75 + h(1.595 - 1) \\ &= 75 + h(0.595) \end{aligned}$$

$$h = 16.5 \text{ cm CCl}_4$$

$$\begin{aligned} h_f &= 75 + 16.5(0.595) \\ &= 84.82 \text{ cm} = 2.78' \end{aligned}$$



$$\begin{aligned} \text{Net large pipe loss} &= \text{pipe loss} - \text{bend loss} \\ &= 2.78 - 2.52 = 0.26' \end{aligned}$$

$$\text{Loss per foot} = \frac{\text{net loss}}{\text{pipe length}}$$

$$\text{Pipe length} = \frac{1266.5}{30.5} = 40.2'$$

$$\text{Loss per foot} = \frac{0.26}{40.2} = 0.00646$$

$$\text{Length of lower section}_1 = \frac{690.5}{30.5} = 22.6'$$

$$\text{Length of upper section}_2 = \frac{682}{30.5} = 22.4'$$

$$\text{Loss}_1 = 22.6 \times 0.00646 = 0.146'$$

$$\text{Loss}_2 = 22.4 \times 0.00646 = 0.145'$$

Bend loss:

$$\begin{aligned} h_f &= 75 + h(0.595) \\ &= 75 + 3.1(0.595) \\ &= \frac{76.85}{30.5} = 2.52' \end{aligned}$$

Contraction Loss:

$$\begin{aligned} h_f &= 0.595 h \\ h &= 35.5 \text{ cm } \text{CCl}_4 \end{aligned}$$

$$h_f = \frac{35.5}{30.5}(0.595) = 0.692'$$

Large pipe length : 1.31'

Small pipe length : 1.56'

Large pipe loss = $1.56 \times 0.205 = 0.319'$

Small pipe loss = $1.31 \times 0.00646 = 0.00846'$

$$\begin{aligned} \text{Contraction loss} &= h_f - \text{pipe loss} \\ &= 0.692 - (0.319 + 0.00846) \\ &= 0.3645' \end{aligned}$$

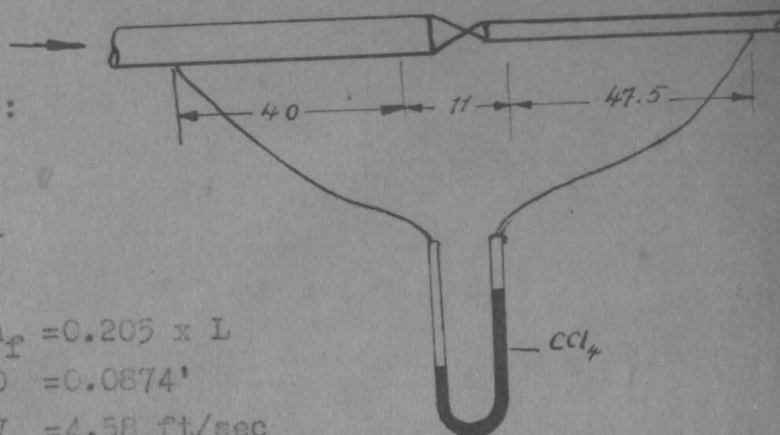
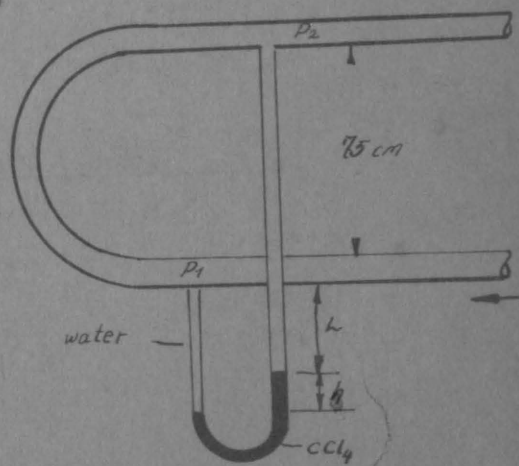
Friction factor for small pipe:

$$h_f = f \frac{L}{D} \cdot \frac{V^2}{2g}$$

$$h_f = 0.205 \times L$$

$$D = 0.0874'$$

$$V = 4.58 \text{ ft/sec}$$



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$$0.205 \times L = f \frac{L (4.58)^2}{0.0874 \times 64.4}$$

$$f = 0.055$$

Friction factor for large pipe:

$$h_f = 0.00646 \times L$$

$$D = 0.172'$$

$$V = 1.18 \text{ ft/sec}$$

$$0.00646 \times L = f \frac{L \times (1.18)^2}{0.172 \times 64.4}$$

$$f = 0.0515$$

Enlargement factor:

$$h_f = K_e \frac{(V_1 - V_2)^2}{2g} \quad \text{ref. Elementary Fluid Mechanics}$$

b. Vennard, pp. 212

$$h_f = 0.0074'$$

$$V_1 = 4.58 \text{ fps.}$$

$$V_2 = 1.18 \text{ fps.}$$

$$K_e = \frac{64.4 \times 7.4 \times 10^{-3}}{11.6} = 0.041$$

Contraction factor:

$$h_f = K_c \frac{V_1^2}{2g} \quad \text{ref. Same as above, pp. 216}$$

$$h_f = 0.358'$$

$$V_1 = 4.58 \text{ fps.}$$

$$K_c = \frac{0.358 \times 64.4}{21} = 1.1$$

Calculation of velocity heads:

For small pipe,

$$\text{Vel. Head} = \frac{V^2}{2g}, \quad V = 4.58 \text{ fps.}$$

$$= \frac{(4.58)^2}{64.4} = 0.328'$$

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For large pipe,

$$\text{Vel. Head} = V^2/2g = \frac{(1.18)^2}{64.4} = 0.0218'$$

Values of the Friction factor as determined from the textbook:

For small pipe,

Temperature of water: 54.5°F

Kinematic viscosity: $\mu/\rho = 1.3 \times 10^{-5}$ Ref. Fluid Mechanics, by
Cox-Germano, fig. 47
pp. 178

$$N_{Re} = D V / \mu/\rho \quad D = 0.0874'$$

$$V = 4.58 \text{ fps.}$$

$$\mu/\rho = 1.7 \times 10^{-5} \text{ ft}^2/\text{sec.}$$

$$N_{Re} = \frac{8.74 \times 10^{-2} \times 4.58}{1.3 \times 10^{-5}} = 3.08 \times 10^4 = 30800$$

$$f_{\text{small pipe}} = 0.028$$

Ref. Fluid Mechanics, by
Cox-Germano, fig. II9

For large pipe,

$$N_{Re} = \frac{0.172 \times 1.18}{1.3 \times 10^{-5}} = 15600$$

$$f_{\text{large pipe}} = 0.032$$

Calculations based on the estimate method of the textbook:

Drop for small pipe,

$$h_f = f \frac{L}{D} \frac{V^2}{2g} \quad \text{Ref. Elementary Fluid Mechanics, by}$$

$$\text{Vennard, Chp. 9}$$

$$f = 0.02$$

$$L = 11'$$

$$D = 0.0874'$$

$$V = 4.58 \text{ fps.}$$

$$h_f = 0.02 \times \frac{11}{0.0874} \times \frac{21}{64.4} = 0.785'$$

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Drop for large pipe,

$$f = 0.02$$

$$D = 0.172'$$

$$L = 45'$$

$$V = 1.18 \text{ fps.}$$

$$h_f = 0.02 \times \frac{45}{0.172} \times \frac{1.39}{64.4} = 0.113'$$

Loss for sudden enlargement:

$$h_f = K \frac{(V_1 - V_2)^2}{2g}$$

Ref. Elementary Fluid Mechanics, by
Vennard, Chap. 9

$$K = 1$$

$$V_1 = 4.58 \text{ fps.}$$

$$V_2 = 1.18 \text{ fps.}$$

$$h_f = \frac{3.4}{64.4} = 0.12'$$

Loss for sudden contraction:

$$\frac{A_2}{A_1} = \frac{0.854}{3.355} = 0.255$$

$$K_{\text{app.}} = 0.385$$

Vennard, pp. 216

$$h_f = K \frac{V_1^2}{2g} = 0.385 \frac{21}{64.4} = 0.126'$$

Loss for bend:

$$h_f = K \frac{V^2}{2g} = 2.2 \frac{(1.18)^2}{64.4} = 0.0475'$$

$K = 2.2$ for commercial pipe fittings
Vennard, PP. 220, Table: 4

Appendix:

References:

1. Elementary Fluid Mechanics
John K. Vennard
3. Edition
2. Steam Power Plants
Philip J. Potter
3. Fluid Mechanics
Glen N. Cox
F.J. Germano
4. Fluid Mechanics
Richard H.F. Pao

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DETERMINATION OF REYNOLD'S NUMBER AT THE TRANSITION FROM LAMINAR TO TURBULENT FLOW

Experiment No: FM.C4

Object: To determine the Reynold's number at the transition from laminar to turbulent flow within a circular tube.

Theory: Dimensional analysis, and dimensionless quantities in fluid mechanics and heat transfer have made it possible to explain, manipulate and handle a number of fundamental equations.

In the early 20 th. century, Osborne Reynolds introduced the dimensionless quantity $\frac{VD\rho}{\mu}$, which is called the Reynolds' Number, in his honor.

For any fluid flow a N_{Re} , can be associated which determines the kind of flow, that is whether it is laminar, turbulent or at the transition stage.

Apparatus:

- A) Container, Leybold No 366 12
- B) Graduated cylinder, 500 ml.
- C) Constant level tank, Genco 20720
- D) Glass tube, 3 ft., 5/16 in. inside diameter, Pyrex
- E) Stop watch, Leybold No 313 05
- F) Stand base, Leybold No 300 01
- G) Stand base adjusting screws, Leybold No 300 06
- H) Stand rods, 50 cm long, 12 mm diam. Leybold No 300 42
- I) Dunsen Clam, Leybold No 302 62
- J) Tubing clamps, Welch No 4913
- K) Polyethylene tubing, Genco No 18294-I
- L) Thermometer, No 388 14, Leybold No 388 85
- M) $KMnO_4$ crystals
- N) Injector
- O) Water supply and sink

Procedure:

- 1) Connect apparatus as shown in the diagram
- 2) Insert $KMnO_4$ crystals before inserting the injector.

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- 3) Allow water to run until constant conditions are achieved.
(The tubing not being connected to the tap .
- 4) Increase water level by steps and study the flow.

Requirements:

I. Take necessary data and calculate W_{re} .

M.B _____ - FLUID MECHANICS and HYDRAULICS LABORATORY REPORT

EXPERIMENT NO : FM.04

CRITICAL VALUE OF REYNOLD'S NUMBER IN
LAMINAR FLOW ϕ

SUBMITTED TO :

SUBMITTED BY :

DATE OF EXPERIMENT :

DATE OF REPORT :

ROBERT COLLEGE ENGINEERING SCHOOL
BEBEK / ISTANBUL

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Abstract: This experiment as performed in its present form bears a demonstrational character. The Reynolds' Number at the transition from laminar to turbulent flow is tried to be calculated. Due to imperfections in the apparatus set up this value of N_{Re} is far from being exact.

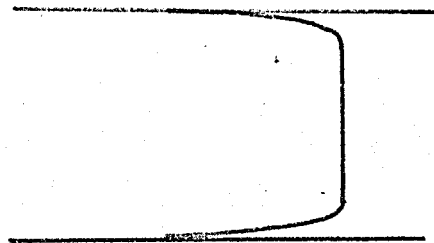
The method used is by the injection of dye through the flow in a glass tube.

Object: To determine the Reynolds' number at the transition from laminar to turbulent flow in a circular tube.

Theory: The realm of fluid dynamics and heat transfer enlarged their fields by the introduction of dimensional analysis and the dimensionless groups. The equations are brought to forms that can be handled more easily by arranging certain groups of properties, and bringing them into dimensionless forms. These dimensionless quantities have large significance in engineering problems.

In the early 20 th. century Osborne Reynolds' introduced the dimensionless quantity $\frac{VD\rho}{\mu}$, which is called the "Reynolds' Number".

In this number V denotes the velocity of flow of the fluid. In cases where the viscosity of the fluid is high so that it can not be neglected and assuming a parabolic velocity distribution, the velocity in the N_{Re} , denotes the average velocity of the flow stream. This fact has no considerable effect on the number because in turbulent flow (a situation on which prevails, most engineering problems) the velocity distribution has the following form,



so that the average velocity is almost the same as the maximum velocity.

D is a quantity which represents length. It can either be the hydraulic diameter of the conduit ($D = 4 \times \text{Area} / \text{Wetted perimeter}$), or the displacement " x " of the fluid. The former is denoted by N_{Re_D} ,

and the latter by Re_x .

ρ and μ are the density and viscosity of the fluid respectively at the conditions under consideration.

To any fluid flow we can associate a N_{Re} , the value of which determines the kind of flow. For a N_{Re} of about 2000 a transition from laminar to turbulent flow starts. There is a transition range and then the flow is completely turbulent. However with careful performance and delicate apparatus a much higher number can be attained.

In laminar flow the fluid appears to move in layers with one layer of fluid sliding over the other, although fluid molecules do, however, move from one layer to the next.

In turbulent flow the fluid is observed to mix in a rather chaotic manner as it moves along the tube. The motion of fluid is apparently influenced by the prevailing forces. The frictional forces produced by the fluid viscosity tend to constrain the motion of fluid in parallel layers, and the inertia forces, which are due to the mass and the velocity of fluid particles, tend to diffuse fluid particles. At low velocities the frictional forces produced by the fluid viscosity are predominant, and the resulting laminar flow is thus viscous in nature. As the velocity of flow increases, the inertia forces overcome the frictional forces and the fluid layers break up into a turbulent flow.

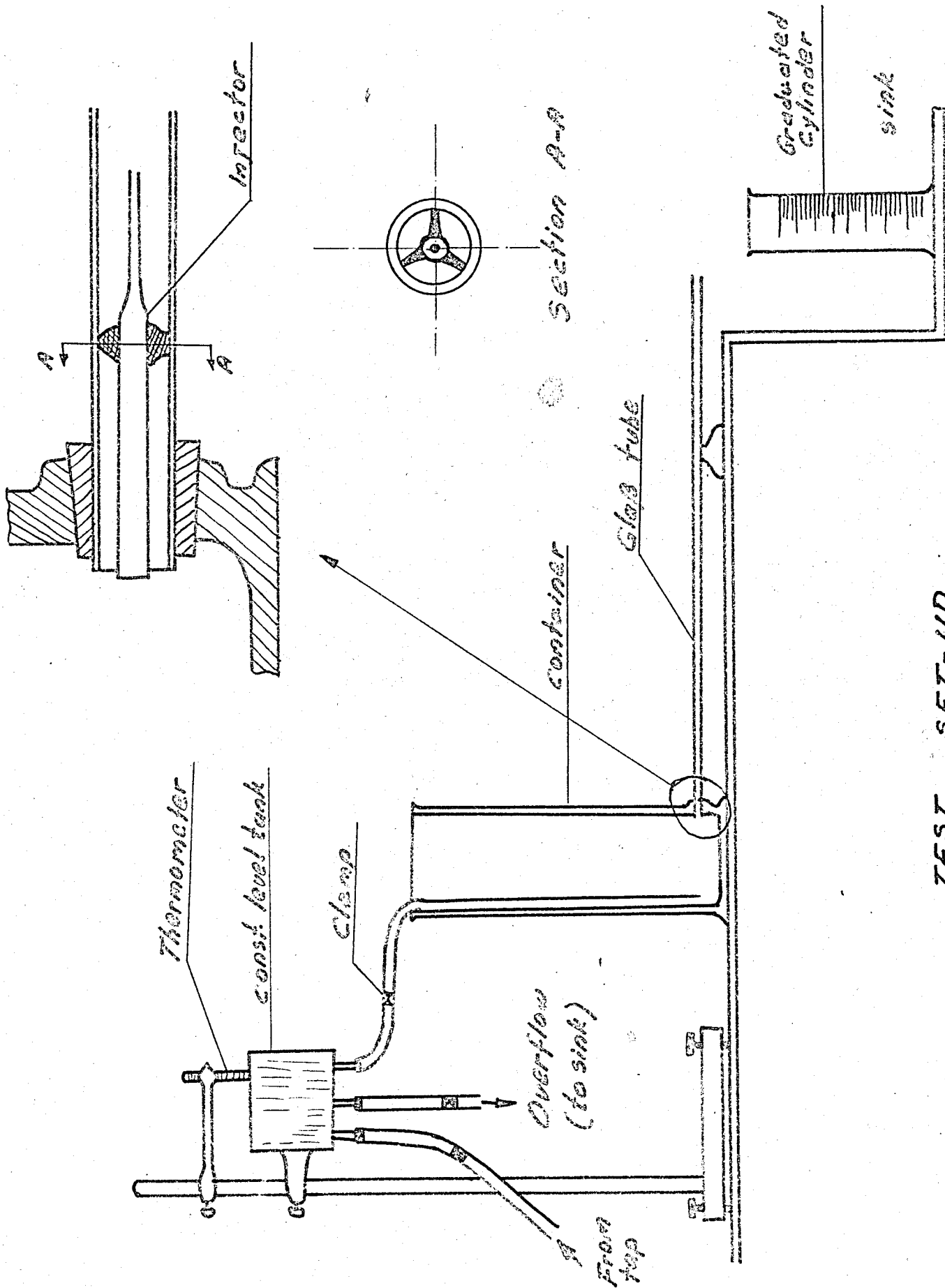
Apparatus: The items of apparatus are as listed on the experiment sheet, namely: 1. Container, 2. Graduated cylinder, 3. Constant level tank, 4. Glass tube, 5. Stopwatch, 6. Stand base, 7. Stand base adjusting screws, 8. Stand rods, 9. Bunsen clam, 10. Tubing clamps, 11. Polyethylene tubing, 12. Thermometer, 13. $KMnO_4$ crystals, 14. Injector, 15. Water supply and sink.

Procedure: The injector used was a Parker ball point refill whose ball had been removed and the refill cleaned. On the injector three solder spots were made in order to center the injector and stabilize it within the glass tube. Solder being mild provides a smooth fitting of the injector. Just before inserting the injector in the glass tube some $KMnO_4$ crystals had been put in it.

After connecting the apparatus as shown in the diagram, water was allowed to run for a while in order to get a flow of fixed temperature, before connecting the tap to the tubes.

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The two outer tubings of the constant level tank were polyethylene ones being transparent, in order to control the regularity of the flow. The inlet was then connected to a rubber tube which was connected to the tap.

After that of allowing water to run through the tube, and eliminating any air bubbles within the conduits, water flow was regulated through the the clamps.

For the lowest possible position of water level the dye stream followed a straight path throughout the three feet long glass tube without any mixing and in a perfectly ordered manner.

The water level was increased by steps through the clamps and in each step the flow was studied.

After the level reached a certain height turbulence began to appear from the end part of the tube which approached the injector nozzle as the velocity increased.

Data was taken, and the corresponding Reynolds' Number was calculated.

Data and Results:

Conduit diameter: 5/16 in. ϕ

Temperature of fluid: 15 deg.C or 60 deg.F.

Corresponding kinematic viscosity: 0.0435 ft²/Hr

Flow rate: 400 cc/min

$$N_{Re} = \frac{VD}{\nu} = \frac{QD}{AV} = \frac{4Q}{\pi D^3} = \frac{4 \times 400 \times 60 \times 16 \times 12}{5 \times \pi \times 0.0435 \times 28316}$$

$$N_{Re} = 955$$

Discussion: As it can be seen from the result that the obtained value is far from that expected theoretically.

Although at first it looks like a simple experiment the sources of error are plenty. The delicacy of the experiment arises from the fact that the history of the flow effects greatly the experiment. The main problem of the experiment are the following:

1. Constant supply and uniform flow
2. Proper injector and injection
3. Dye

4. Water temperature control

The constant supply of water was established by both the constant level tank and the tubing clamps which were on the polyethylene tubes. Care must be taken not to leave any air bubble in the tubes when starting the experiment. If any bubbles are left they get free by time and disturb the fluid thus causing turbulence. It is for this purpose that it is better to use transparent tubes like polyethylene.

Since the velocity of the flow is a function of the position head (provided the pressure is the same both at the container and the glass tube exit so that the pressure head is zero), the flow-rate can be adjusted by just keeping a constant level of water. Since the area is constant the velocity of flow can be determined by dividing the flow rate by the area. The obtained velocity is the average velocity of flow. The flow rate control can be made from the clamp.

A reason that the data taken were not so accurate is that, the injector due to its shape caused some turbulence and the fluid had to build up its flow after it got free from the effect of it, but the injection was done before fully developed flow was established.

The flow within the tube consisted of two parts. One that of the water flow and the other of the dye. These two flows had to be similar that is the two velocities had to be equal. For this purpose the dye flow had to be adjusted to that of water. This adjustment was almost impossible because there was no means of measuring the dye flow. If the velocity were higher turbulence was set up, if less the dye did not correspond to the real flow. So an approximate adjustment was made. The injector was connected through by a polyethylene tube to a funnel which contained the dye. (not shown in the diagram). The flow control of the dye was done by a clamp. The dye which had to be used in the experiment had to have the following properties:

- a) Soluble in water (if had to be prepared in solution)
- b) Not easily diffusing in water (this did not matter much in the laminar flow because there is no mixing of layers)
- c) Almost the same density as water, to provide for:
 - 1. Not to effect the density of water
 - 2. Not to form a parabolic trajectory in the flow
- d) Almost the same viscosity as water

The possible dyes are:

1. Ink solution: Proved to be improper because it diffuses in water
2. Laundry bluing: Did not diffuse, but formed a parabolic trajectory and sedimentation within the glass tube due to the size of the particles.
3. NaOH solution with phenolphthalein: proved to diffuse easily
4. $KMnO_4$ crystals: The dye was prepared by passing water through the $KMnO_4$ crystals. It is a good dye not diffusing and also solving the problem of dye flow control.

For this purpose some $KMnO_4$ crystals were put in the injector and it directly communicated with the container. The water which passed around the injector passed also through the injector thus emerging colored from the nozzle and having the same velocity as the main flow.

The concentration of the $KMnO_4$ solution is determined by the velocity of the water flow. The higher the velocity, the lower the concentration because less time is left for water to dissolve the crystals. The less the concentration the more accurate the results are.

It is a fact that any foreign material present in a fluid changes its physical properties appreciably. Thus the $KMnO_4$ solute although small in quantity, it has an effect on the viscosity and density of water. The effect is lessened when the flow is laminar and there is no mixing in the flow stream. In order to allow precision and to avoid large errors in the density and viscosity the dye stream must be as thin as possible.

Since the water was from the tap the temperature of it was apt to fluctuate at the beginning, attaining a steady value later. Care must be taken to let water run for a while and then start the experiment, because for a temperature range of 50 deg. F the viscosity of water almost doubles and the density does not change appreciably, so that the Re , decreases by 1/2.

A second point is to use water of temperature as low as possible. Water of low temperature has high viscosity thus obtaining a larger range of the velocity variation through the critical value of Re .

Suggestions: As far as flow control is concerned the experiment does not present imperfections.

The part that deserves attention is the container and the injection process.

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A new container must be supplied. This container should be lower and wider in size. The cross-sectional shape of the container has no great importance because the velocities involved are small, but if accuracy is sought a cylindrical one is advisable in order to avoid turbulence due to corner effects. Under these conditions a container of about 9 in. diameter and 8 in. height is advisable. Under these conditions the thermometer can be directly immersed in the container instead in the constant level tank. Also the hole of the container must be larger in order to be suitable for larger glass tubes.

The reason for larger container is mainly for the dye injection. A new injector should be made of glass. The shape of this injector must be as the original, but the diameter reduction should be continuous instead of presenting jumps. The injector nozzle should be made as small as possible. The injector must be placed outside the glass tube and adjusted such that the nozzle injects the dye just through the center of the tube. It is recommended to use bell-mouthed glass tubes in order to avoid any end effects and in order to attain fully developed flow in a more quicker time.

References:

1. Heat Transfer by Alan Chapman, Chapters : 6 and 7 .
2. Fluid Mechanics by Richard H.F. Pao, Chapter 5.
3. Mechanical Engineering Experimentation, Page 231 - 3
by G.L. Tuve
4. Leybold, Genco and Welch
Apparatus catalogs

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TEST OF AN AIR COMPRESSOR

Experiment No: FM. 05

Object: To determine the characteristics of a two-cylinder, single stage reciprocating air compressor at constant speed and varying discharge pressures.

Description of the machine to be tested:

Gardner-Kix Compressor 4 1/2" x 4 1/2"

The Gardner Governor Co.

Maximum speed : 500 rpm.

Minimum speed : 300 rpm.

Maximum air pressure : 150 psi.

Operation:

To start the compressor:

- 1) Open cooling water valve to the compressor water jacket.
- 2) Check to make sure that the valve between the compressor and receiver tank is open.
- 3) Close the three-phase knife switch, this brings power to the compressor control board.
- 4) Turn the rotary switch. This starts the compressor motor.

To stop the compressor:

- 1) Reverse the above procedure. Leave the valve between the compressor and the receiver tank open.

Test procedure:

The controlling factor in compressor testing is the time required for the test conditions to become constant after a change of pressure. ASME Power Test Code recommends that 1 hour be the minimum test period.

For this test seven runs will be made at 0, 10, 20, 30, 40, 50 and 60 psi each with an interval of 10 minutes. Readings should be recorded at the end of the interval, but should be watched during the interval to see that a steady state is being reached. Discharge pressure is controlled with the orifice valve.

Measurements:

Input power to motor
 Tank pressure
 RPM of motor and compressor
 Amount of cooling water
 Temperature of cooling water (in and out)
 Temperature of air at orifice
 Temperature of air at compressor outlet
 Pressure potential across the orifice.
 Barometric pressure
 Pulley diameters of motor and compressor
 Indicator cards
 Spring constant 70 lbs/in²/in.
 Orifice diameter 7/8"
 Motor efficiency 85 %
 Belt efficiency 95 %
 Take C = 0.623

Requirements:

Determine:

Capacity
 Isothermal HP
 Adiabatic HP
 Indicated HP
 Brake HP,
 Electrical HP
 Volumetric efficiency
 Compression efficiency
 Mechanical efficiency
 Overall efficiency
 Exponent "n" of compression curve
 Heat balance in % of total energy input and amounts of energy

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Plot:

1. Capacity

Volumetric efficiency

Compression efficiency

Overall efficiency (

versus

Discharge pressure.

2. A heat balance graph with energy quantity summations as the ordinate and discharge pressure as the abscissa.

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M.E. FLUID MECHANICS and HYDRAULICS LABORATORY REPORT

TEST OF AN AIR COMPRESSOR

Experiment No: Fl. 05

Date of experiment: _____

Date of report: _____

Submitted by: _____

Submitted to: _____

ROBERT COLLEGE SCHOOL OF ENGINEERING, Bebek -- ISTANBUL

Object: To determine the characteristics of a two-cylinder, single stage reciprocating air compressor at constant speed and varying discharge pressure.

Description of the machine to be tested:

Gardner - Rix Compressor 4 1/2" - 4 1/2"
The Gardner Governor Co.
Maximum speed : 500 rpm.
Minimum speed : 300 rpm.
Maximum air pressure : 1150 psi.

Name Plates:

Motor: Induction motor
Model no. A 6019, Type KT 750-6-5 ICCC Norm C
Cycle: 50 , Three phase
Volts: 190 , Amp. 17.2
Full load speed : 940 rpm.
No: 4132022 , HP: 5
Continous 50° C
General Electric Co. , Schenectady, N.Y. , USA.

Record revolution counter:

Indicator
Crosby Steam Gate and Valve Co.
Boston, Mass. USA.

Pressure Governor:

CR. 2922 CAT. I769124 36
Class - 103 - 160 Form - A
A-C, 220 volts - 40 cycle
220 volts - 60 cycle
Pressure limits 50 - 130 lb/in²
General Electric Co. Schenectady, N.Y., USA.

Wattmeter:

Wattmeter de precision pou courant continu et alternatif

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150 volts , 5000 ohms
Fitalon horizont
True Tauber and Co. , Zurich

Operation and procedure:

To start the compressor:

The water valve to the compressor jacket was opened before starting the compressor. Next the valve between the compressor and the receiver tank was opened. Three phase switch, bringing power to the compressor control board was closed, after which the rotary switch was turned, to start the compressor motor.

To stop the compressor:

The above procedure was reversed, this time leaving the valve between the compressor and the receiver open.

The controlling factor in compressor testing is the time required for the test conditions to become constant after a change of pressure.

Although ASME Power Codes recommend one hour to be the minimum I had to leave 30 minutes, due to the shortage of time. Six runs have been performed for this test at 15, 25, 35, 45, 55 and 65 psig. pressures, each with an interval of 30 minutes. Readings were taken at the end of the intervals, after the steady state conditions were reached. Discharge pressure was controlled by the orifice valve.

Data:

a) General data

Barometric pressure : 30.18" Hg.

I^o (elec.) : 150 watts

Bucket tare: 1.68 Kg.

Pulley diameters : a) Motor 17.5 cm.

b) Compressor.. 51 cm.

Manometer correction: 0.335 ft. of H₂O

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b)

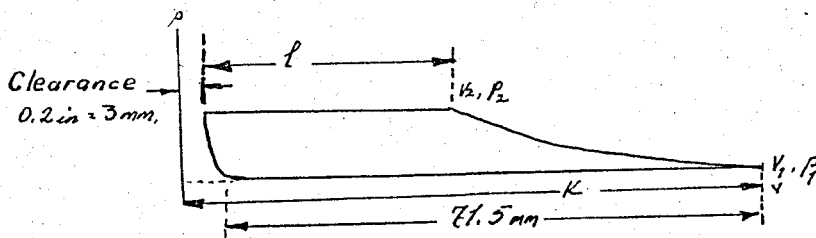
Run no.	Dis.Press. (Psig)	Input Motor Speed rpm.	Compressor speed rpm.	Temp. before orifice °C	Temp. after orifice °C	Room Temp °C	Press. drop at or. ft. of water
1	15	19.5	970	335	21.2	50	17.2
2	25	23	948	330	25.4	52	"
3	35	25.6	942	327	26.6	63	"
4	45	28	938	324	29.9	70	16.8
5	55	30.5	926	323	31.25	75	"
6	65	32.4	904	317	32.3	80	15.2

c) Indicator card:

RUN NO.	AREA cm ²	LENGTH mm	INTAKE LENGTH mm
1	1.83	75	74.5
2	3.38	"	71.5
3	5	"	69.5
4	6.1	"	69
5	6.12	"	68
6	7.54	"	64

Run number: 2 , Discharge pressure : 25 psig

$$A = 3.7 - 0.036 \times 3.7 = 3.38 \text{ cm}^2 = 0.524 \text{ in}^2$$



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d) Cooling water:

Run no.	Amount	Inlet Temp.	Outlet Temp.	Time	Starting Time
1	12.45 Kg.	10.9 °C	13.2 °C	60Sec.	13:00
2	12.3	11	14	"	15:30
3	12.5	11	14.5	"	16
4	29.9	11	14	"	16:30
5	31.2	10.9	13.4	"	17
6	32.3	10.9	14.2	"	17:30

Calculations: Run:2

a) Determination of capacity:

$$Q = C A V$$

$$Q = C A \sqrt{2gh}$$

$$Q = C A \sqrt{2g \frac{h_w \rho_w}{\rho_a}}$$

Q = Quantity of flow

$$C = 0.623$$

$$A = \frac{\pi}{4} d^2 \quad d = 7/8"$$

$$A = \frac{\pi}{4} \left(\frac{0.875}{12} \right)^2 = 0.00417 \text{ ft}^2$$

$$g = 32.2$$

$$\rho_w = 62.4$$

h_w = Drop at orifice.

$$h_w = (0.335 - 0.11) \times 2 = 0.45 \text{ ft.}$$

ρ_a = Density of air

$$\rho_a = \frac{P_a}{RT}$$

where:

$$P_a = \text{Barometric press.} = 30.18 \text{ "Hg.}$$

$$R = 55.3$$

$$T = 25.4^\circ\text{C} = 77.2^\circ\text{F} = 557.2^\circ\text{R}$$

$$\rho_a = \frac{30.18 \times 14.7 \times 144}{29.9 \times 55.3 \times 557.2}$$

$$\rho_a = 0.0746$$

$$Q = 0.623 \times 0.00417 \sqrt{\frac{2 \times 32.2 \times 0.45 \times 62.4}{0.0746}}$$

$$Q = 0.405 \text{ ft}^3/\text{sec}$$

$$Q = 24.3 \text{ ft}^3/\text{min}$$

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b) Determination of Isothermal HP

$$HP = \frac{144 \times Q}{33000} \times P_a \ln \frac{P_d}{P_a}$$

$$Q = 24.3 \text{ ft}^3/\text{min}$$

P_a = Barometric pressure

$$= \frac{30.18 \times 14.7}{29.9} = 14.82 \text{ psi}$$

P_d = P_a + Discharge pressure

$$= 14.82 + 25 = 39.82 \text{ psi}$$

$$HP = \frac{144 \times 24.3 \times 14.82}{33000} \ln \frac{39.82}{14.82}$$

$$HP = \underline{1.56}$$

c) Determination of Indicated HP

$$HP = \frac{P_m L A N}{33000} \times 2$$

$$P_m = \frac{\text{Area of indicator card} \times \text{spring constant}}{\text{Length of card}}$$

$$\text{Area of ind. card} = 3.38 \text{ cm}^2 = 0.524 \text{ in}^2$$

$$\text{Spring constant} = 70 \text{ psi/in.}$$

$$\text{Length} = 75 \text{ mm} = 2.95 \text{ in.}$$

$$P_m = \frac{0.524 \times 70}{2.95} = 12.4 \text{ psi}$$

$$L = 4.5 \text{ in}$$

$$A = \pi/4 \times (4.5)^2$$

$$N = 330 \text{ rpm}$$

$$\text{Number of cylinders} = 2$$

$$HP = \frac{12.4 \times 4.5/12 \times 0.785 \times (4.5)^2 \times 330 \times 2}{33000}$$

$$HP = \underline{1.48}$$

d) Determination of Brake HP

$$BHP = \frac{\text{Input (Kw)}}{0.746} \times \text{Motor eff.} \times \text{Belt eff.}$$

$$\text{Input} = 23 \text{ degrees}$$

$$= 23 \times 0.150 = 3.45 \text{ Kw.}$$

$$\text{Motor eff.} = 0.85$$

$$\text{Belt eff.} = 0.95$$

$$BHP = \frac{3.45}{0.746} \times 0.85 \times 0.95$$

$$BHP = \underline{3.73}$$

e) Determination of electrical HP

$$\text{EHP} = \frac{\text{Input (Kw)}}{746} \quad \text{Input} = 3.45 \text{ Kw.}$$

$$\text{EHP} = \frac{3.45}{0.746} = \underline{4.62}$$

f) Determination of volumetric efficiency

$$n_v = \frac{\text{Capacity } Q}{\text{Volume displacement}} \quad Q = 24.3 \text{ ft}^3/\text{min.}$$

$$n_v = \frac{24.3}{2 \times \frac{4.5}{12} \times 0.785 (4.5/12)^2 \times 330}$$

$$n_v = 0.89 = \underline{89 \%}$$

g) Determination of mechanical efficiency

$$n_m = \frac{\text{IHP}}{\text{BHP}} \quad \text{IHP} = 1.48$$

$$\text{BHP} = 3.73$$

$$n_m = \frac{1.48}{3.73} = 0.397$$

$$n_m = \underline{39.7 \%}$$

h) Determination of overall efficiency

$$n_o = \frac{\text{HP}_{\text{is.}}}{\text{EHP}} \quad \text{HP}_{\text{is.}} = 1.56$$

$$\text{EHP} = 4.62$$

$$n_o = \frac{1.56}{4.62}$$

$$n_o = 0.338 = \underline{33.8 \%}$$

where: n_o is based on isothermal expansion

i) Determination of exponent "n"

$$P_1 V_1^n = P_2 V_2^n$$

$$P_1 = 14.82 \text{ psi}$$

$$P_2 = 14.82 + 25 = 39.82 \text{ psi}$$

$$\frac{P_2}{P_1} = \left[\frac{V_1}{V_2} \right]^n$$

$$V_1/V_2 = K/l$$

$$K = 78 \text{ mm}$$

$$l = 36 \text{ mm}$$

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$$\left[\frac{78}{36}\right]^n = \frac{39.82}{14.82}$$

$$(2.14)^n = 2.685$$

$$n \cdot \log 2.14 = \log 2.685$$

$$n \cdot (0.33041) = 0.42894$$

$$\underline{n = 1.298}$$

k) Determination of Adiabatic HP

$$HP = \frac{144 \times Q \times n}{33000(n-1)} \times P_a \left[\left(\frac{P_d}{P_a} \right)^{\frac{n-1}{n}} - 1 \right]$$

$$HP = \frac{144 \times 24.5 \times 1.298}{33000(1.298-1)} \times 14.82 \left[\left(\frac{39.82}{14.82} \right)^{\frac{1.298-1}{1.298}} - 1 \right]$$

$$Q = 24.5 \text{ ft}^3/\text{min}$$

$$n = 1.298$$

$$P_a = 14.82$$

$$P_d = 14.82 + 25 = 39.82$$

$$HP = 0.83 \left[(2.69)^{0.23} - 1 \right]$$

$$HP = \underline{1.75}$$

l) Determination of compression efficiency

$$N_c = \frac{n_o}{n_m}$$

Ref. Applied Thermodynamics by Faies

pp.149

$$N_c = \frac{0.338}{0.397}$$

$$n_o : 0.338$$

$$n_m : 0.397$$

$$N_c = 0.85 = \underline{85 \%}$$

m) Determination of Overall efficiency and compression efficiency based on adiabatic expansion.

$$n_o = \frac{\text{Adiabatic HP}}{\text{EHP}}$$

$$HP_{ad.} : 1.75$$

$$\text{EHP} : 4.62$$

$$n_o = \frac{1.75}{4.62}$$

$$n_o = 0.379 = \underline{37.9 \%}$$

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$$n_c = \frac{n_o}{n_m}$$

$n_o = 0.379$, (based on adiabatic expansion)

$$n_c = \frac{0.379}{0.397}$$

$n_m = 0.397$

$$n_c = 0.905 = \underline{90.5 \%}$$

n) Determination of heat balance

Mechanical loss: 5 % BHP

Imperfect compression loss: 4 % BHP

Cooling water : $w C (t_2 - t_1)$

Input = BHP

$$\text{IHP (output)} = \frac{2\text{PLAN}}{33000}$$

$w = \text{weight of cooling water} = 12300 - \text{Tare}$
 $= 10620 \text{ gm.}$

$$\text{BHP} = 3.73$$

$$\text{Mechanical loss} = 0.05 \times 3.73 = 0.186$$

$$\text{Imperfect compression loss} = 0.04 \times 3.73 = 0.149$$

$$c = 1 \text{ cal/gm.}^\circ\text{C}$$

$$t_2 = \text{outlet temperature} = 14^\circ\text{C}$$

$$t_1 = \text{inlet temperature} = 11^\circ\text{C}$$

$$\text{time of flow} = 60 \text{ sec.}$$

$$\text{IHP} = 550 \text{ ft-lb/sec}$$

$$\text{Cooling water} = 10620 \times 1 \times (14 - 11) = 31900 \text{ cal.}$$

$$1 \text{ cal.} = 3.087 \text{ ft-lb.}$$

$$= 31900 \times 3.087 = 98400 \text{ ft-lb.}$$

$$= \frac{98400}{60} = 1640 \text{ ft-lb/sec.}$$

$$= \frac{1640}{550} = \underline{2.98 \text{ HP}}$$

Input = Output + Cooling water + Mechanical loss + Imperfect compression loss

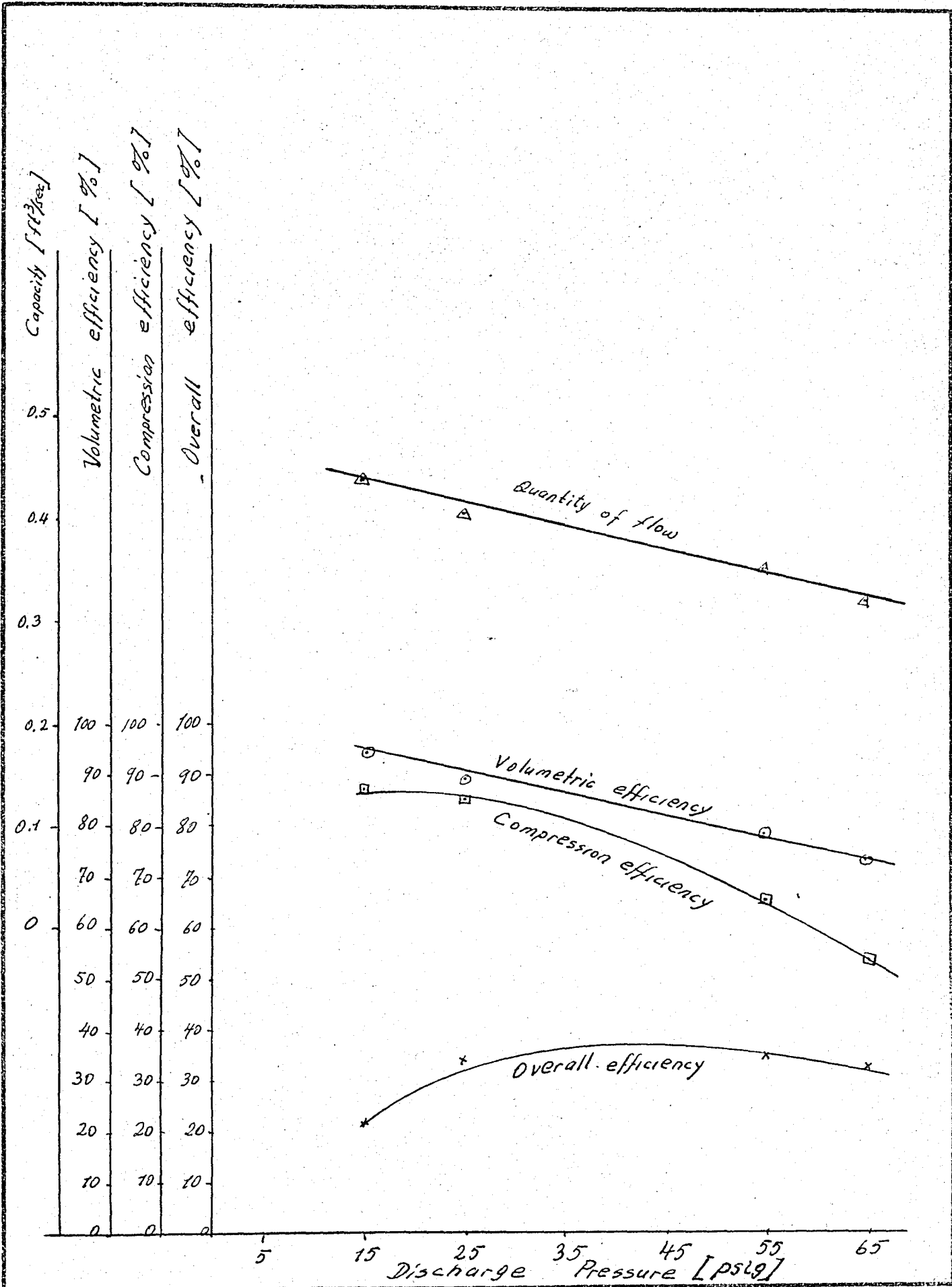
$$3.73 = 1.48 + 2.98 + 0.186 + 0.146$$

$$3.73 = 4.795$$

Therefore: $\frac{4.795}{3.73} = \underline{128 \%}$

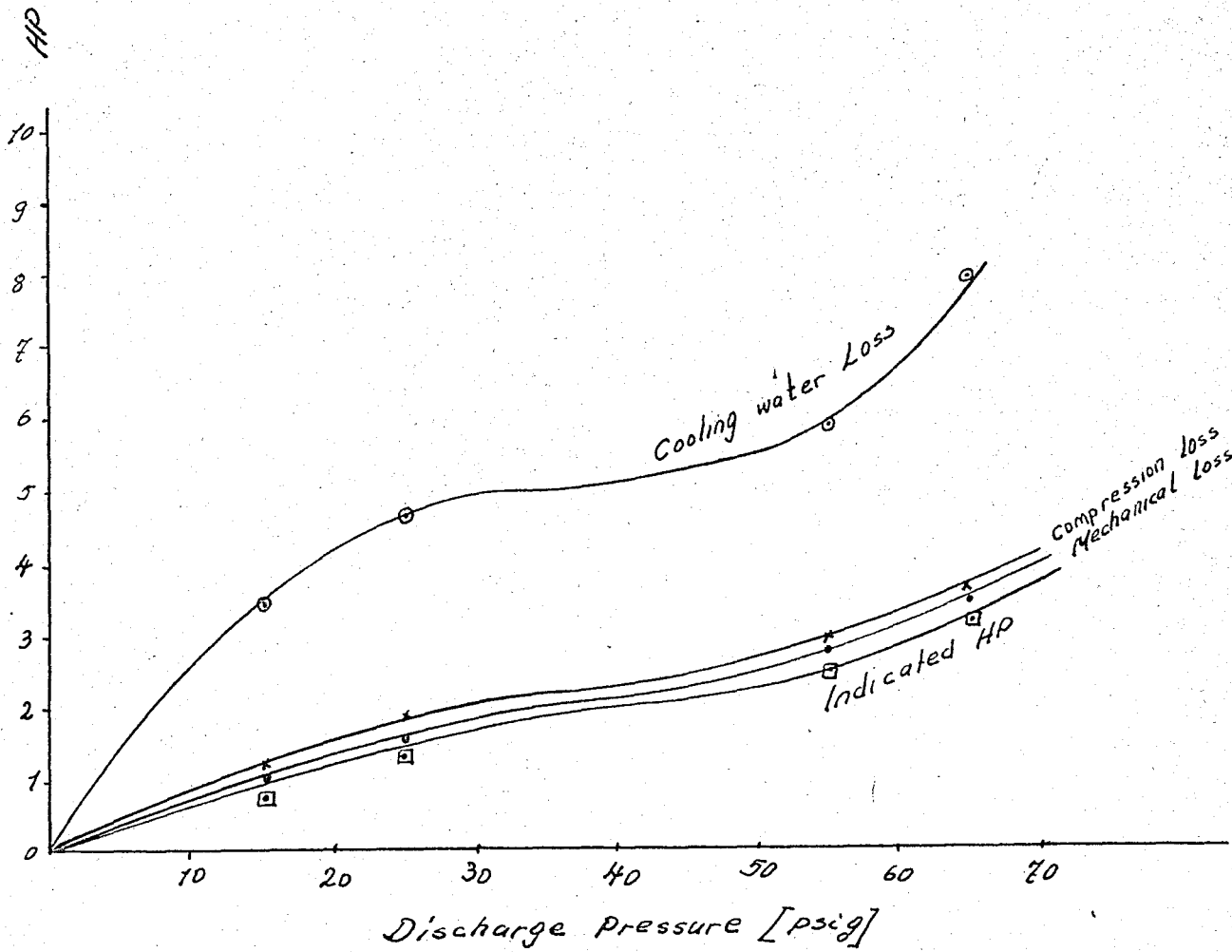
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Conclusion: Satisfactory results of the performed experiment are seen on the graphs drawn for runs 1,2,5,6 .Runs 3 and 4 are not considered, because , the results obtained in these two runs exhibit large fluctuations and irregularities between the points of their data.

It is concluded that: Volumetric efficiency decreases as the pressure in the tank increases.

The capacity decreases as the pressure in the tank increases, which also shows that the flow through the orifice has decreased.

Error in capacity readings are mainly due to inexact manometer readings.

Other factors being constant isothermal HP is directly dependent on Q.

Indicated HP is dependent mainly on indicator card dimensions and on the rpm of the compressor.

Input HP, with constant motor and belt efficiencies, is dependent on IHP.

The curves for the volumetric efficiencies exhibit results very near to theoretical curves. (Kent's Handbook, I-45).

The value of "n" being found as 1.298 is in accordance with the normal results of such an experiment, the case being between isothermal and adiabatic .

The accuracy in the calculation of the value of "n" depends on the indicator card.

TEST OF A TRIPLEX PUMP

Experiment no: PM.06

Object: The object of this experiment is to determine the capacity and plot the performance characteristics of a triplex pump operating against various discharge pressures.

Description of the machine to be tested:

Worthington Triplex pump
Vertical, single acting, single stage
Size 4" x 6"
Rated discharge capacity: 84 gpm
Rated speed : 62 rpm.

Necessary measurements:

Motor and pump speeds
Discharge and suction pressures
Distance between pressure gages
Input power (two wattmeter method)
Quantity of discharge
Time of discharge
Effective diameters of suction and discharge pipes
Belt efficiency : 95 %
Motor efficiency : 91 %
Discharge orifice coefficient : 91%

Operating instructions:

- 1) Open the pump discharge valve.
- 2) Check the three-phase starting rheostat on the motor to see that it has maximum resistance. It should be the left.
- 3) Close the 3-phase knife switch on the switchboard. It is the left hand switch.
- 4) Turn the starting rheostat to the right to remove the armature resistance.

Requirements:

Make at least 6 runs by varying the discharge head. Begin with

maximum head at about 35 ft. Do not go higher or you will stop the pump. The discharge water should be weighed in the tank provided. Duration of runs should be approximately the time needed to fill the tank. Take readings every 15 or 20 seconds depending on the duration of runs.

Calculate:

EHP, BHP, IHP (EHP : Electrical Horsepower)

Actual discharge in gpm

Whp (Water Horsepower)

Slippage

Mechanical efficiency

Hydraulic efficiency

Pump efficiency

Overall efficiency

Volumetric efficiency

Plot:

Capacity, Mechanical efficiency, overall efficiency and slippage against total discharge pressure.

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M.E FLUID MECHANICS and HYDRAULICS LABORATORY REPORT

TEST OF A TRIPLEX PUMP

Experiment No : MM .06

Date of experiment: _____

Date of report: _____

Submitted by: _____

Submitted to: _____

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Object: to determine the capacity and the performance characteristics of a tri plex pump, operating with various discharge pressures.

Characteristics of the pump tested:

Wothington, Triplex pump
Vertical, single acting, single stage
Size : 4" x 6"
Rated discharge capacity : 84 gpm.
Rated speed (original) : 87 rpm.
(at present): 62 rpm.

Characteristics of the electric motor:

St. L'Eclair Electric
Ateliers Lorraine de Jorville
Moteur no: 70703 - 3 phase
Volts: 110/100 , Amps: 37/21
Tours: 950 , cycle: 50

Characteristics of the wattmeter:

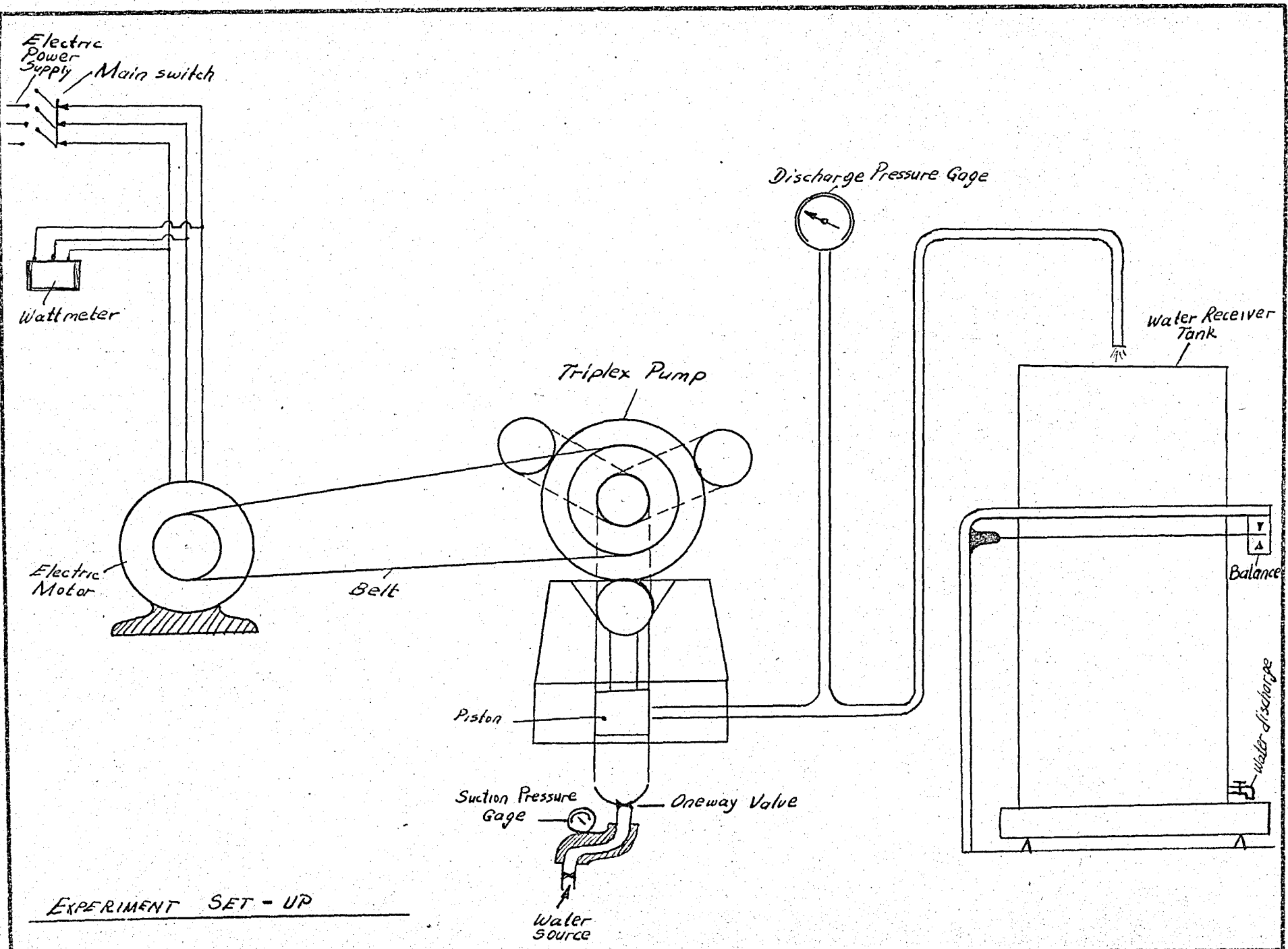
Wattmeter de precision
150 volts, 5000 ohms
Trub Tauber et Co. , Zurich

Auxiliary equipment:

Various gages and balance

Procedure:

At the beginning of the experiment the discharge valve of the pump was opened, letting out previously built up pressure. The motor was then connected to the electric supply with the maximum starting resistance at the starting. After the motor has started the starting switch was turned from left to right to remove the armature resistance from the motor. A wattmeter was connected to the electrical circuit to measure the power that was consumed. The triplex pump that was connected to the motor with a belt, began to operate. The discharge pressure was adjusted in ft. of water at a certain level by adjusting the discharge valve. Water was pumped for 60 secs. and the amount that was collected was weighed on a platform balance.



EXPERIMENT SET - UP

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- During the test a) Suction pressure
b) Motor speed
c) Pump speed

were recorded.

The above procedure was repeated for every suction pressure two times and was repeated for seven runs, each time decreasing the discharge pressure.

Data:

Run	RPM MOTOR	RPM PUMP	P(disch.) ft. of wa.	P(suc.) in. of Hg	Power Kw	Q Kg/min
1	965	58	210	-4	3.3	251
2	962	59	185	-3.5	3	253
3	974	60	140	-3.5	2.4	258
4	980	61	100	-3	1.875	263
5	881	62	70	-3	1.575	264.8
6	985	63	30	-3.5	0.975	269
7	983	63	12	-3.5	0.780	269.5

Wattmeter k : 1° = 150 watt

Values of Q include the tare weight of 55 kgs.

Height between gages : 150 cm

suction pipe diameter : 3"

Discharge pipe diameter : 2"

Calculations:

Determination of Indicated HP :

Run no: 1

$$IHP = \frac{PLAN}{33000}$$

$$L = 6/12 = 0.5'$$

$$A = \frac{\pi}{4} d^2 = 12.6 \text{ in}^2$$

$$N = 62 \text{ rpm}$$

$$P = (P_d - P_s) + (z_d - z_s) + \frac{v_d^2 - v_s^2}{2g} = 31 \text{ psi}$$

$$IHP = \frac{3 \times 62 \times 12.6 \times 0.5 \times 31}{33000} = 1.09 \text{ Hp}$$

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Determination of Brake Hp:

$$BHP = \frac{P(\text{watts})}{746} \times e_m \times e_b$$

$e_m = \text{Motor efficiency} = 91\%$
 $e_b = \text{Belt efficiency} = 95\%$
 $P = 1575 \text{ watts}$

$$BHP = \frac{1575 \times 0.91 \times 0.95}{746} = 1.82 \text{ Hp}$$

Determination of water Hp:

$$WHP = \frac{Q_A \times h_w}{33000}$$

$$WHP = \frac{22}{62.4} \times \frac{210 \times 62.4}{33000} \times \frac{70}{0.98} = 1 \text{ HP}$$

Determination of actual discharge: in gpm

$$Q_G = \frac{Q_h}{3.785} = \frac{210}{3.785} = 56 \text{ gpm}$$

Determination of Electrical Hp:

$$EHP = \frac{\text{Input in watts}}{746 \times e_m}$$

Input = 1575 watts

e_m : motor efficiency: 91 %

$$EHP = \frac{1575}{746 \times 0.91} = 2.14 \text{ HP}$$

Determination of Mechanical efficiency: e_m

$$e_m = \frac{IHP}{BHP}$$

IHP = 1.09 Hp

BHP = 1.82 Hp

$$e_m = \frac{1.09}{1.82} = 0.6 = 60\%$$

Determination of Hydraulic efficiency: e_H

$$e_H = \frac{WHP}{IHP}$$

WHP : 1 Hp

IHP : 1.09 Hp

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$$e_H = \frac{I}{1.09} = \underline{0.918} = \underline{91.8 \%}$$

Determination of pump efficiency:

$$e_p = \frac{WHP}{BHP}$$

WHP : 1 Hp

BHP : 1.82 Hp

$$e_p = \frac{I}{1.82} = \underline{0.55} = \underline{55 \%}$$

Determination of overall efficiency:

$$e_o = \frac{WHP}{EHP}$$

WHP : 1 Hp

EHP : 2.14 Hp

$$e_o = \frac{I}{2.14} = \underline{0.465} = \underline{46.5 \%}$$

Determination of volumetric efficiency:

Volume of cylinder = $62 (12.6 \times 3 \times 6) = 14000 \text{ in}^3 / \text{min.}$

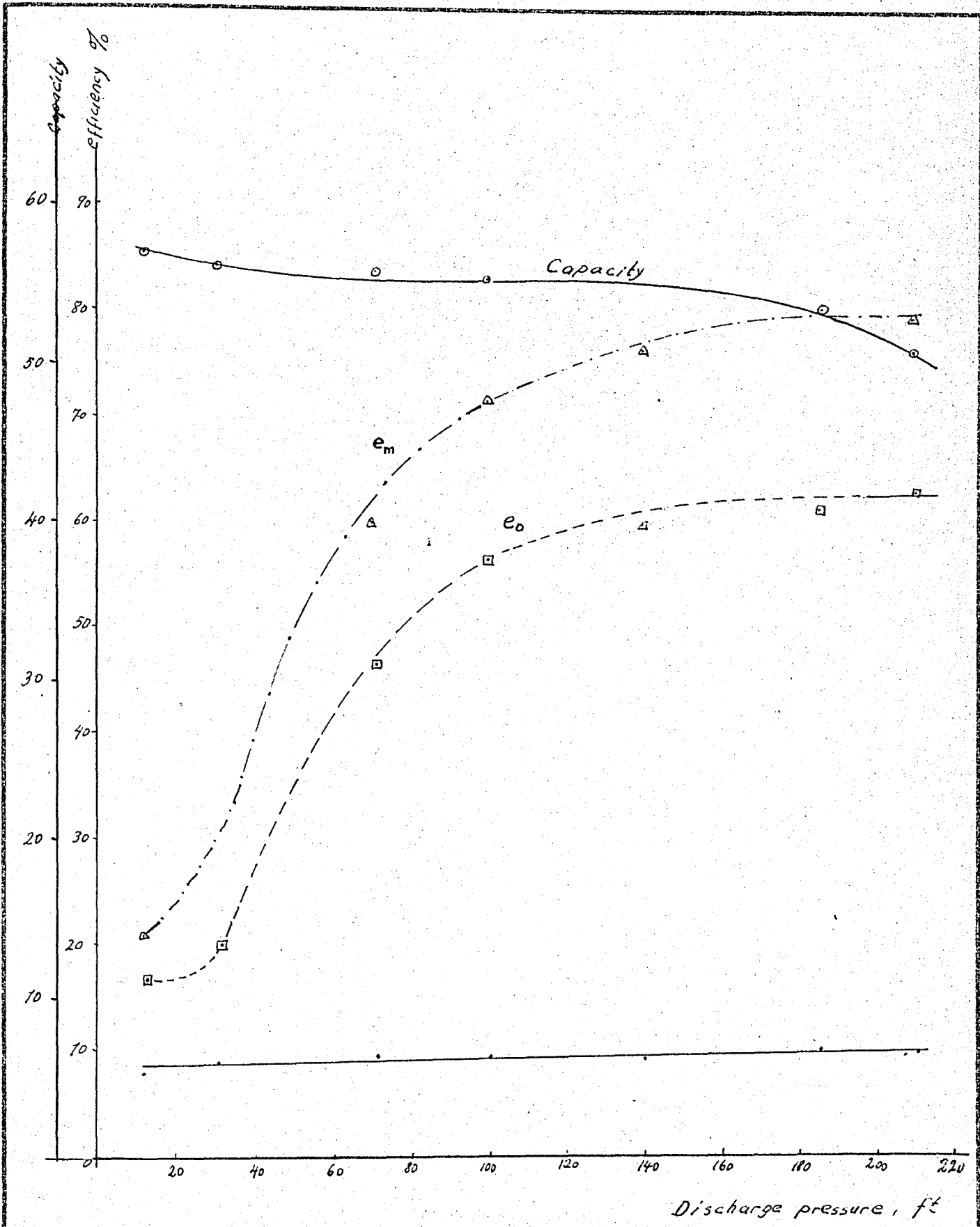
Volume of water pumped = $\frac{210 \times 12^3 \times 2.2}{62.4} = 12800 \text{ in}^3 / \text{min}$

Therefore:

$$\text{Volumetric efficiency} = \frac{14000 - 12800}{14000} = \underline{0.86} = \underline{86 \%}$$

Determination of slippage:

$$s = 1 - 0.86 = \underline{0.14} = \underline{14 \%}$$



Performance Characteristics of a Triplex Pump

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Table of Results:

Run	BHP	EHP	IHP	WATER DISC. gpm	WHP	SLIP	e_m	e_H	e_p	e_o	Volumetric efficiency
1	3.82	4.42	3.04	51.5	2.78	9.86	79.5	90.5	72.6	63	90.14
2	3.48	4.03	2.78	53.6	2.48	9.8	80	89.2	71.1	61.3	90.2
3	2.78	3.22	2.12	52.3	1.93	9	76.5	91	69.3	60	91
4	2.17	2.51	1.55	55.5	1.41	7.5	71.5	91.5	65.5	56.5	92.5
5	1.82	2.14	1.09	56	1	14	60	91.8	55	46.5	86
6	1.13	1.13	0.47	56.5	0.43	8.9	23.6	91.2	38.6	33.4	91.1
7	0.90	1.04	0.18	56.8	0.17	9	20.6	93.8	19.6	16.95	91

Conclusion:

Due to the characteristics of the mptor, the pump is run with a slightly variable speed, which influences the results obtained. The results show deviations with the values given in handbooks.

The main item that influenced the accuracy of the results, was that when the pump was operating its valves were not properly functioning. Inlet and outlet valves, which are located before the three pistons, did not give out the proper amount of water from the pistons.

Appreciable inaccuracies were observed in weighing the amount of collected water.

It can be concluded in general that the efficiencies are quite low, but as a whole the experiment can be considered to be a satisfactory one.

TEST OF RADIAL FAN WITH FORWARDLY CURVED BLADES

Experiment no: FM 07

Object: To determine the performance characteristics of a radial fan with forwardly curved blades.

Description of the Machine to be tested:

Forward-blade centrifugal fan
48 Blades
Held at center by 6 triangular blades.

Operation:

This fan is operated by a D-C motor, where it is necessary to operate the laboratory motor generator set to run the fan.

At the main lab. switchboard:

- 1) Close the line switch
- 2) Close the M-G Motor switch
- 3) Push lever on M-G motor starter forward until motor reaches speed.

Then pull it forward quickly and set catch to hold it in place.

- 4) Close M-G generator switch.
- 5) Close diesel engine panel switch. The diesel switchboard has the M-G generator resistance.

6) At upper left hand rheostat of diesel engine switchboard, move rheostat very slowly to the left, watching the voltmeter as you do so. Move the rheostat until the voltmeter reads about 80 volts. This rheostat decreases the field resistance of the generator.

- 7) Close the radial fan switch on the main switchboard.

Return to fan control board. The voltmeter on it should read 75 volts. If it does not call the instructor.

8) Turn the fan motor field resistance to its maximum position. (Lower rheostat) This reduces motor field resistance.

9) Slowly decrease the armature resistance. This starts the fan. (Upper rheostat).

To stop the machine:

- 1) Put in all motor resistance by turning the rheostat to the left.
- 2) Push armature resistance rheostat all the way to the left.

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Procedure:

Test the fan at three different speeds. For each speed take measurements at each of the five exit openings. (open, 2/3, 1/2, 1/3, closed). For each run measure the velocity pressure and the total pressure at three different positions across the diameter of the duct and average them. (For a duct with laminar flow, more readings should be taken and the readings plotted versus position in duct). To save time, first read all three velocity heads and then all three total heads.

Measurements:

- Velocity head
- Total head
- Discharge air temperature
- Discharge area
- Duct diameter
- Voltage
- Amperage
- Motor speed
- Pulley diameters
- Air velocity (using anemometer to check pitot tube readings)
- Barometric pressure
- Wet and dry bulb temperatures

Efficiencies of the motor for various loads are given in the table:

<u>LOAD (watts)</u>	<u>MOTOR EFFICIENCY (%)</u>
400	25
500	35
600	45.5
700	50
800	56
900	60
1000	63
1100	65
1200	66.5

For duct friction correction and general information on fan characteristics, consult:

Kent's Handbook, Power Sect. I-55 and I-82

Requirements:

Determine:

- Capacity
- Air HP
- Fan efficiency
- Static fan efficiency
- Overall efficiency
- Volumetric efficiency

Plot:

- Discharge pressure
- Air horsepower
- Fan efficiency
- Overall efficiency

against

Capacity in CFM for each speed.

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TEST OF RADIAL FAN WITH FORWARDLY CURVED BLADES

Experiment No: FM. 07

Date of experiment: _____

Date of report: _____

Submitted by: _____

Submitted to: _____

Object: To determine the performance characteristics of a radial fan with forwardly curved blades.

Description of test set-up:

- a) Fan: Forward blade centrifugal fan
48 Blades
Held at center by 6 triangular blades
- b) Fan motor: Societe Provinciale, Marseilles, France
volts: 220, amp.: 22, rpm: 2000
- c) Induction motor: General Electric Co.
volts: 220, amp: 26, rpm: 1065
HP: 10
- d) Generator: Electro Dynamic Co., Bayonne, N.J
volt: 80, amp.: 56, rpm: 700, Kw.: 4.5

Accessories used:

- a) Chronometer
- b) Wind speed measuring instrument
- c) Ellison draft gage
- d) Thermometer

Procedure:

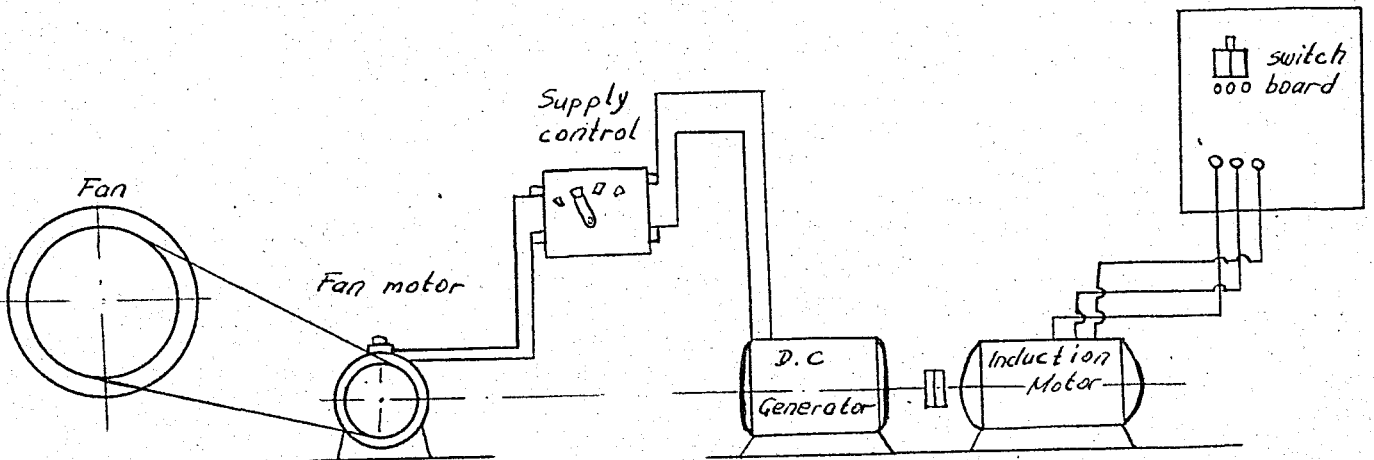
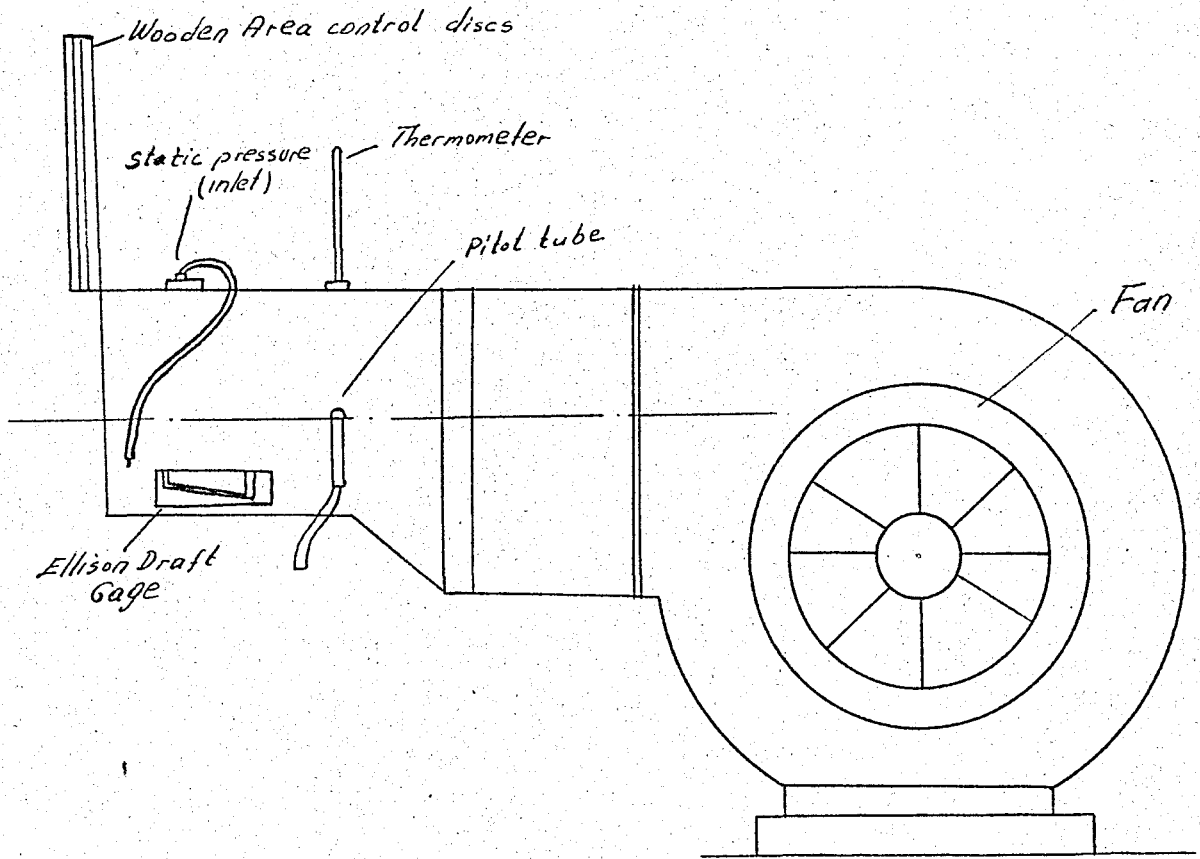
The fan was tested at two speeds. For each speed measurements at each of the five exit openings (open, 2/3, 1/2, 1/3, closed) were taken. Velocity pressure and total pressure was measured for each run, for three different positions across the diameter of the duct, and they were averaged. Readings were taken for laminar flow conditions and they were plotted against position in duct.

First all three velocity heads were read and then the three total heads.

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Data:

		VELOCITY PRESSURE " OIL		TOTAL PRESSURE " OIL		STATIC PRESSURE " OIL		FAN SPEED RPM	MOTOR SPEED RPM	DISCH. TEMP. °C	ROOM TEMP. °C	WIND SPEED M/min
<u>Part I</u>												
open	1	0.17	0.16	0.29	0.29	0.25	0.26	141	703	21.2	21.6	477
		0.16	0.16	0.29	0.29	0.25	0.25					
2/3	2	0.13	0.12	0.29	0.29	0.27	0.27	140	700	"	"	481
		0.13	0.13	0.29	0.29	0.27	0.27					
1/2	3	0.10	0.11	0.30	0.30	0.30	0.29	140	700	"	"	500
		0.10	0.10	0.30	0.30	0.30	0.29					
1/3	4	0.10	0.09	0.30	0.30	0.31	0.31	141	701	"	"	500
		0.09	0.09	0.31	0.31	0.31	0.31					
closed	5	0.10	0.10	0.32	0.32	0.32	0.31	143	703	"	"	0
<u>Part II</u>												
	1	0.21	0.21	0.5	0.49	0.41	0.41	196	980	20.5	21.6	655
		0.19	0.19	0.48	0.47	0.38	0.39					
	2	0.16	0.16	0.48	0.49	0.45	0.46	197	987	"	"	650
		0.15	0.15	0.49	0.49	0.45	0.46					
	3	0.14	0.14	0.50	0.51	0.49	0.49	196	978	"	"	726
		0.14	0.14	0.51	0.50	"	"					
	4	0.11	0.11	0.51	0.51	0.52	0.51	195	976	"	"	785
		0.10	0.10	0.50	0.51	0.51	0.51					
	5	0.10	0.10	0.51	0.51	0.51	0.51	193	975	"	"	0

Zero reading Pitot tube : 0.1"

Specific gravity of oil : 0.834

Duct diameter : 34.5 cm

Voltage : 74 v.

Amperage : 8.6 amp.

Pulley diameter₁ : 89 cm.

Pulley diameter₂ : 18 cm.

Barometric pressure : 29.3 "Hg.

Humidity:

wet dry

19 21

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Average values:

Part I	RUN	VELOCITY PRESSURE "oil	TOTAL PRESSURE "oil	STATIC PRESSURE "oil
	1	0.062	0.190	0.155
	2	0.050	0.190	0.170
	3	0.010	0.200	0.190
	4	0.005	0.205	0.210
	5	0	0.220	0.220

Part II

1	0.100	0.385	0.285
2	0.050	0.390	0.350
3	0.045	0.405	0.390
4	0.010	0.410	0.410
5	0	0.414	0.408

Calculations :

Discharge capacity:

Area (m ²)		2/3 A	1/2 A	1/3 A
$\frac{(0.345)^2}{4}$	=0.0935	0.0624	0.0467	0.0312

$$Q = A \cdot V$$

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- | | | | | |
|--|----------|---|-----|--------------------------------|
| 1) $Q = 0.935 \times 477 = 44.6 \text{ m}^3/\text{min.}$ | \times | " | $=$ | 1570 $\text{ft}^3/\text{min.}$ |
| 2) $Q = 0.0624 \times 481 = 30$ | \times | " | $=$ | 1060 |
| 3) $Q = 0.0467 \times 500 = 23.4$ | \times | " | $=$ | 825 |
| 4) $Q = 0.0312 \times 500 = 15.6$ | \times | " | $=$ | 550 |
| | | | | |
| 1) $Q = 0.935 \times 655 = 61.2$ | \times | " | $=$ | 2160 |
| 2) $Q = 0.0624 \times 650 = 40.5$ | \times | " | $=$ | 1430 |
| 3) $Q = 0.0467 \times 726 = 33.9$ | \times | " | $=$ | 1200 |
| 4) $Q = 0.0312 \times 785 = 24.5$ | \times | " | $=$ | 865 |

Correction factor:

Reference:
ASTM Fan test Code

$$Q_a = Q_d \frac{l_a}{l_d}$$

where:

$$l_a = \frac{P_a - 0.38 P_p}{0.754 T_a}$$

$$T_a = \text{Air temperature} = 21.6^\circ\text{C} = 70.8^\circ\text{F} = 530.8^\circ\text{R}$$

$$0.754 T_a = 0.754 \times 530.8 = 400$$

$$P_a = \text{Air pressure} = 29.98 \text{ "Hg.}$$

$$P_p = P_g - \frac{P_g (t_a - t_w)}{2700}$$

$$t_a : \text{Dry bulb temperature} = 21.6^\circ\text{C} = 69.8^\circ\text{F.}$$

$$t_w : \text{Wet bulb temperature} = 19^\circ\text{C} = 66.2^\circ\text{F.}$$

$$t_a - t_w = 69.8 - 66.2 = 3.6^\circ\text{F.}$$

$$P_g : \text{Saturated vapor pressure} = 0.7802 \text{ "Hg}$$

$$P_p = 0.7802 - \frac{29.98(3.6)}{2700} = 0.7802 - 0.04 = 0.7402 \text{ "Hg}$$

$$0.38 P_p = 0.38 \times 0.7402 = 0.282$$

$$l_a = \frac{29.98 - 0.282}{400} = 0.0723$$

$$l_d = l_a \frac{P_a + (P'_s / 13.6)}{P_a} (T_a / T_d)$$

$$l_a = 0.0723$$

$$P_a = 29.98 \text{ "Hg.}$$

$$T_a = 530.8^\circ \text{R}$$

$$T_d = \text{a) Part I : } 21.2^\circ \text{C} = 70 \text{ F} = 530 \text{ R}$$

$$\text{b) Part II: } 20.5^\circ \text{C} = 69 \text{ F} = 529 \text{ R}$$

$$\frac{T_a}{T_d} = \text{a) Part I : } 530.8/530 = 1.01$$

$$\text{b) Part II : } 530.8/529 = 1.02$$

$$\frac{P'_s}{13.6} = \text{Static pressure}$$

$$1) 0.155 \times 0.834/13.6 = 0.00950 \text{ " Hg}$$

$$2) 0.170 \times \text{ " } = 0.01040$$

$$3) 0.190 \times \text{ " } = 0.01165$$

$$4) 0.210 \times \text{ " } = 0.01290$$

$$1) 0.285 \times \text{ " } = 0.0175$$

$$2) 0.350 \times \text{ " } = 0.0214$$

$$3) 0.390 \times \text{ " } = 0.0239$$

$$4) 0.410 \times \text{ " } = 0.0252$$

$\frac{l_a}{}$	\times	$\left[\frac{P_a + (P'_s/13.6)}{P_a} \right]$	$=$	$\frac{T_a}{T_d}$	$\frac{l_d}{}$
1) 0.0723	x	$I + \frac{0.0095}{29.98}$	=	1.01	0.0730
2) "	x	$I + \frac{0.0104}{29.98}$	=	"	"
3) "	x	$I + \frac{0.01165}{29.98}$	=	"	"
4) "	x	$I + \frac{0.0129}{29.98}$	=	"	"

Since the value of $\frac{P_a + (P'_s / 15.6)}{P_a}$, is very small for part two

$$l_d = 0.0723 \times 1.02 = 0.0736$$

$$l_a/l_d = \begin{matrix} \text{a) Part I} = 0.0723/0.0736 = 0.99 \\ \text{b) Part II} = 0.0723/0.0736 = 0.98 \end{matrix}$$

Part I

- 1) $Q = 1570 \times 0.90 = 1550 \text{ ft}^3/\text{min.}$
- 2) $Q = 1060 \times " = 1050$
- 3) $Q = 825 \times " = 816$
- 4) $Q = 550 \times " = 545$

Part II

- 1) $Q = 2160 \times 0.98 = 2120$
- 2) $Q = 1430 \times " = 1400$
- 3) $Q = 1200 \times " = 1175$
- 4) $Q = 865 \times " = 846$

Air Horsepower:

$$HP_a = \frac{5.193 Q h t}{33000}$$

Part I

	$\frac{5.193 Q}{33000}$	$h t$	HP_a
1) $5.193 \times 1550 = 8050$	$0.19 \times 0.834 = 0.1585$		$\frac{0.0386}{0.1585}$
2) " $\times 1050 = 5450$	$0.19 \times " = 0.1585$		$\frac{0.0261}{0.1585}$
3) " $\times 816 = 4240$	$0.20 \times " = 0.1670$		$\frac{0.0214}{0.1670}$
4) " $\times 545 = 2830$	$0.205 \times " = 0.1710$		$\frac{0.0147}{0.1710}$

Part II

1) " $\times 2120 = 11000$	$0.38 \times " = 0.321$		$\frac{0.1070}{0.321}$
2) " $\times 1400 = 7250$	$0.39 \times " = 0.325$		$\frac{0.0714}{0.325}$
3) " $\times 1175 = 6100$	$0.40 \times " = 0.338$		$\frac{0.0625}{0.338}$
4) " $\times 846 = 4400$	$0.41 \times " = 0.342$		$\frac{0.0456}{0.342}$

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Fan efficiency:

$$\epsilon = \frac{\text{Air HP}}{\text{BHP}}$$

$$\text{BHP} = \text{EI} \cdot \epsilon = 74 \times 8.6 \times 0.478 = 304 \text{ watts}$$

where: $\epsilon = 0.478$ for a 635 watt load, therefore:

$$\text{BHP} = 304 \times \frac{\text{HP}}{746} = 0.407 \text{ Hp}$$

Part I

	<u>Air HP</u>	<u>BHP</u>	<u>Efficiency</u>
1)	0.0386	0.407	0.095
2)	0.0261	"	0.064
3)	0.0214	"	0.0525
4)	0.0147	"	0.0360

Part II

1)	0.1070	""	0.262
2)	0.0714	""	0.175
3)	0.0625	""	0.154
4)	0.0456	""	0.112

Static fan efficiency:

$$E_s = \frac{Q_a P_s}{6356 P}$$

$$6356 P = 6356 (0.407) = 2600$$

Part I

	<u>Q_a</u>	<u>P_s</u>	<u>E_s</u>
1)	1550	0.155x0.834=0.1290	200/2600 = 0.0770
2)	1050	0.170x " =0.1420	149/2600 = 0.0573
3)	816	0.190x " =0.1585	129/2600 = 0.0495
4)	545	0.210x " =0.1750	95.5/2600= 0.0368

Part II

1)	2120	0.285x " =0.238	305/2600 = 0.194
2)	1400	0.350x " =0.292	410/2600 = 0.158
3)	1175	0.390x " =0.325	382/2600 = 0.147
4)	846	0.410x " =0.342	290/2600 = 0.112

Overall efficiency:

$$E_o = \frac{Q_a \times P_t}{6356 P} \quad , \text{where: } P_t = \text{Total pressure}$$

$$6356P = 6356(0.407) = 2600$$

Part I

	Q_a	P_t	E_o
1)	1550	0.1585	$246/2600 = 0.0945$
2)	1050	"	$166.5/2600 = 0.0640$
3)	816	"	$136/2600 = 0.0524$
4)	545	"	$93/2600 = 0.0358$

Part II

1)	2120	0.321	$680/2600 = 0.262$
2)	1400	0.325	$455/2600 = 0.175$
3)	1175	0.338	$396/2600 = 0.152$
4)	846	0.542	$289/2600 = 0.115$

Volumetric efficiency:

$$E = \frac{Q_a}{\pi r^2 w n}$$

, where: n = RPM of fan

r = Radius of fan wheel = 1.5 ft

$$r^2 = (1.5)^2 = 2.25$$

w = Width of fan wheel = 1.7 ft.

$$r^2 w = 3.14 \times 1.7 \times 2.25 = 12$$

Part I

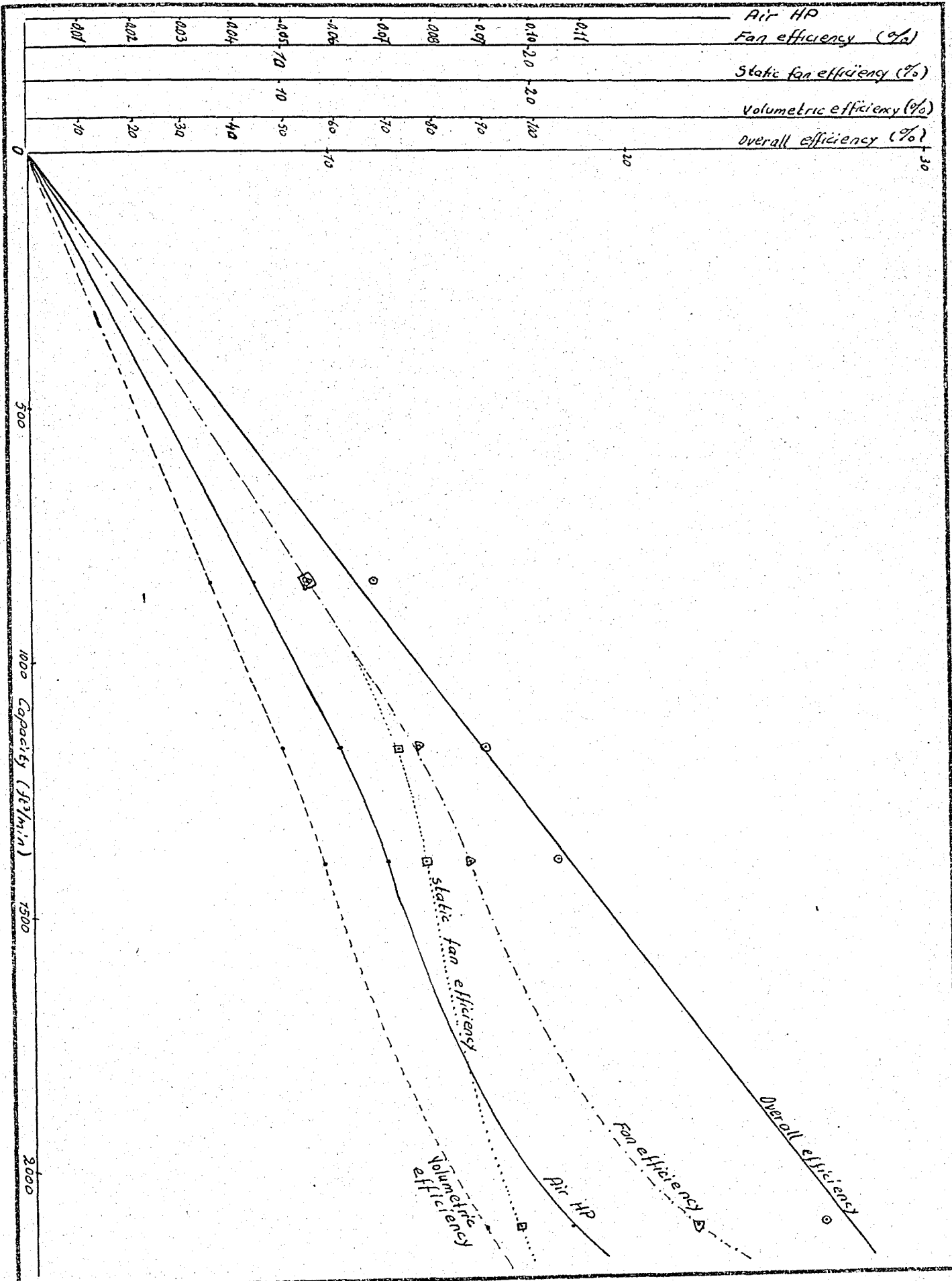
	$\pi r^2 w$	Q_a/n	Efficiency
1)	12	$1550/141 = 11$	0.916
2)	"	$1050/140 = 7.5$	0.625
3)	"	$816/140 = 5.85$	0.485
4)	"	$545/141 = 3.87$	0.322

Part II

1)	"	$2120/196 = 10.8$	0.900
2)	"	$1400/197 = 7.1$	0.591
3)	"	$1175/196 = 6.0$	0.500
4)	"	$846/195 = 4.34$	0.362

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Table of Results

Run	Capacity ft ³ /min	Air HP	Fan eff. %	Static fan eff. %	Overall eff. %	Volumetric eff. %
<u>Part I</u>						
I	1550	0.0386	9.5	7.7	9.45	91.6
2	1050	0.0261	6.4	5.73	6.4	62.5
3	816	0.0214	5.25	4.95	5.24	48.5
4	545	0.0147	3.6	3.68	3.58	32.2
5	0	0	0	0	0	0
<u>Part II</u>						
I	2120	0.1070	26.2	19.4	26.2	90
2	1400	0.0714	17.5	15.8	17.5	59.1
3	1175	0.0625	15.4	14.7	15.2	50
4	846	0.0456	11.2	11.2	11.5	36
5	0	0	0	0	0	0

Conclusion:

Graphs of discharge pressure, air horsepower, fan efficiency and overall efficiency are plotted versus the flow, expressed in cfm.

Fan speed, being a test requirement, remained approximately constant at each run, which resulted in a constant air supply at constant velocity for the same cross-sectional area.

An examination of the table of results, leads to the following conclusions:

- 1) Capacity decreases as the area of flow is reduced.
- 2) The capacity of part I, is less than of part II, due to the low rpm of part I. It is thus obvious that higher amounts of air is discharged at higher fan speeds.
- 3) The overall efficiency decreases with decreasing fan rpm and decreasing outlet cross-sectional area.
- 4) The volumetric efficiency seems not to be affected by the fan rpm, but decreases with decreasing area.
- 5) Since there are not enough points between the positions of, 1/2 open and closed, these 2 points are approximated by a straight line.

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An important point to be noticed, in the experiment is that, the sum of the static and velocity pressures obtained by the test, does not check with the total pressures measured. This condition introduces errors into the calculations. To decrease the degree of errors and for consistency, the measured total pressures are used in the calculations.

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PART II

THE DESIGN OF THE NEW MECHANICAL ENGINEERING
FLUID MECHANICS AND HYDRAULICS LABORATORY

The design of a laboratory has to fulfill certain requirements and structural features. These will be presented individually.

LOCATION

The new R.C-M.E Fluid Mechanics and Hydraulics Laboratory, is recommended to be constructed in the place of the M.E laboratory, in the old engineering building. Reasons for this suggestion depend on factors, such as:

- 1) There are certain machines and equipment already installed in the room.
- 2) Power lines and distribution systems exist. (even though they need to be repaired and renewed).
- 3) Water supply is available and disposal system is present.
- 4) There is a) an instructors room
b) space for a stock room.
- 5) Changes in the building, and renewal of the old equipment can be accomplished cheaply and easily.

CONSTRUCTURAL FEATURES

The selection of construction materials for floors, walls and ceilings of a present day laboratory is influenced by a large number of factors. The order of importance of any one consideration varies for each different laboratory. Beside the commonly recognized conditions, as the method of distributing services within a laboratory, the lighting arrangements, heating, furniture, air-conditioning, etc. are other requirements to be met properly.

Unusual conditions occur in laboratory design so often that, they may be termed as individual conditions, in addition to those conditions which are common to all labs, termed as standard conditions.

Interior structural materials must be selected in the light of all known conditions, both standard and individual.

The kind of work to be done in the laboratory is the primary factor affecting the choice of interior surfaces and their construction methods.

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To the already existing multiple considerations, other additional factors such as, cost, maintenance, length of life, corrosion resistance, strength, hardness, ease of cleaning, acoustics of material and the value of finer appearance must be added.

Under the light of the above considerations, the following recommendations can be stated for the different parts of the building.

1) Ceiling, walls and floor:

Ceiling and the part of the walls above 1 1/2 meters will be painted in white. Lower portions of the walls will be in gray. The floor will be covered by square shaped "marley" pieces, of gray, white and black, changing alternately.

2) Noise:

Noise within or outside the laboratory requires careful choice of the materials to be used in the renewal of the laboratory. (This point is mentioned as a requirement which the architect should take into consideration)

3) Vibration:

Foundations suitable for absorbing vibration and resisting the weight of common laboratory apparatus already exist in the hall. This problem has been dealt with, at the time the building was erected.

4) Electric power:

In the laboratory electric power is required for stationary equipment, portable equipment and specially built in apparatus.

Most of the equipment will require A-C power, which will be taken from the city mains.

There are some instances where D-C current will be needed in several common voltages.

D-C power will be provided by either of :

- a) Storage batteries
- b) Motor-generator sets
- c) Rectifiers
- d) Synchronous converters

Special installations have to be arranged in the future, if a compressible flow wind tunnel is constructed.

5) Distribution system:

In the distribution system, service feeders should extend from switchboard to each of the electric shafts in the building. The feeders may be run in conduits or wiring through with pull boxes at proper places for easy and practical useage . Sub feeders, protected by fusible disconnect switches, cut-cut or circuit breakers. In each room, installation of branch circuit panel boards , is wise where central control is required.

In many cases it is important that power should not be interrupted during an experiment.

6) Lighting:

Satisfactory seeing requires not only a comfortable visual environment but also suitable visibility characteristics of the tasks .

In laboratories the eyes are not only used closeup visual tasks, but also for other tasks involving relatively more distant viewing such as chalk boards.

The following points are recommended for laboratory illumination:

a) Lighting at work benches should be about 50 foot-candles.

b) Diffused light giving a good intensity of illumination on vertical surfaces so as to make it easy to read instruments such as meters, pipettes and the like.

c) Fluorescent lamps are preferable to incandescent lamps because they provide diffused light sources and also because they provide more lumens per watt and therefore more light per operating TL.

In the lectric design direct glare should be avoided and uniform illumination should be provided.

The system of lighting of the laboratory should be of the "direct lighting" type.

7) Heating and Air-conditioning:

A) Heating:

Heat will be supplied to the laboratory from the central heating system of Robert College.

B) Air-conditioning:

1) Dust:

The type and the amount of dust, with the necessity of cleanliness will affect the choice of the interior materials.

Moisture:

Moisture present in the unusual amounts in the air can have a very bad effect upon surrounding structural materials, particularly if corrosive agents are present.

Ventilation:

The function of ventilation is to maintain a low concentration of atmospheric impurities that may be generated within the space, or to prevent the build-up of immoderate temperatures. The contaminants in rooms where people congregate are body odors, body heat, water vapor and tobacco smoke.

There are basically two mechanisms whereby ventilation accomplishes the desired conditions. One is general ventilation and the other local exhaust, wherein the contaminant is withdrawn at its point of origin by an air exhaust system for discharge to the exterior. The enclosed hoods used in laboratories operate on this basis.

Air motion and summer-air conditioning should also be provided.

The practical basis for the ventilation of laboratories is the provision of adequate hoods.

Average face velocity for hood ventilation should be 50-60 ft/min., but laboratory furniture manufacturers consider 60-80 ft/sec as an advisable figure.

8) Water supply:

Water will be taken from the college main water-system. The necessary pipe connections for the water to come to the building exist.

9) Waste water disposal:

Waste and dirty water will be disposed into the schools main sewage system, which already has a connection to the laboratory building at present.

GENERAL NOTES AND COURSE POLICY

1) Objectives of the laboratory work:

The objectives of the laboratory, are to strengthen and supplement the lecture and recitation, by direct experience with fluid behavior, fluid flow phenomena, and to make the student be aware of basic measuring techniques in fluid mechanics and finally the operational characteristics of fluid machinery.

2) Laboratory notebook:

All work will be done on 22 x 29.5 cm. standard sheets. Each report will be stapled together and submitted with a "Report title sheet" as the first page. Each student will be issued an Acco clip and as corrected or graded work is returned to him, he will punch it and fasten it together with the most recent work on top.

3) One period experiments:

The reports for the one period experiments will consist of calculations, results and answers to specific questions. These reports will be graded as satisfactory or unsatisfactory. Reports marked unsatisfactory, must be reworked and resubmitted, one week after they are returned to the student.

Reports will be marked 'unsatisfactory' if calculations are seriously wrong, answers are wrong or incomplete or if there are several errors in grammar, punctuation or spelling.

4) Two period experiments:

The two period experiments will require complete reports which will be written according to the report form as recommended by the ASME Power Codes.

5) Laboratory grade:

The laboratory grade reported to the recitation instructor will be based upon:

- a) The grades on the two period experiments, and
- b) The satisfactory completion of all experiments.

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R.C FLUID MECHANICS AND HYDRAULICS LABORATORY

REPORT TITLE SHEET

Experiment No. _____

Reported by _____

Partners _____

Grade: + satisfactory
- improvement is needed

Organization & Neatness	Accuracy	Discussion (if required)	Overall Grade (if assigned)

Grader's comments:

REPORT FORMS

The following rather comprehensive form of report is recommended by the ASME Power Codes:

- A- Title page
 - 1) Name of experiment
 - 2) Submitted by
 - 3) Submitted to
 - 4) Submitted on
- B- Table of contents
- C- Summary
 - 1) Object
 - 2) Results
 - 3) Conclusions
 - 4) Recommendations
- D- Description of apparatus tested
 - 1) Sketch of test set including all instruments at their places.
- E- Methods of testing
 - 1) Location
 - 2) Conditions of operation
 - 3) Arrangement
 - 4) Method of using instruments
 - 5) Method of using testing apparatus
 - 6) Factors held constant
 - 7) Number and duration of trials
 - 8) Frequency of readings
 - 9) Conformance with the standard test codes when appropriate
- F- Sample calculations
 - 1) Indication of the number of run
 - 2) Statement of the appropriate relation for the calculation of the item.
 - 3) Statement of each constituent of the relation in words and its value as shown on the data sheet with its proper unit.
 - 4) Application of the relation
 - 5) Giving the answer on the right hand side of the

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the report and underlying it.

- 6) Using the same method for the calculation of the rest of the items

G- Discussion of data and results

- 1) Discuss the accuracy of data and the results
- 2) Their bearings on the object of the test including,
 - a. Statement of facts or evidence
 - b. Opinion of the tester
- 3) Results should be analysed and their significance be interpreted.
- 4) Explanation of errors or apparent discrepancies
- 5) Report of any unusual occurrences observed during the test.

H- Tables and graphs of data and results

- 1) Table of results
- 2) Graphical results in ink.

I- Appendixes

- 1) References
- 2) Original data sheet
- 3) Method of calculation
- 4) Calibration data if present
- 5) Description of special testing apparatus
- 6) Instruction sheets
- 7) Results of preliminary or special tests.

LABORATORY OPERATIONAL INSTRUCTIONS

For the conductance of successful laboratory work, the student is recommended to take notice and follow the listed regulations both for his safety and for the orderly performance of the experiments.

A- Before the experiment:

Before operating any equipment be sure to know :

- 1) What is to be done
- 2) Why it is done
- 3) How it is done

B- Performance:

1) Errors (To be kept at minimum)

- a. Personal observation errors
- b. Accidental errors
- c. Instrumental errors
- d. Method errors

2) Original data sheets should contain:

- a. Date of performance
- b. Group leader and group members
- c. Barometric pressure and temperature
- d. General data
- e. Specific data
- f. Name plates of tested machinery and instruments.

C- Precautions:

The following precautions should be taken during the performance of an experiment, against:

- a. Carelessness during the experiment time.
- b. Starting and stopping experiments.
- c. Incorrect use of instruments.
- d. Interval between runs.
- e. Unavoidable conditions.

D- Emergency cases:

In the case of unfortunate small injuries, the "First aid box" in the laboratory will be used.

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ME FLUID MECHANICS and HYDRAULICS LABORATORY

TEXT REFERENCES

Text: Mechanics of Fluids, I.H. Shames, Mc Graw-Hill Co., 1962.

<u>Experiment Title</u>	<u>Reference</u>
Manometer study	Art. 3-1 to 3-2
Flow patterns in smoke tunnels	Chapter 4
Wind tunnel velocity measurements	
Pressure distribution around a cylinder	Art. 5-15 to 5-17, 8-16
Laminar and turbulent flow	Art. 10-1 to 10-2
Pipe friction	Art. 10-7 , 10-12
Viscosity measurement	Art. 10-9
Drag measurement	Art. 11-9
Lift measurement	Art. 5-17, 11-7 to 11-9
Limiting pipe flow	Art. 13-9, 13-17
Converging nozzle study	Art. 13-2, 13-5, 13-14
Boundary layer study	Art. 11-1, 11-2, 11-7
Schlieren study	Art. 13-12 to 13-13
Momentum study :Jet deflection	Art. 5-3 to 5-5'
Force on elbow	Art. 5-3 to 5-5
Forced vortex study	Art. 5-6

Other useful reference books:

Mechanical engineering laboratory by Lessersmith and Werner

Fluid Mechanics by Cox and Germano

Fluid Mechanics by Vennard

ASME stds., Codes and Reports Binder I and 2 , Library No: 621.1 Am

3 Pl

Mechanical engineering Lab. Methods by Smallwood and Keator

Experimental Mechanical Engineering by Diederichs and Andrae, 621-D5

OUTLINE OF EXPERIMENTS

- A- Demonstrative experiments
 - a) Water table
 - b) Flow patterns

- B- Manometer study
 - a) Measurement of atmospheric pressure
 - b) Pressure measurements by manometers
 - c) Pressure measurements by Bourdon tube, diaphragm and
 Bellows pressure elements
 - d) Measurement of flow by Pitot tube

- C- Pipe flow and flow metering
 - a) Measurement of flow by volumetric flow meters
 - b) Measurement of flow by rate meters, rotameter
 - c) Measurement of flow by variable head meters
 Venturi, flow nozzle, orifice plate
 - d) Types of pipe flow
 - e) Pipe friction
 - f) Limiting pipe flow
 - g) Velocity and pressure drop for isothermal flow
 in a tube

- D- Momentum study
 - a) Jet deflection
 - b) Force on elbow

- E- Viscosity measurements
 - a) Viscosity measurement of water by the capillary tube
 method.

- F- Wind tunnel and compressible flow experiments
 - a) Velocity measurements
 - b) Pressure distribution around a cylinder
 - c) Drag measurements
 - d) Boundary layer study
 - e) Compressible flow in a converging nozzle
 - f) Schlieren study

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G- Flow in open channels

- a) Measurements in open channels and hydraulic jump

H- Fluid machinery

- a) Test of an air compressor
- b) Test of a triplex pump
- c) Test of a radial fan with forwardly curved blades
- d) Efficiency of a Pelton wheel

DEMONSTRATIVE EXPERIMENTS

In this category of experiments the student is intended to be introduced to the Fluid Mechanics and Hydraulics Laboratory.

In these first meetings of the laboratory introductory lectures in the lab. are necessary to be given by the instructor, in which various fluid phenomena, regulations for the use of the lab. and the performance of experiments, safety measures, required report forms, deadlines, regulations in handling completed work and the system of grading, should be emphasized.

Following the above introduction, two experiments carrying demonstrative character will be performed. These are:

FM. IC1	Water Table
FM. IC2	Flow Patterns

WATER TABLE

Experiment No: FM IOI

Object: To study laminar and turbulent flow, surface waves and two and three dimensional flow past various bodies.

Theory: A water table is essentially a broad, flat, nearly level surface over which water may flow. The table has glass sides and bottom, making it ideal as a visual aid to various phenomena in fluid mechanics.

Description:

It necessarily consists of (starting from the upstream end), a manifold to distribute the incoming water, a reservoir or settling chamber, a transition section, a flat surface with two side walls (the working section), and a downstream catch basin.

The distinguishing features of the water table are as follows :

1. The reservoir is two feet long and is a minimum of seven inches deep. The transition section is twelve inches in length and has a minimum radius of curvature of eight inches. These dimensions permit operation at high flow rates with a minimum of disturbances from upstream.

2. The sides of the reservoir are constructed of aluminum with grooves, so that flow straighteners and wave suppressors may be inserted without introducing flow disturbances at the sides.

3. The glass side walls are eight inches high and extend seven feet from the beginning of the transition section to the catch basin. Again there is a minimum of wall disturbances.

4. Metal to glass and glass to glass seals are made, using "O" ring cord and clamping. They provide very tight maintenance free seals and enable easy replacement of any of the glass, if necessary.

5. The bottom glass plate (six ft. by four ft.), is positioned above all the metal parts so that there is no visual obstructions from the top or sides. Except for the two-inch channel supporting the bottom glass along its periphery, there are no visual obstructions from the bottom. These features give the maximum possible flexibility to viewpoint and lighting.

6. All four corners of the table may be adjusted for height and leveling. The downstream end is lowered or raised with a crank, depending upon the slope needed for the desired flow test.

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Usage: The Water Table will be used both for visual demonstrations and as a student performed laboratory experiment. Some of the phenomena observed are: Gravity and capillary waves, hydraulic jumps and other analogies to compressible flow of gases, growth of boundary layers and skin friction, transition from laminar to turbulent flow and the growth of turbulence. Accessories can be built for the Water Table for the use of the hydrogen bubble technique of flow visualization. Very small hydrogen bubbles are produced on a submerged wire and act as tracers in the flow.

Two students, working together, do the lab. work. One of them writes the report and the other writes a criticism of it.

Procedure:

A) Laminar and turbulent flow

1. At two laminar flow rates find the relation between depth of flow and angle. Measure the mass flow rate and temperature of the water. Measure depth of flow as a function of distance down the table.

2. Increase the flow rate and find the transitional Reynold's number.

3. Note effect of placing tripwire in the flow.

B) Surface Waves

1. Place various shapes in a laminar flow and observe gravity and capillary waves (measure the angles the waves make with the body). Record depth and flow rate. Repeat for another flow rate.

C) Flow visualization

1. Place short wire in downstream end of table and with hydrogen bubbles observe: (Be sure to make the appropriate measurements so that Reynold's number may be computed)

a) The flow past cylinders of different diameters above boundary layer.

b) The flow past a cylinder in the boundary layer

c) The flow past a flat plate. Pulse the bubbles to observe boundary layer growth

d) The flow past an airfoil. Use also a streamline generating bubble wire.

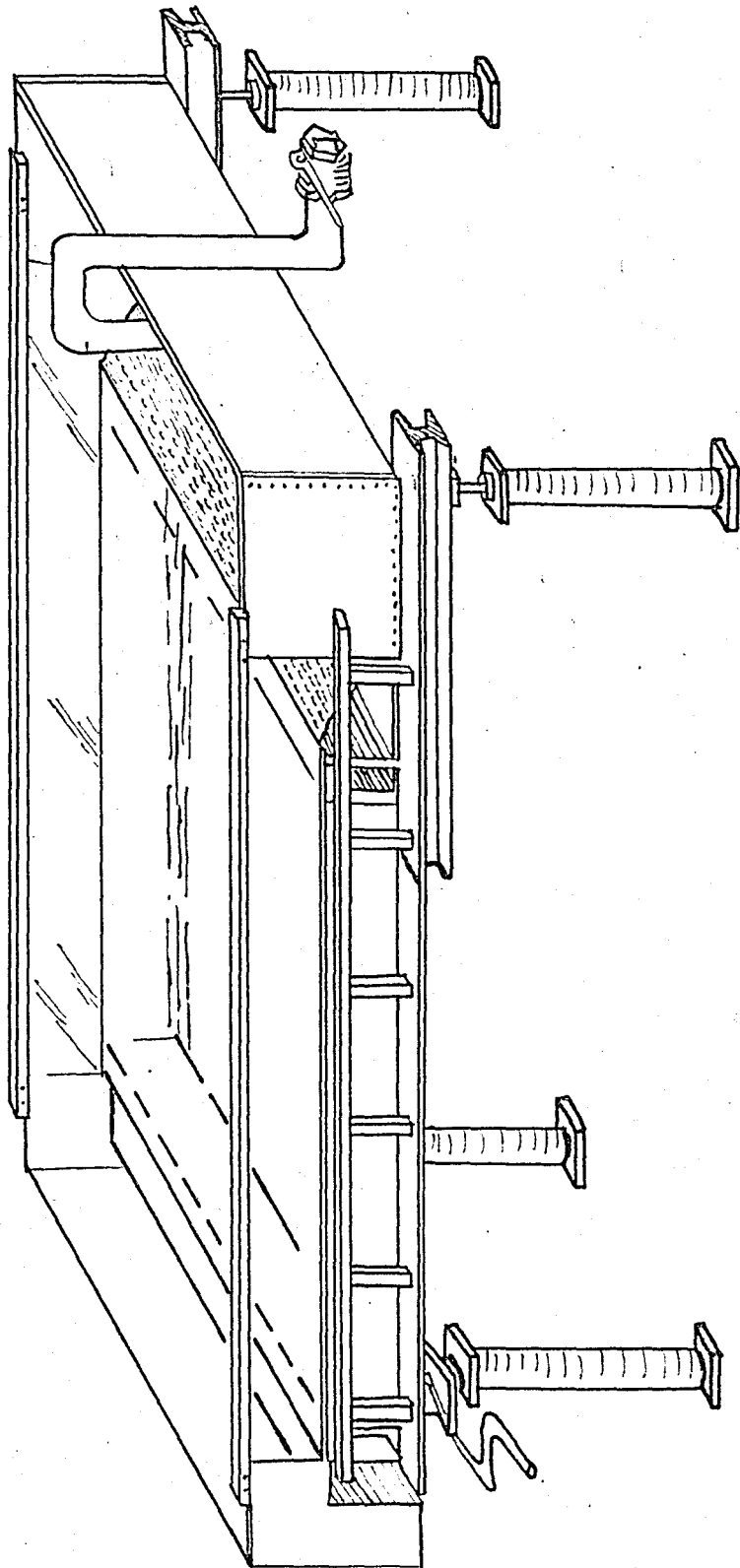
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Requirements:

- PART A) Compare experimental measurements with theory. Derive the necessary formulas.
- PART B) Measure the gravity wave speed by two methods and compare results. Discuss observations and relate to supersonic flow analogy.
- PART C) Discuss all observations.
-



WATER TABLE

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FLOW PATTERNS

Experiment No: FM 102

Object: The object of this experiment is to study the two dimensional flow patterns around several objects.

Reference: Shames, Mechanics of Fluids, Chapter 4.

Apparatus: Three smoke tunnels, each with a set of appropriate models, flow patterns sheets.

Performance of experiment:

1. The smoke tunnels will be operated by the instructor or the laboratory mechanic.
2. Pass out class notes, flow patterns sheets.
3. Each student should make a sketch of the flow pattern in each tunnel using the form provided.
4. By suitable notes and arrows indicate on each sketch the stagnation points, points of separation and highly turbulent areas.

General Remarks: A diagram showing the layout of the smoke tunnels is available in the lab. Students waiting to observe can examine the construction of the tunnels.

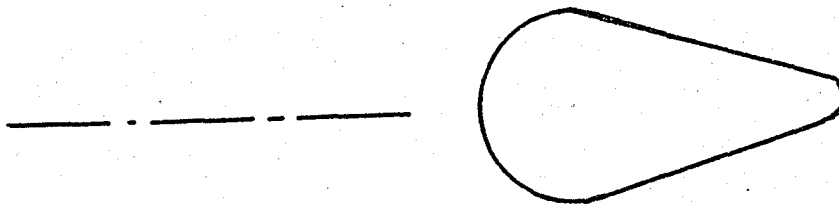
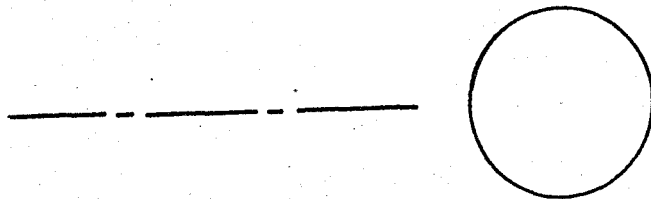
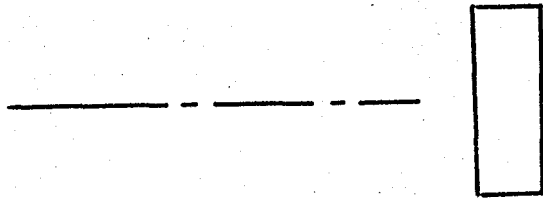
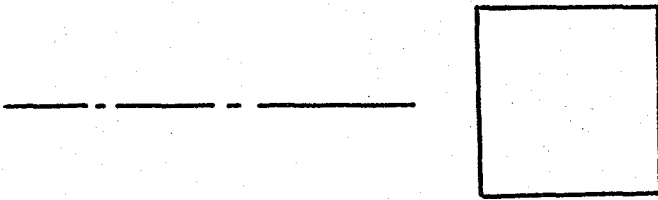
Report: The report is to consist of this instruction sheet, sketches of flow patterns with notes, the answers to following requirements:

- A) Discuss streamlines and path-lines
- B) Indicate application of continuity and energy equations to predict pressure and velocities from observed patterns of smoke lines.
- C) Discuss separation, turbulence, extent of wake, etc.
- D) Note that the flow of smoke is nominally 2-dimensional, but there are some 3-dimensional effects which should be recognized as such, particularly at the leading edges of the models.

Time allotted: One and one-half hours.

FM. EXP. 102 FLOW PATTERNS

NAME: _____



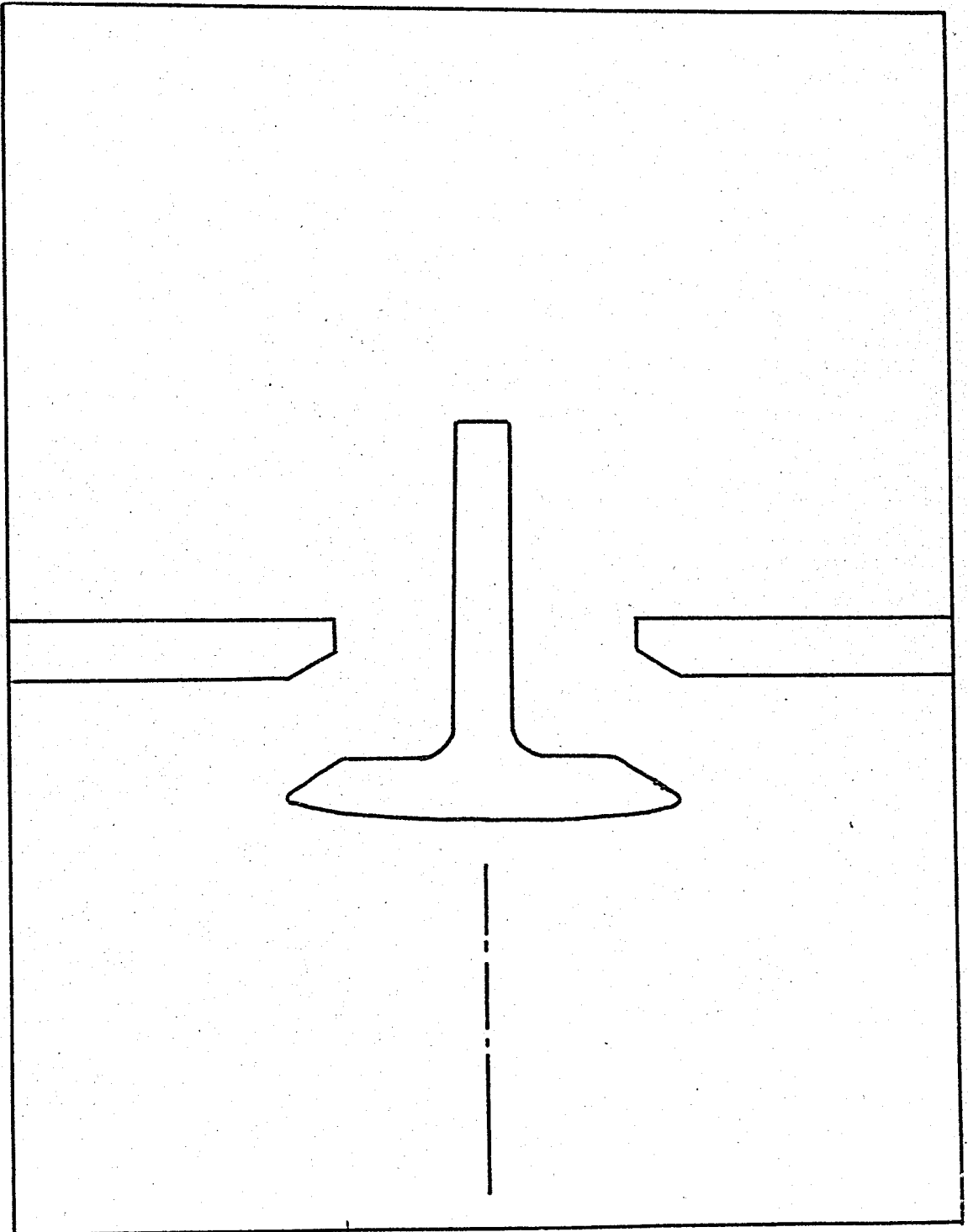
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FM. EXP. 102 FLOW PATTERNS

NAME:



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MANOMETER STUDY

In this category of laboratory experiments, the presentation is divided into two main groups, namely:

- a) Experiments for various individual measurements
- b) A combined experiment, including several or all of the above measuring techniques

The same idea will be followed by the author, in the presentation of other groups of experiments also.

In this category the individual experiments are:

- FM.201 Measurement of atmospheric pressure
 - FM.202 Pressure measurements by Bourdon tube, Diaphragm and Bellows pressure elements
 - FM.203 Pressure measurement by manometers
 - FM.204 Pressure measurement by the Pitot tube
-

The combined experiment is:

- FM.205 Manometer study

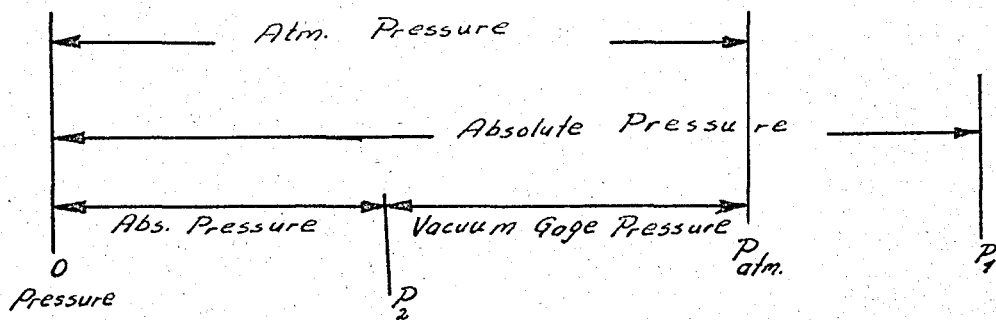
MEASUREMENT OF ATMOSPHERIC PRESSURE

Experiment No: 201

Object: Measurement of atmospheric pressure.

Theory: In pressure measurements, the pressure of atmosphere is used as the reference or known pressure. The instruments used in the measurement of atm. press. are called barometers.

The basic relations of atm. press. and other pressures is shown in the following diagram.



That is, when P_{abs} is greater than $P_{atm.}$:

$$\text{Absolute pressure} = \text{Atm. pressure} + \text{Gage pressure}$$

When P_{abs} is less than $P_{atm.}$:

$$\text{Absolute pressure} = \text{Atm. pressure} - \text{Gage pressure}$$

Liquid barometers have their reference ends subjected to vacuum, that is zero pressure and the other end is opened to free atmosphere. The most common type of liquid barometers are the well-type manometers. At the end of the tube vacuum is maintained and the reservoir is left open to atmosphere. In fig.1 a typical barometer is shown. Mercury is universally used as liquid in manometers. In order to keep constant level of mercury in the reservoir with respect to the scale, the following type, shown in fig.2 is used.

Ivory point is fixed at a given distance with respect to the scale. By adjusting the screw, it is possible to fix Hg level, just touching the ivory point, thus keeping the level constant all the time.

Possible accuracy obtained with such a barometer is within 0.005 to 0.01 in.

Standard barometric pressure is specified as 29.92 in. of Hg, (760 mm) at 0 deg.C and sea level. Corrections are needed for accurate readings. These are altitude, latitude and temperature corrections, usually given in tables.

Due to the existence of Hg vapor, the vacuum above the Hg column is not perfect, but since the vapor pressure of Hg at 0 deg.C is only 0.000185 mm and at 20 deg.C, 0.001201 mm., these can be considered as negligible for practical purposes.

Another apparatus to measure Atm. pressure is the aneroid barometer. It consists of an evacuated and hermetically sealed bellows and a mechanically connected pointer.

The movement of the bellows is transferred to the pointer, and it becomes possible to read barometric pressure directly. Accuracy is within 0.01 to 0.1 in. for properly handled and temperature compensated aneroid barometers. Schematic diagram is shown in Fig.3.

Apparatus:

- 1) Well type barometer
- 2) Aneroid barometer
- 3) Several correction charts

Procedure:

- 1) Take readings by the well type barometer
 - a) Adjust the level of mercury
 - b) Take readings using vernier
 - c) Make corrections for: Altitude, latitude, temperature
- 2) Compare these with aneroid barometer readings

Requirements:

- 1) Draw a temperature compensated aneroid barometer and explain fully.

FM. EXP : 201

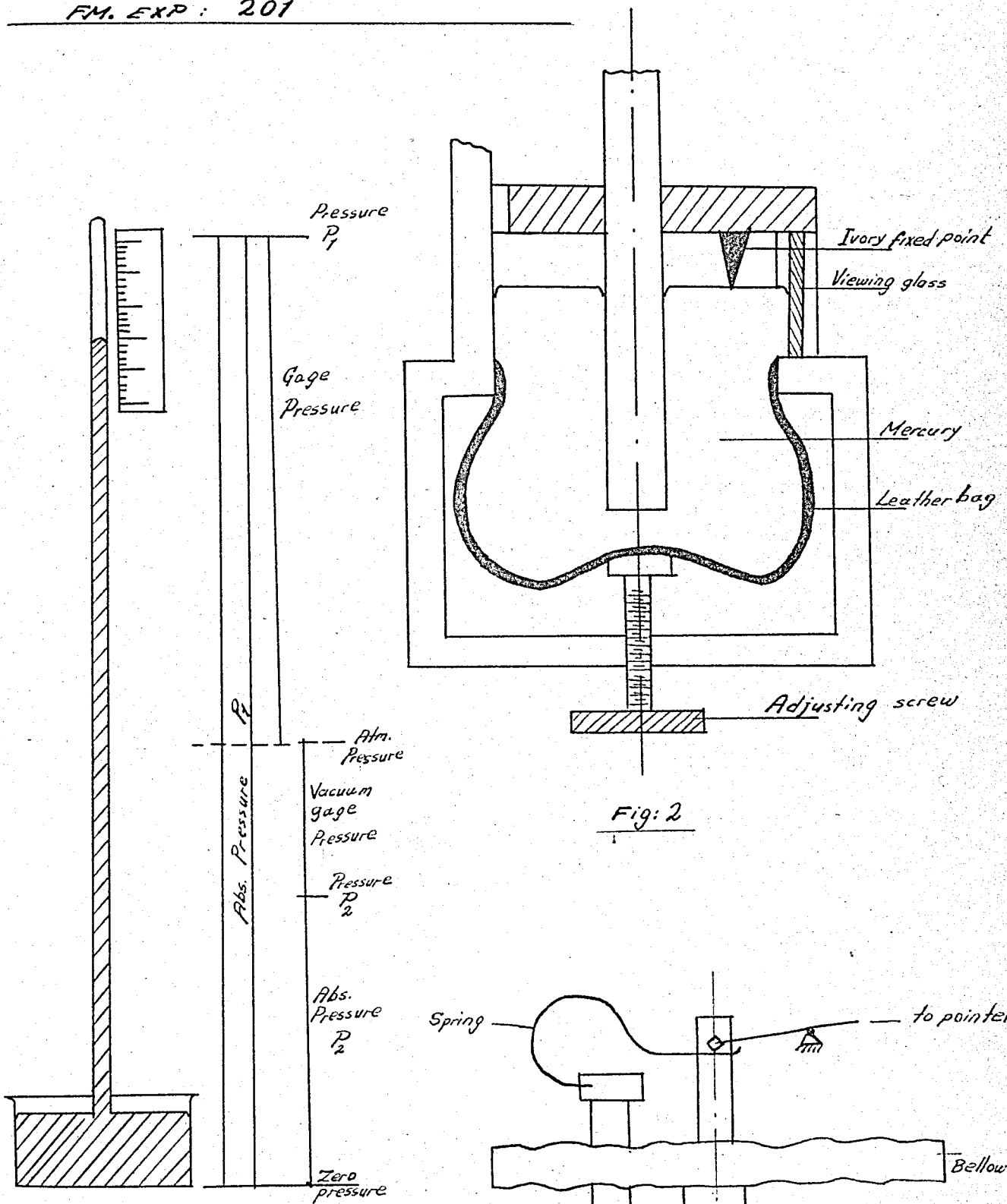


Fig:1

Fig:2

Fig:3

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PRESSURE MEASUREMENTS BY BOURDON TUBE, DIAPHRAGM, and BELLOWS PRESSURE ELEMENTS

Experiment No: PL. 202

Object: Pressure measurements by Bourdon tube, diaphragm and bellows pressure elements.

Theory: Bourdon tube is a circular tube with an elliptical cross-section constructed, either as a single turn or a coil. One end is closed and free, the other end is open but fixed in position. When a higher pressure than that of surrounding is applied to the tube the tendency will be to make the cross-section circular, which in turn will change the position of the free end with respect to the other end. This movement is transferred to a pointer by mechanical means. After a proper calibration direct reading of gage pressure is obtained. Schematic diagram is shown in fig. I. In the following table the material and the range of bourdon tube pressure elements are shown.⁽¹⁾

<u>Material</u>	<u>Range</u>
Bronze	600 psi
Beryllium-Copper	10000 psi
Steel or alloy steel	10000 - 20000 psi

The accuracy is not very high about $\pm 1\%$ of the readings beyond the first 5% of its scale. Its use is extensive, due to its compactness and ease of handling.

In fig. 2, a diaphragm pressure gage is shown schematically. Here the movement of the diaphragm due to pressure difference between the two sides of the diaphragm is transmitted to a pointer mechanically. The diaphragm is made of good quality leather, plastic or metal. Main point here to consider is to provide enough area for the diaphragm to function properly.

These gages are used for rather low pressure ranges or vacuum not greater than 5 psi. This is simply because the relation between diaphragm deflection and pressure difference becomes nonlinear quite soon.

In fig. 3, Bellows pressure element is shown. Usually metallic bellows work under the action of spring on one side and pressure on the other

(1) From Industrial Instrumentation by Donald P. Eckman, John-Wiley, 1957

side range is determined then by the spring constant and the net effective area of the bellows. For bellows construction: brass, phosphor bronze, beryllium copper, copper nickel alloy, silver clad brass, mild steel and monel are suitable metals. The range of their application is between 0.5 psi to 100 psi.

Cage calibration apparatus:

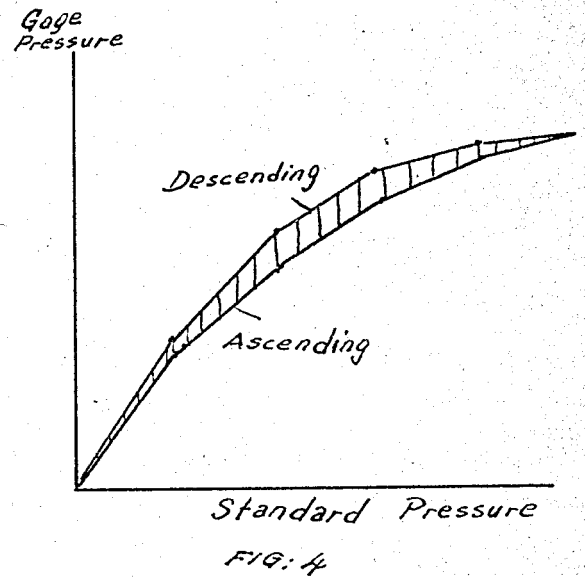
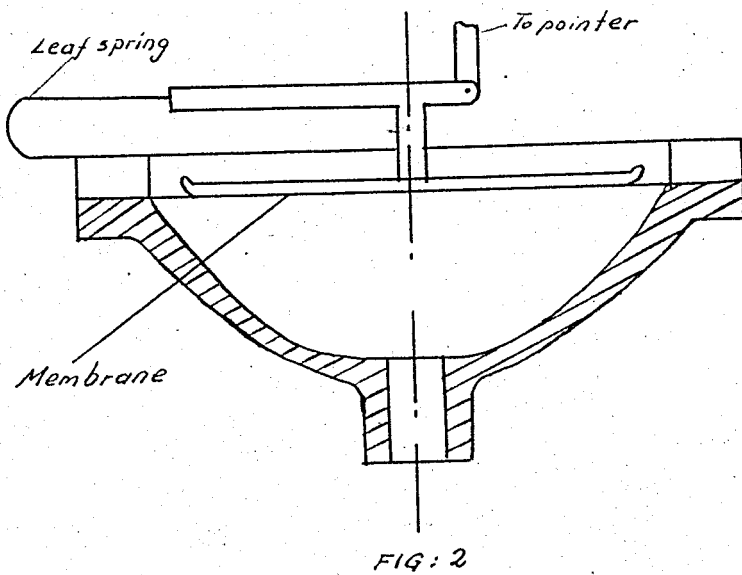
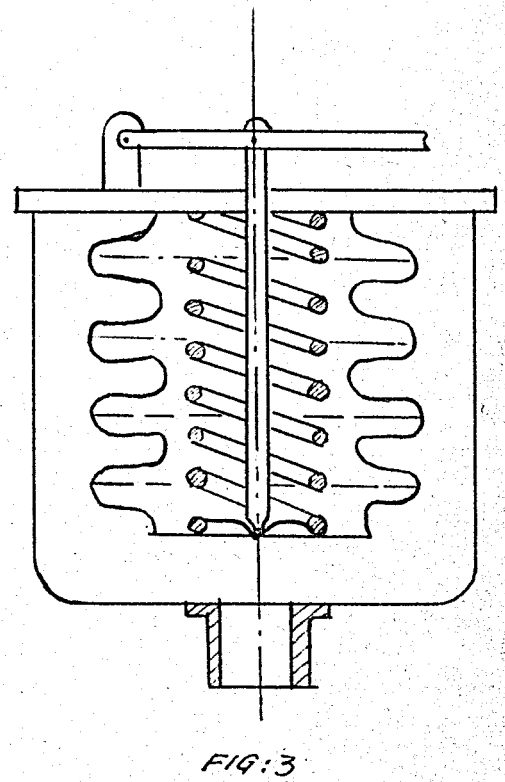
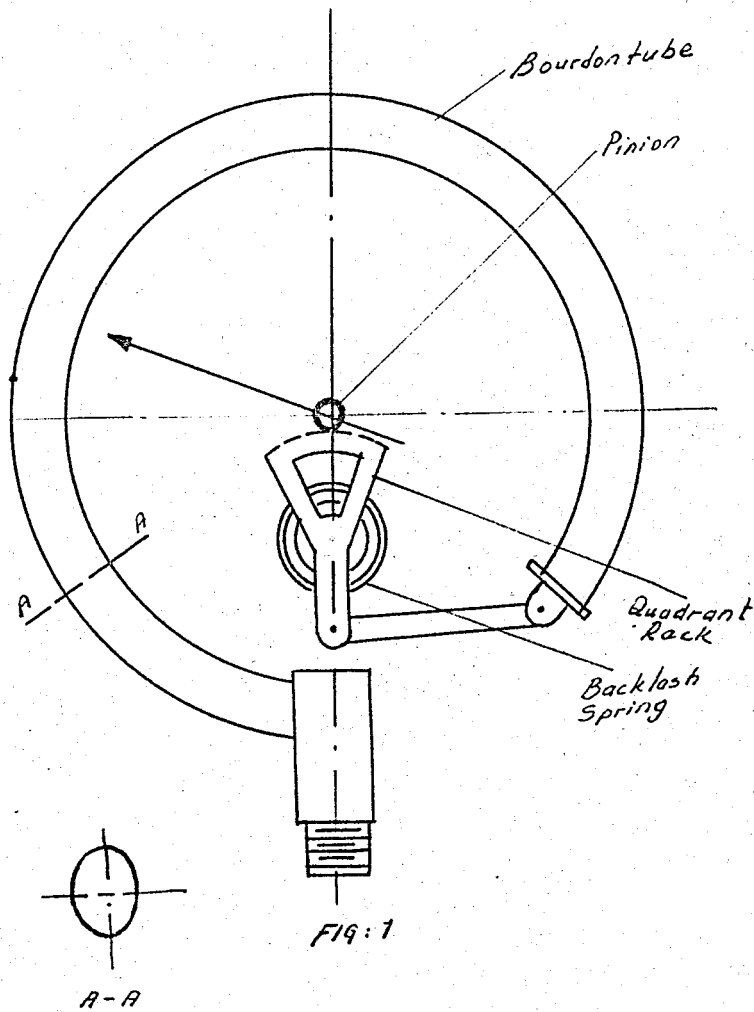
Deadweight tester: This apparatus is used to calibrate gages (bourdon, diaphragm, and bellows type) for the range of 1500 to 3000 psi.

Actually it is a hydraulic system. It consists of a pressure producing plunger and a transmitting medium, a fluid. The area of the plunger is definite, such as $1/10, 1/8, 1/5$ in² and the like. Thus any weight, placed on top of this plunger's pan, will produce an additional pressure on the fluid. Since the plunger area and weight are known, a standard pressure could be maintained to the gage and the calibration will be done.

Calibration:

- 1) The gage to be calibrated is connected to the tester and the valve is opened to let the oil reach the gage.
 - 2) Proper weights are placed on the plunger's pan.
 - 3) Oil pump is operated and the weight is raised to its marked mid position.
 - 4) The pan is spinned slowly, to assure that no friction exists between the plunger and the cylinder.
 - 5) During this spinning, the reading of the gage is recorded.
 - 6) It is necessary to have the plunger, perfectly vertical to avoid any friction between the cylinder and itself.
 - 7) Same procedure will be followed for each 5 psi steps up to the max. value of the gage.
 - 8) Same procedure is repeated for the same pressure values, but in reverse order, that is coming down from max. pressure to the lowest value, and gage readings are recorded.
 - 9) They are plotted as shown in fig. 4. The zone between two readings, ascending and descending, is called dead zone, or hysteresis area.
 - 10) Such a graph will show what is wrong with the gage and the required remedies.
- Ideally no such zone should exist, but in practice it does.

FM. EXP: 202



PRESSURE MEASUREMENTS BY MANOMETERS

Experiment No: FM. 203

Object: Pressure measurements by manometers.

Theory: Pressure is defined as the amount of force per unit area. There are several methods of pressure measurements, one being by the use of manometers. Manometers are differential indicators and show the difference between two pressures.

The simplest one as shown in fig. I is the vertical U tube manometer. The U tube is partially filled with a liquid. One end of the tube is connected to a known pressure P_1 , and the other end to the unknown pressure. A level difference will be observed if P_1 is not equal to P_2 . Analyzing fig. I we conclude that, since the liquid stays steadily, it is in equilibrium. Consider a unit area in the cross-section of the tube at C. The force on both sides of it should be equal to each other for equilibrium. Forces on the left are:

$$P_2 + h_2 \rho \quad \text{where } \rho \text{ is the density of the fluid}$$

The forces on the other side are:

$$P_1 + h_1 \rho + h_2 \rho$$

Equating them to each other, and solving for P_2 ,

$$P_2 + h_2 \rho = P_1 + h_1 \rho + h_2 \rho$$

$$P_2 = P_1 + h_1 \rho$$

Since P_1 and ρ are known values and h_1 can be measured, P_2 can be determined.

As a general rule, the higher the pressure, the liquid having the greater density is used. Examples of liquids used are: Mercury, water, alcohol, etc.

In order to increase sensitivity liquids possessing lower densities are used in inclined tube differential manometers. Such a manometer is shown in fig. 2.

A pressure difference of $h \rho$ units is represented by a scale with 1 unit in length.

Since both two levels are moving each time, in some cases it is not easy to determine the height of liquid. For easy reading, a well type or cistern-type manometer is preferable, as shown in fig. 3.

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One branch of U tube is changed into a reservoir. At neutral position, when $P_I = P_2$, the level of the fluid in the tube is marked as zero. The pressure equivalent of the liquid raised in the tube beyond the initial mark zero represents the pressure difference between P_2 and P_I , providing that the scale is calibrated in such a way that the X/l , distance lowering is compensated. Thus a high ratio of the crosssection of the well to the crosssection of tube should be preferred.

It is possible to have inclined well-type manometers in order to increase the accuracy, as shown in fig.4.

- Apparatus:
- 1) U tube (vertical and inclined type) manometer
 - 2) Well-type (vertical and inclined type) manometer
 - 3) Connecting tubings
 - 4) Small capacity air compressor with tank and several outlets for manometer connections
 - 5) Several liquids with different densities

- Procedure:
- 1) Connect the equipment to the compressed air tank
 - 2) Take simultaneous readings at different pressures, and using different liquids.

Questions:

- 1) Why a low density liquid is more suitable for accurate pressure measurements ?
- 2) What are the properties of good manometer fluids, why ?

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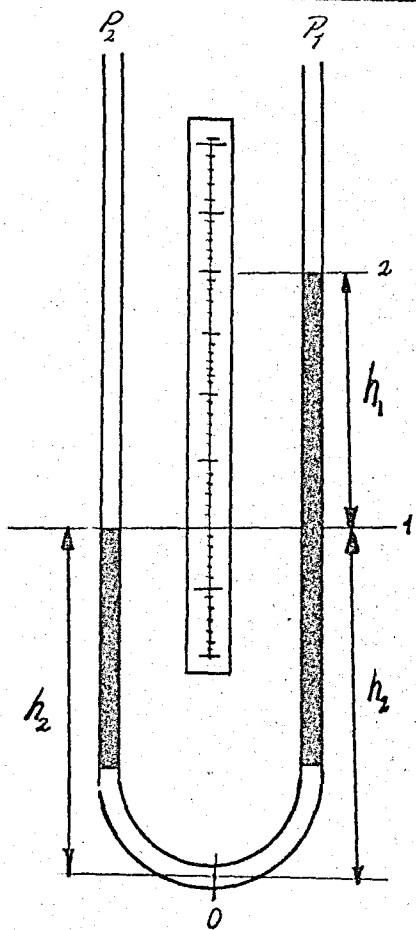


FIG: 1

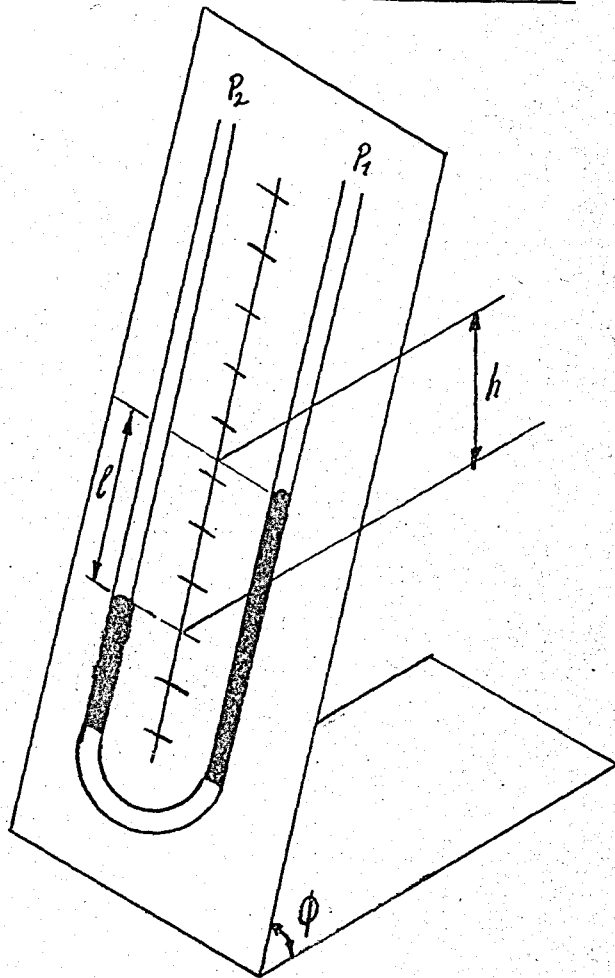


FIG: 2

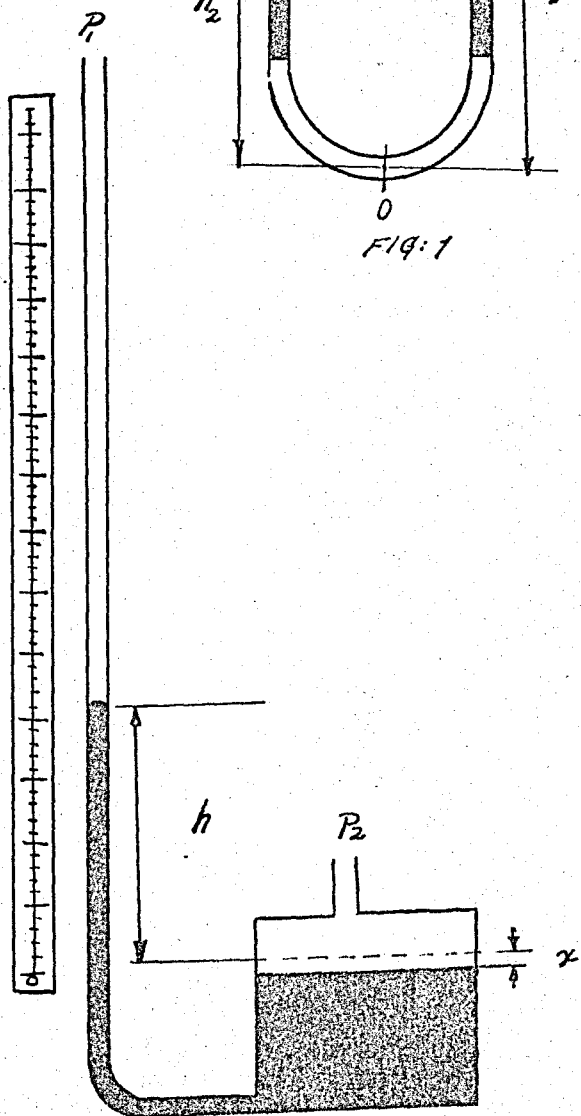


FIG: 3

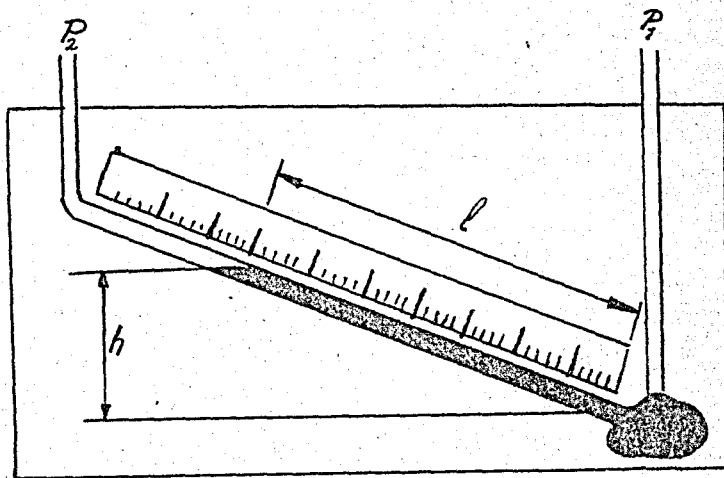


FIG: 4

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MEASUREMENT OF FLOW BY PITOT TUBE

Experiment No: FM 204

Object: Measurement of flow by Pitot tube.

Theory: Pitot tube is an instrument to measure static pressure, velocity and total pressure in a stream of air or gas. As shown in the figure it consists of two concentric tubes which usually are L shaped for convenient handling and which provides two separate outlets for connection to pressure gages. The essential part of the instrument is the short straight portion of the L, which is inserted into the stream, parallel to the direction of flow and with the opening always pointed upstream. The inner tube has an open mouth, facing the stream, and conveys to a pressure the so called impact pressure which is the total pressure at this point of flow. The outer tube has a number of small radial holes in its cylindrical wall and the annular space between the two tubes conveys to another pressure gage, the static pressure. Since velocity pressure is the difference between total pressure and static pressure, it is possible to measure it directly by a differential manometer, connecting total pressure to one side and static pressure to the other.

For incompressible fluids the relation between velocity pressure and the velocity is,

$$\bar{v} = C \sqrt{2g \frac{\Delta P}{\rho}}$$

where

\bar{v} = Average velocity at the Pitot tube location.

C = Calibration coefficient

ΔP = Velocity pressure = $P_{\text{total}} - P_{\text{static}}$

ρ = Density of flowing fluid

g = Gravitational constant

For the standard Pitot tube, C is between 0.98 and 1.0. The equation for air, thus becomes, for standard conditions as,

$$\bar{V} = 4005 \sqrt{\Delta P}$$

where,

P = Velocity pressure in inches of water

For compressible fluids, a correction factor given in the graph should be used.

Since it is possible to determine velocity at a point in the flow, velocity diagram can be constructed for a given flow cross-section. Integration of the distribution graph yields the flow rate. In practice this is done by dividing the flow cross-section into imaginary sections and velocity is determined at a representative point of the section. The summation of products of individual velocity and related sectional area will give the flow rate.

The imaginary sections for a rectangular duct will be again small rectangles. For the same subdivision in a circular duct, concentric annular areas with equal values are used. The standard locations of a pitot tube in such a circular cross-section, and the boundaries of annular sections are given in the figure. The location of the traverse points of Pitot tube are at the centers of those concentric sections not midway along the diameter between adjacent boundary circles.

Apparatus:

- 1) Pitot tube
- 2) Connecting hose
- 3) Inclined U manometers
- 4) Air duct with variable flow rate arrangement
- 5) Propeller type anemometer

Procedure:

- 1) Install the equipment as shown in the figure.
- 2) Be sure that the L section of the tube is parallel to the stream lines.
- 3) Take several readings by pitot tube and the anemometer and plot the results on the same graph paper.

Questions:

- 1) Why the velocity at the center of a circular cross-section is not used as the characteristic velocity of the central section ?
- 2) Why the Pitot tube is quite sensitive to yaw. (the inclination angle between the axis of the tube and the direction of flow)
- 3) If a hot-wire anemometer is operated at high temperatures, what will be the main cause of error ? Explain.

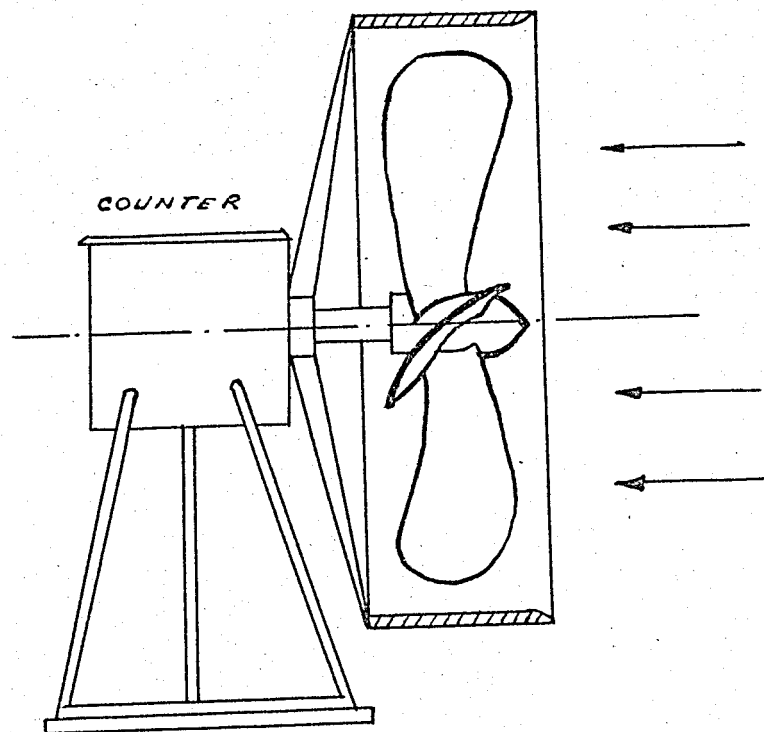
Appendix to : FM. 204

Anemometers:

In order to measure the velocity of a moving fluid stream, there are other devices, called the anemometers. As an example the propeller type is shown in figure. It consists of a propeller and a counting mechanism.

The meter records the amount of fluid passed. It has a clutch mechanism to stop and start the counting mechanism, providing a rated operating time. The flow rate is calculated by dividing the flow by the time.

Hot wire anemometer is a thermal meter, consisting of a very thin wire, and circuits for heating and power measurement. The wire is placed in a stream of air, and heated at a rate which maintains a constant temperature at the wire. This means that the amount of heat dissipated from the wire is taken away by the flowing fluid. Since the cooling rate is related with the flow rate, after proper calibration it is possible to obtain the rate of flow by measuring the amount of electrical energy consumed in the wire.

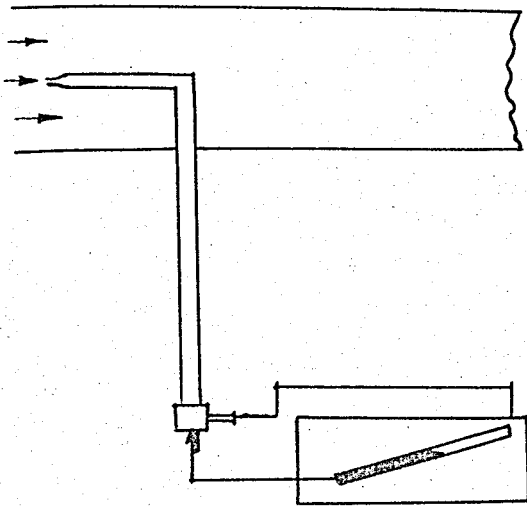


PROPELLER TYPE ANEMOMETER

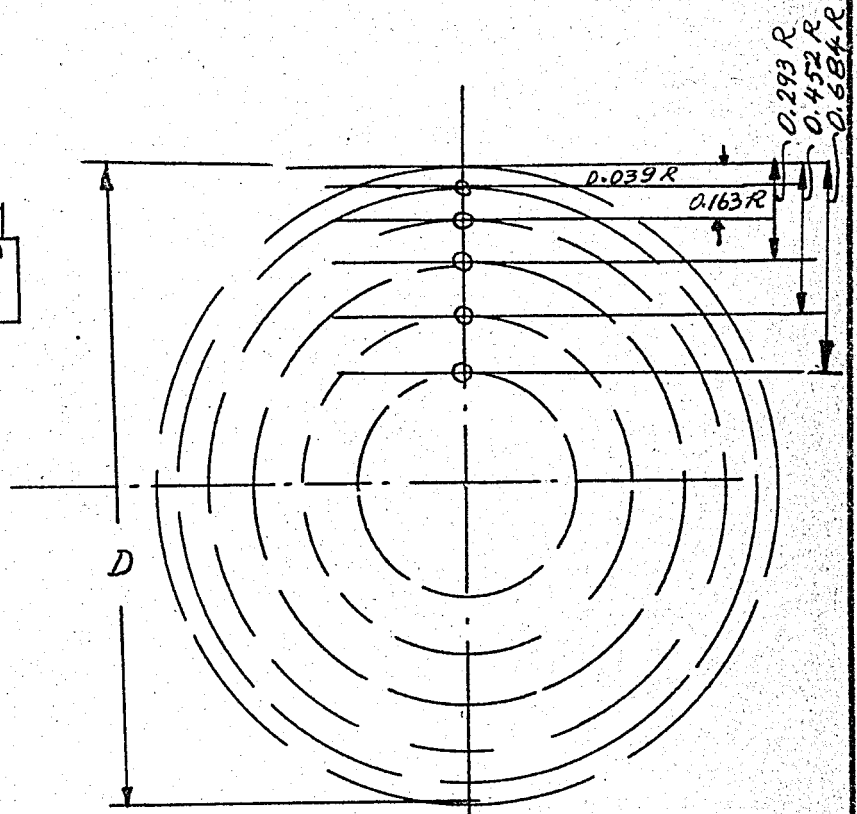
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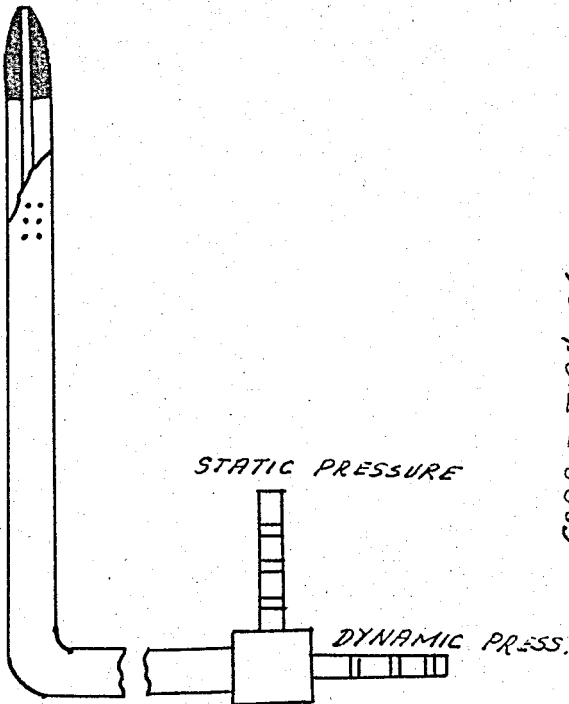
FM: EXP. 204



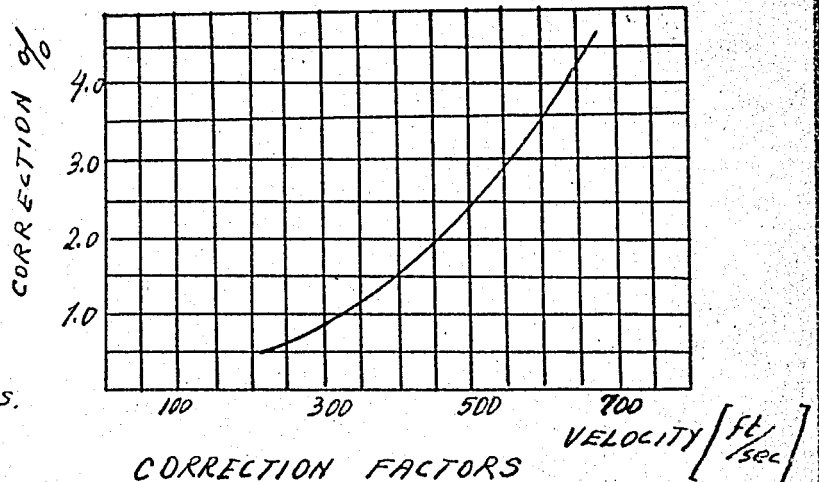
PITOT TUBE CONNECTION



TRAVERSE POINTS
IN DUCT
(Amca standard)



PITOT TUBE



CORRECTION FACTORS
FOR COMPRESSIBLE FLUID
FLOW

(ASME Fluid Meters 1937)

MANOMETER STUDY

Experiment No: FM. 205

Object: The object of this experiment is to acquaint the student with basic pressure height relation by measuring pressure differences with fluid manometers, and to familiarize him with the steam tables and barometer correction chart.

References: Shames, Mechanics of Fluids, Art. 3-1 to 3-2, Keenan and Keyes Thermodynamic properties of steam, pp. 74 - 75.

Organization of student groups: Divide the class into groups of two or three. Each group should perform the calculations independently.

Theory: For full information on apparatus, its use and characteristics, areas of applicability, connection techniques, degrees of accuracy and the necessary corrections to be made provided with needed charts, please refer to "Theory" sections of experiments: FM 201 to 204.

Apparatus: Various pitot tubes and associated manometers, barometer hung on the wall of the instructor's room.

Procedure and Requirements:

I. Multiple Fluid Manometer

Air pressure will be applied by the instructor from a portable air tank. Take readings of all fluid levels. Complete the following on a separate sheet:

1. Show the scale readings on a simple sketch .
2. Calculate the air pressure applied in psig.
3. What is the value of such a manometer ?
4. What are the disadvantages of such a unit ?

2. Reservoir Manometer (Dwyer plastic type)

The reservoir diameter is $5/8$ in. and the tube diameter is $3/16$ in. The unit is calibrated for use with a fluid of specific gravity 0.827.

Answer the following questions about this manometer:

1. Calculate the required distance between marks on the scale for one in. of water pressure difference (assume reservoir level is not observed).
2. Check your calculations by measurement of scale (scale removable from spare unit).
3. How much should the reservoir level change when the fluid level moves one in. (actual distance) in the small tube?
4. What is the advantage of using a large reservoir?

3. Inclined tube Manometer

This unit has a scale calibrated for a fluid of specific gravity 0.827

1. What is the specific gravity of the fluid now in the manometer? (determine by comparing manometer readings).

4. Pitot tube readings

Operate the wind tunnel at the speed setting specified by the instructor. Read pressures on the lower manometer. Read and record the pressures indicated below:

Stagnation press. in tunnel, P_0	=		in. of water
Static press. in tunnel, P	=		" " "
Pressure difference $P_0 - P$	=		" " "

Manometer Problem:

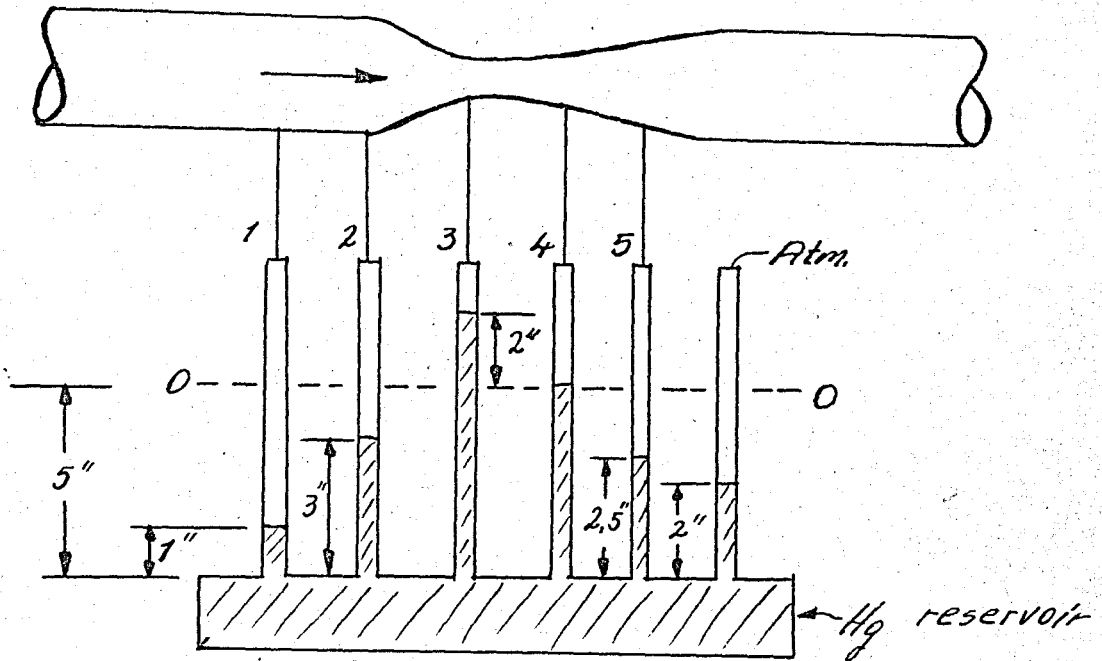
Consider air flow in the system shown. Assume atm. press. is 29.4 in Hg. and the ambient temperature is 80 deg. F.

- a) Complete the following table of pressure along the pipe.
- b) Show all calculations.

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Item	Pressure Tap				
	1	2	3	4	5
Gage Pressure in. Hg.					
Abs. Pressure in. Hg					
Abs. Pressure lb/ft ²					
Abs. Pressure lb/in. ²					

FLOW METERING and PIPE FLOW

Individual Experiments:

- FM. 301 Measurement of flow by volumetric flow meters
- FM. 302 Measurement of flow by rate meter - Rotameter
- FM. 303 Measurement of flow by variable head meters
 - Venturi meter
 - Flow nozzle
 - Orifice plate
- FM. 304 Velocity and Press. drop for isothermal flow in a tube
- FM. 305 Types of Pipe flow
- FM. 306 Pipe Friction
- FM. 307 Limiting Pipe Flow

Combined Experiment:

- FM. 308 Flow metering and Pipe flow

MEASUREMENT OF FLOW BY VOLUMETRIC FLOW METERS

Experiment No: FM. 301

Object: Measurement of flow by volumetric flow meters

Theory: These types of flow meters measure the total amount of fluid flowing.

The most simplest one is a weighing tank. A known volume of reservoir is filled with fluid and time required to empty it is measured. Thus a very accurate and reliable flow measurement is obtained. It has restrictions. A fuel meter is shown in the figure.

Another device used as volumetric meter is the nutating disc. Its principle construction is shown in the figure. Liquid comes into the chamber and due to the differential pressure, causes the disc to rotate. By this rotation each time a definite amount of fluid is transferred from inlet chamber to the outlet, separated by a partition. Error is usually less than 1%. These kinds of meters are suitable for 15 to 500 gal/min.

A rotary vane meter is shown in the figure. The eccentrically located rotor is turned by the moment of flow from inlet towards the outlet. The amount of fluid passed is confined by the vanes during rotation. Thus accurate metering is obtained. The effects of viscosity and density changes are not high because the clearance between the vanes and the casing is about zero. Accuracy is within 0.2 - 0.3%.

Sealed drum meter consists of a cylindrical casing, and a rotor with spiral vanes. The gas inlet is at the center of this rotor. When gas enters into the rotor, it accumulates in one of the vanes in displacing the water which has filled the space previously. This evacuation relieves the rotor that particular vane and an upward torque is produced. At the end, the rotation on the rotor is obtained, which is proportional to the volume of gas traversed. The accuracy of such a meter is about 0.5%.

Weight meter is another application of the sealed drum meter. It is shown in the figure. Liquid enters into the meter through a central port, fills one of the spiral vanes. Due to gravity rotor loses its balance and begins to rotate to maintain the balance. After certain amount of rotation the content of each liquid filled vane begins to discharge.

Two lobed positive displacement pump can be used as a volumetric meter. The construction is shown in the figure. The flow of liquid cause the lobes to rotate and this displacement is proportional to the amount transferred

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from inlet to outlet. The capacity of such meters are up to 1 million cubic feet per hour.

Apparatus:

I) Working models and schematic diagrams or cross-sectioned models of

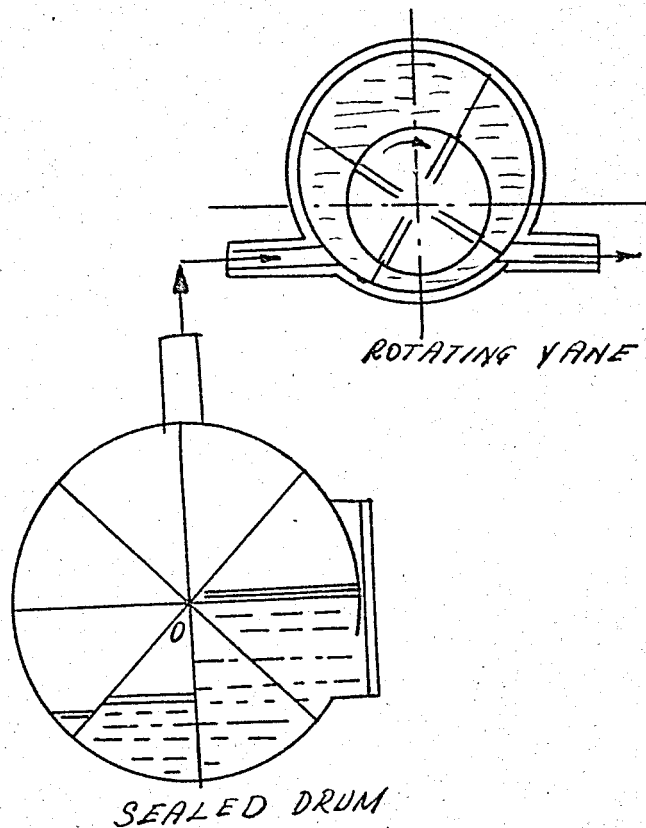
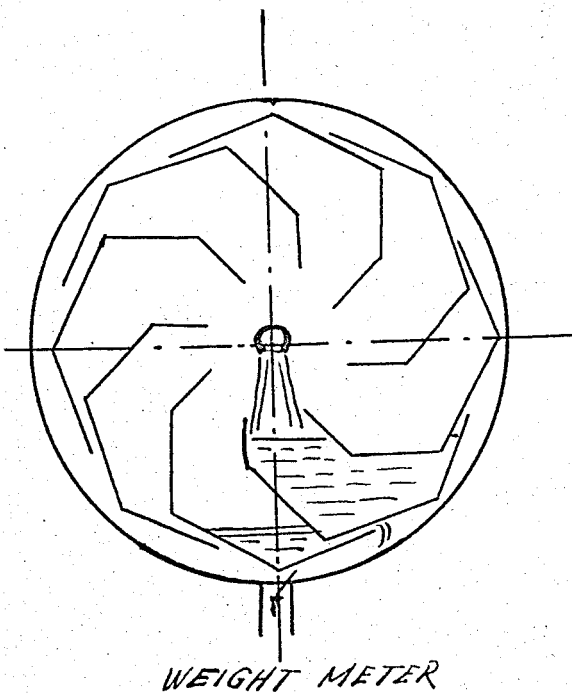
- a) Nutating disc meter
- b) Rotary vane meter
- c) Sealed drum meter
- d) Weight meter
- e) Two-lobed rotary meter

Procedure:

1) The models and diagrams are studied and any simple measurement is done

Questions:

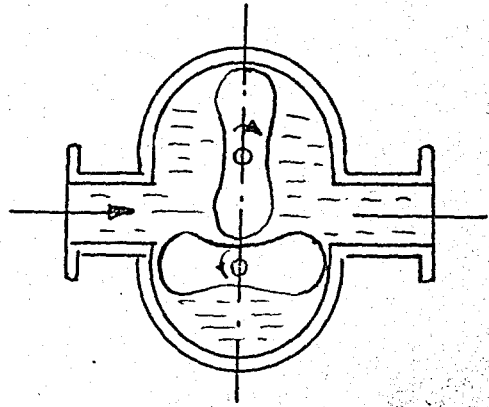
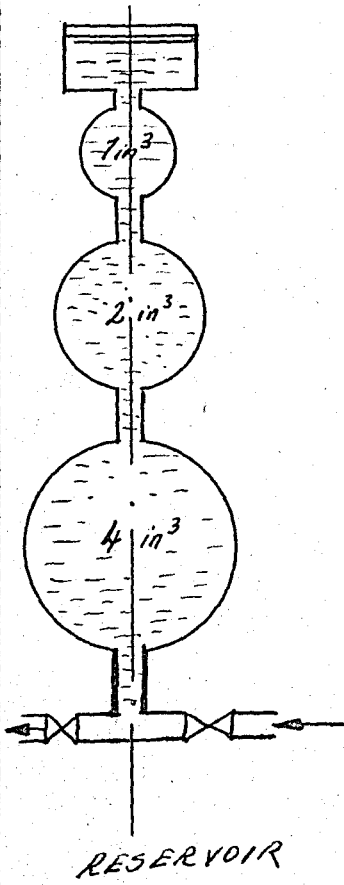
1) What are the application fields of each meter described above ?



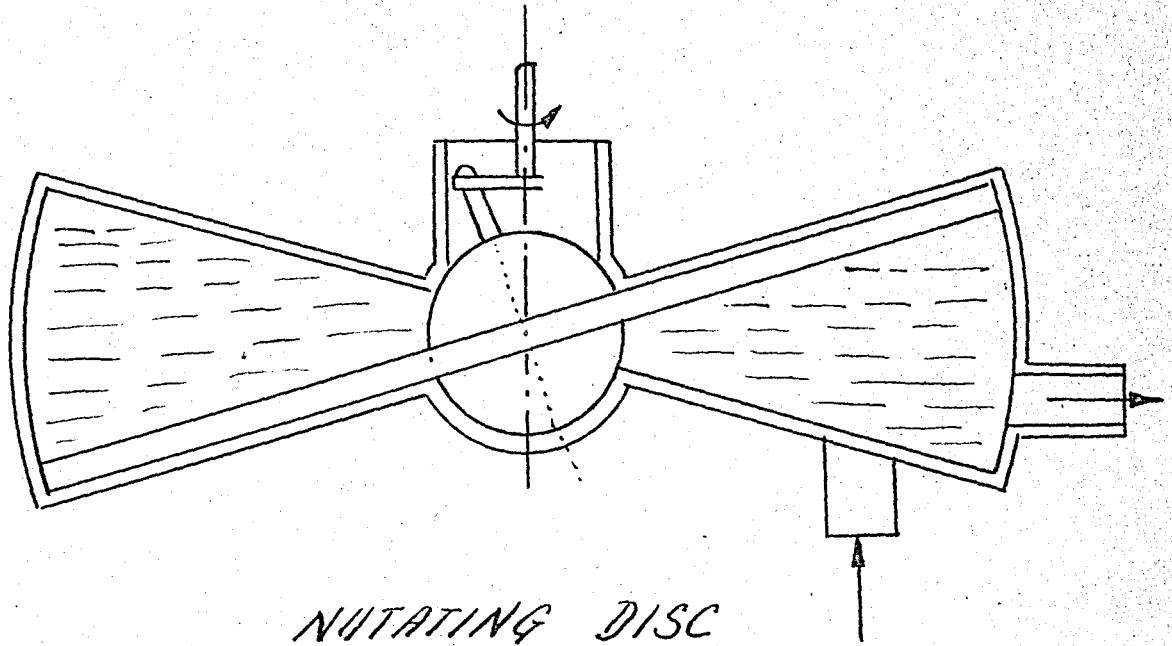
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FM. EXP: 301



TWO LOBED METER



ROTATING DISC

MEASUREMENT OF FLOW BY RATE METERS -- ROTAMETER

Experiment No: FM. 302

Object: Measurement of flow by rate meters, rotameter.

Theory: A rotameter is shown in the figure. The flow rate is determined by measuring the area through which the fluid flows. It consists of a tapered glass tube and a float inside. The flow is from the smaller end to the other end of the tube. To keep the float at any level in the tube, it is required to provide certain pressure differential at that point. The flow passage is proportional to the flow rate. The flow rate is measured by comparing the position of the float with a calibrated scale on the glass tube.

For a static equilibrium position the following analysis of float position is made :

Energy equation of flow for liquids⁽¹⁾ is,

$$\frac{P_2}{\rho} + \frac{V_{m2}^2}{2g} + Z_2 = \frac{P_1}{\rho} + \frac{V_{m1}^2}{2g} + Z_1$$

where:

P = Static pressure

V_m = Fluid stream mean velocity

Z = Height above a datum line

g = Acceleration due to gravity

Usually, the height difference is negligible, therefore:

$$V_{m2}^2 - V_{m1}^2 = \frac{2g}{\rho} (P_1 - P_2)$$

For a stable position, it can be assumed that the pressure acting upward on the bottom of the float is the stagnation pressure, acting downward on the float is static pressure. Although this might not be true in a very strict sense, it is reasonable enough to demonstrate the relation between the rate of flow and the area of annulus, that is position of the float in the tube.

$$A_f \left[P_1 + \frac{V_{m1}^2 \rho}{2g} \right] + V_f \rho = A_f P_2 + V_f \rho_f$$

where:

A_f = Effective area of float

V = Volume of float

ρ_f = Weight density of float

(1) Industrial Instrumentation, by D. Eckman, 1957, John Wiley, 5th. Edition

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ρ = Weight density of fluid

Continuity equation

$$Q = V_{m1} A_1 = C_c V_{m2} A_2$$

where:

Q = Rate of flow of fluid

A_1 = Area of inlet to tapered tube

A_2 = Annular area between float and tube

C_c = Coefficient of contraction = 0.6 - 0.8

and combining them all, to eliminate P_2, P_1, V_{m2} and V_{m1} , we get,

$$Q = C_c A_2 \sqrt{2g V_f / A_f \left[\frac{\rho_f}{\rho} - 1 \right]}$$

- Apparatus:
- 1) Rotameter
 - 2) Connections of water supply
 - 3) Stop watch

- Procedure:
- 1) Examine the rotameter carefully
 - 2) Calibrate it for water
 - a) Supply water at different rates
 - b) Record the value shown by the float
 - c) Collect water in a bucket for definite periods at each level of flow rate indicated by the rotameter
 - d) Plot the actual flow rate vs. meter records

Questions:

- 1) What are the advantages of rotameters ?
- 2) How can the flow rate capacity of a rotameter be changed ?
- 3) Higher accuracies could be obtained at rather lower flow rates, why ?
- 4) In order to compensate the changes in density of the flowing fluid suitable float material is selected for a given fluid. Prove that for the relation of $\rho_{float} = 2 \rho_{fluid}$ exists for proper compensation.

Appendix to Fl. Experiment No: 302

Variable area meter :

It is basically a kind of valve, but it does not control a flow, just the opposite, that is the flow controls it. The piston has several slots around its periphery. In case of no flow, the spring sets the piston on its seat and that point of the indicator is marked as zero. When fluid begins to flow, the piston is raised until the slot area is enough to let the fluid flow through. This new position of the stem is indicated by the pointer.

By the selection of a proper spring and linkage to pointer, it is possible to find the flow rate directly, and accurately for a good range of flow rates.

Variable area and head:

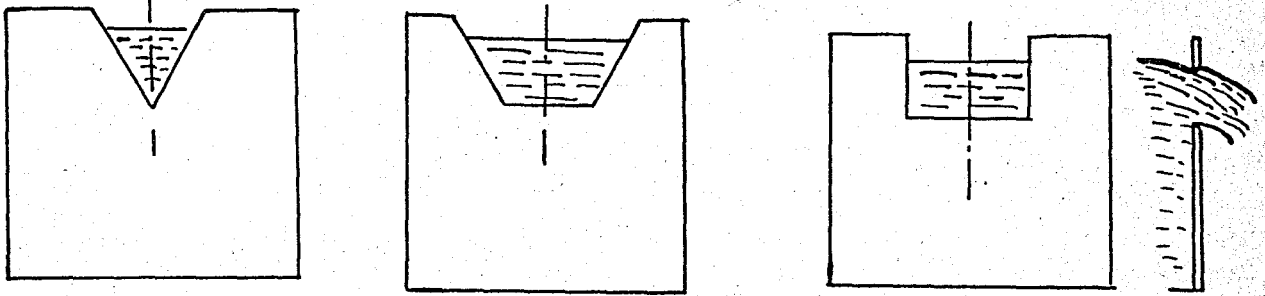
In open channels, flow rate could be measured by passing fluid over weirs. The flow rate is:

$$Q = Kh^n$$

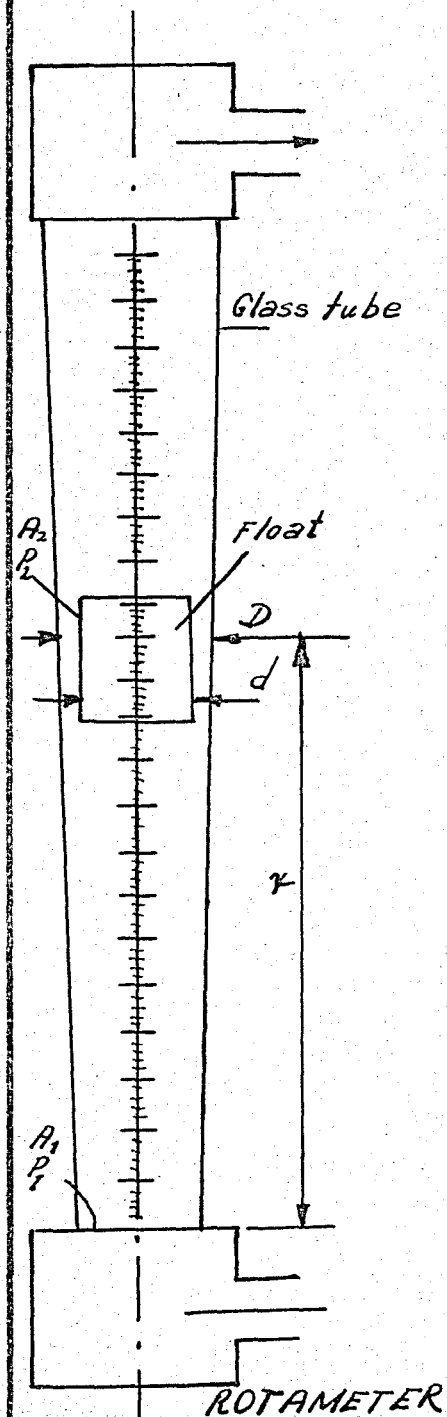
that is flow rate is a function of height and a specific constant for each specific shape of weir. Although some theoretical calculations are possible, actual flow rates can be obtained, only after several experiments are performed with each type of weir.

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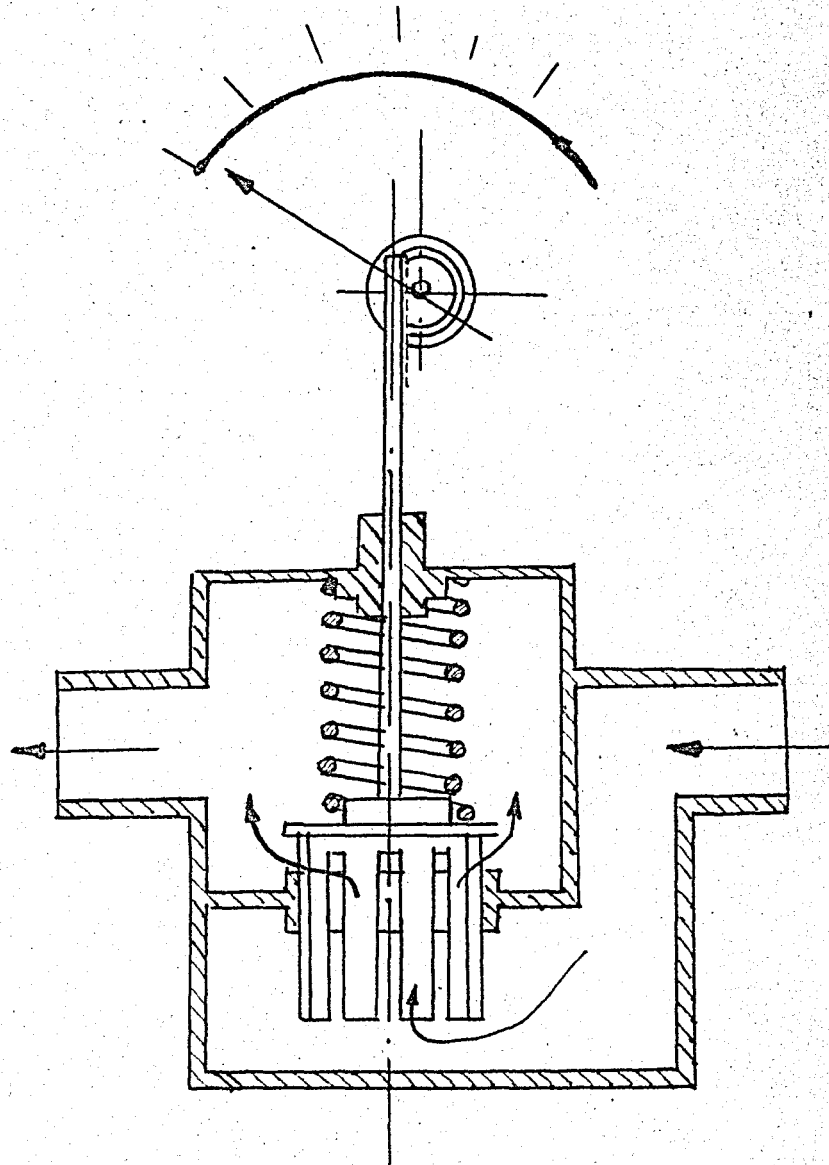
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SEVERAL WEIRS



ROTAMETER



VARIABLE AREA METER

FM. EXP: 302

MEASUREMENT OF FLOW BY VARIABLE - HEAD METERS

VENTURI METER

FLOW NOZZLE

ORIFICE PLATE

Experiment No: FM. 303

Object: Measurement of flow by variable-head meters, venturi meter, flow nozzle and orifice plate.

Theory: The fundamental principles underlying their operations are exactly the same. The velocity of flow is increased by causing the fluid to flow through a constriction. It might be a venturi, a flow nozzle or an orifice plate.

The result is an increase in the kinetic energy of flow accompanied by a corresponding drop in pressure at the constriction.

The mathematical analysis is the same for all of them and is presented in the following section.

Assuming no work is done between the sections 1 and 2, and considering the heat transferred to be negligible, the energy equation for steady state, per unit mass,

$$Z_1 + \frac{V_1^2}{2g} + U_1 + \frac{P_1}{\rho} = Z_2 + \frac{V_2^2}{2g} + U_2 + \frac{P_2}{\rho}$$

where,

Z = Elevation of center of flow stream

U = Internal energy

P = Static pressure

$$V = Q/A = \frac{\text{volumetric flow}}{\text{flow passage area}}$$

For steady state, the continuity equation,

$$\rho_1 A_1 \bar{V}_1 = \rho_2 A_2 \bar{V}_2$$

and assuming the flow passage areas are circular,

$$\rho_1 \bar{V}_1 \frac{\pi D_1^2}{4} = \rho_2 \bar{V}_2 \frac{\pi D_2^2}{4}$$

solving for \bar{V}_1 , we get,

$$\bar{V}_1 = \bar{V}_2 \frac{\rho_2}{\rho_1} \cdot \frac{D_2^2}{D_1^2} = \bar{V}_2 \beta^2 \frac{\rho_2}{\rho_1}$$

where, $\beta^2 = \frac{D_2^2}{D_1^2}$

Substituting these into the energy equation,

$$\frac{\bar{V}_2^2}{2g} \left\{ 1 - \beta^4 \left[\frac{\rho_2}{\rho_1} \right]^2 \right\} = (Z_1 - Z_2) + (U_1 - U_2) + \left(\frac{P_1}{\rho_1} - \frac{P_2}{\rho_2} \right)$$

Usually the difference in height, $(Z_1 - Z_2)$, is made negligible, flow is assumed frictionless, that is $(U_1 - U_2)$ is equal to zero, and the resulting equation,

$$\bar{V}_2 = \sqrt{\frac{2g}{1 - \beta^4 \left[\frac{\rho_2}{\rho_1} \right]^2}} \cdot \left[\frac{P_1}{\rho_1} - \frac{P_2}{\rho_2} \right]^{1/2}$$

Ideal mass flow rate will be,

$$M_i = \rho_2 A_2 \bar{V}_2 = \rho_2 A_2 \sqrt{\frac{2g}{1 - \beta^4 \left(\frac{\rho_2}{\rho_1} \right)^2}} \cdot \left(\frac{P_1}{\rho_1} - \frac{P_2}{\rho_2} \right)^{1/2}$$

For $\rho_1 = \rho_2 = \rho$

$$M_i = A_2 \sqrt{\frac{1}{1 - \beta^4}} \cdot \sqrt{2g\rho\Delta P}$$

This equation is good for frictionless, adiabatic flow of incompressible fluid. These ideal conditions can not be maintained in practice. The pressures measured, might not be at the proper points of flow.

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The area of constriction at room temperature will be different under operating conditions. Thus the actual flow rate

$$\bar{M}_a = A_2 \sqrt{1/(1-\beta^4)} \cdot C \cdot E \cdot \sqrt{2g_s \Delta P}$$

where,

M_a = Actual flow

C = Coefficient of discharge = M_a/M_i

E = Correction factor for thermal expansion

K = Flow coefficient =

Thus,

$$M_a = A_2 K E \sqrt{2g_s \Delta P}$$

For compressible fluid flow, we have to substitute enthalpy h , for ρ , and the ideal flow equation becomes,

$$M_i = \rho_2 A_2 \sqrt{\frac{2g_s}{1-\beta^4} \left(\frac{\rho_2}{\rho_1}\right)^2} \cdot \sqrt{h_1 - h_2}$$

In case of ideal gas and constant specific heat ,

$$h_1 - h_2 = \frac{kR}{k-1} \cdot T_1 \left\{ 1 - \left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}} \right\}$$

where ,

$k = C_p / C_v$

$R =$ Gas constant

$T =$ Absolute temperature

Combining and simplifying the above equations, we get,

$$M_i = \rho_2 \sqrt{2g_s \Delta P} \cdot \left\{ \frac{k}{k-1} \cdot \frac{\left(\frac{P_2}{P_1}\right)^{\frac{2}{k}} - \left(\frac{P_2}{P_1}\right)^{\frac{k+1}{k}}}{1 - \frac{P_2}{P_1}} \cdot \frac{1 - \beta^4}{1 - \beta^4 \left(\frac{P_2}{P_1}\right)^{\frac{2}{k}}} \right\}^{1/2}$$

Using the symbol ϕ for the bracket, the actual flow rate will be expressed ,

$$\dot{M}_a = A_2 K E \phi \sqrt{2 \rho P_1 \Delta P}$$

where the coefficients are the same of those explained before. This equation is good for isentropic flow of compressible fluids.

Table I ^x

Values of ϕ for use of venturi meters and nozzles
(k = 1.4)

P_2/P_1	0.25	0.4	0.5	0.6	0.65
0.98	0.9893	0.9890	0.9884	0.9872	0.9863
0.96	0.9782	0.9776	0.9765	0.9743	0.9724
0.94	0.9672	0.9662	0.9646	0.9613	0.9585
0.92	0.9570	0.9548	0.9526	0.9484	0.9447
0.90	0.9447	0.9432	0.9405	0.9352	0.9309

For orifice plates, the pressure drop will be much less than 90 % and there is too great error in the calculation of flow by using expansion factor , ϕ . Another empirical expansion factor Y , is used instead of ϕ .

The values of P_2/P_1 above 0.99, incompressible fluid flow equation can be used without any great error. In the following table, the error of incompressible fluid equation for different values P_2/P_1 is given .

x) Mechanical Eng'g Laboratory P.67 by Messersmith, Warner Olsen
2 nd. Edition John Wiley

Table: 2 ^x

P_2/P_1	ϕ	% Error or ($1 - \phi$) . 100
1.000	1.000	0.000
0.990	0.994	0.60
0.980	0.9884	1.16
0.960	0.9765	2.35
0.940	0.9646	3.54
0.920	0.9526	4.74
0.900	0.9405	5.95
0.800	0.8780	12.2
0.700	0.8120	18.8
0.600	0.7440	25.6

Venturi Meter :

In the figure, venturi tube is shown schematically. It consists of a cylindrical throat section, a converging section and a diffuser. The optimum angle of diffuser is about 7 degrees, for minimum friction and maximum recovery. The pressure loss from section I to 3 is 10 - 20 % of the differential pressure. Venturi tube sizes are not standardized.

The coefficients are usually function of Reynold's number and meter size. Main disadvantages are its bulkiness and difficulty in construction.

x) Industrial Instrumentation p.275

By Echman, John Wiley

Flow Nozzle:

Some common flow nozzle shapes are shown in figures. Flow nozzles can be considered as venturi meters without diffusers in a way.

The nozzle has a pressure loss of 0.30 to 0.95 of the differential pressure obtained. Flow coefficient is also a function of Reynold's number and a table is given.

Orifice :

The orifice is the simplest form of the constriction. The flow shape is illustrated in the figure. The smallest area is called the vena contracta and the lowest pressure occurring at this section. Thus it is obvious that the location of pressure connections has large influence on the pressure differential determination. The sharp edged orifice is the most used type. The sharpness of the upstream side of the orifice is very important in influencing the flow measurements. Light reflections of any kind should be avoided.

By properly manufactured orifice plates, it is possible to reproduce flow conditions with very high degree of accuracy.

The discharge coefficients are function of orifice type, pipe size, ratio of orifice diameter, the Reynold's number, and the location of the pressure connections.

Very elaborate tabulations of those coefficients for various combinations are given in the publication of ASME, "Fluid Meters, their theory and application ", Part I, 1937.

Apparatus :

- 1) Venturi meter
- 2) Flow nozzle
- 3) Orifice plate
- 4) Suitable differential manometers
- 5) The circulation arrangement shown in the figure
- 6) Stop watch

Procedure:

- 1) Examine each system elements carefully
- 2) Take readings by each one and check them by the water collected at the reservoir for a given time period
- 3) Plot the actual values of flow versus the readings obtained by those three variable head meters.
- 4) Compare the results.

Questions :

- 1) What are the advantages of venturi meters over the others ?
- 2) What is the use of excentric orifice plates ?

FM. EXP: 303

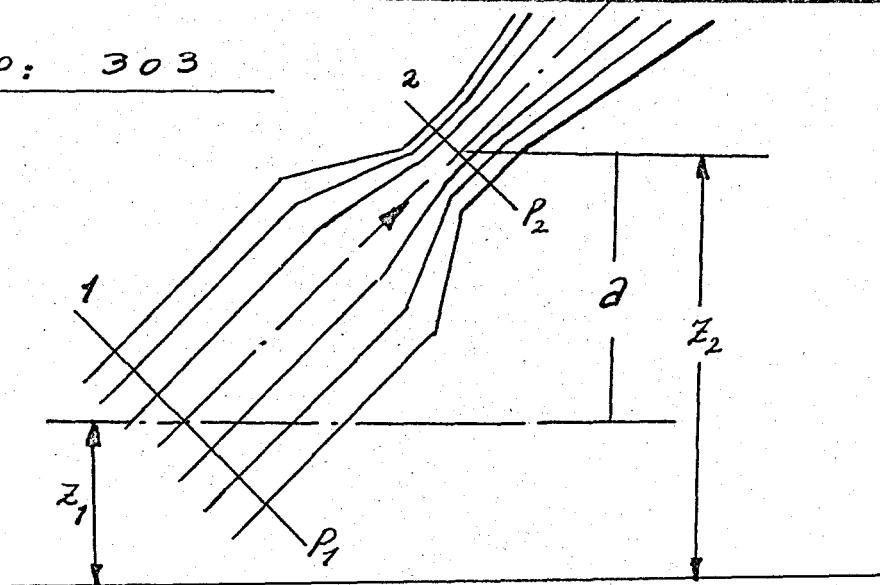
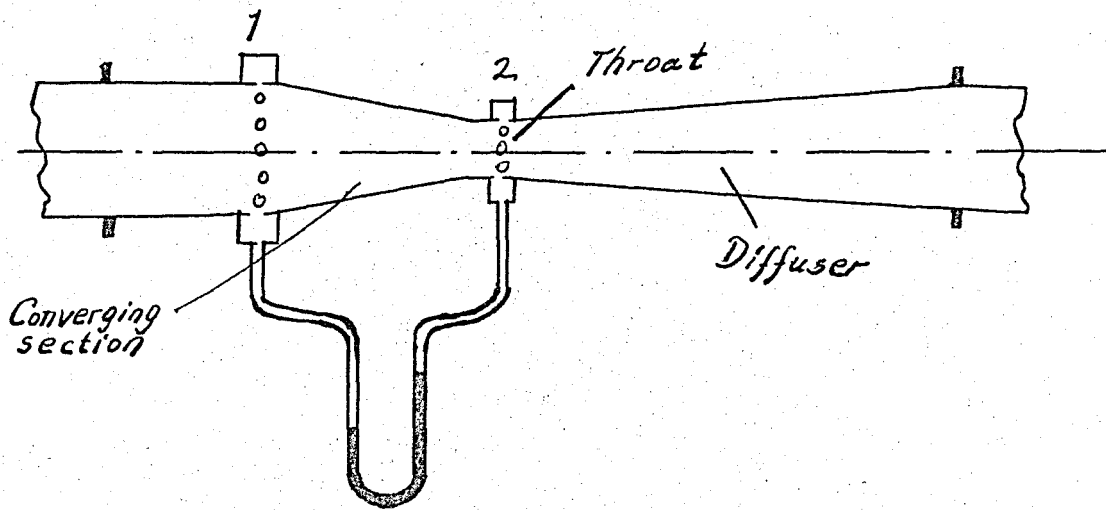
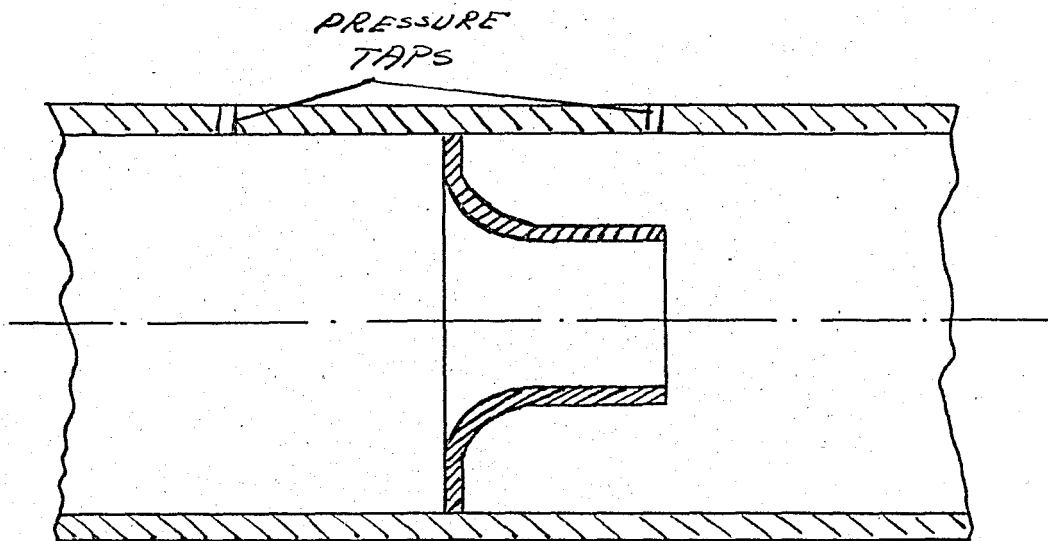


FIG:1



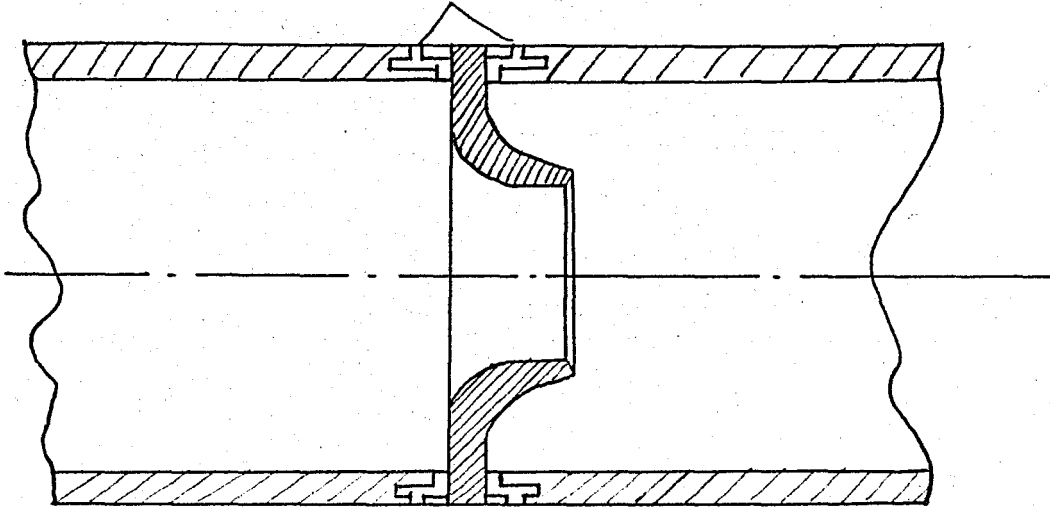
VENTURI METER



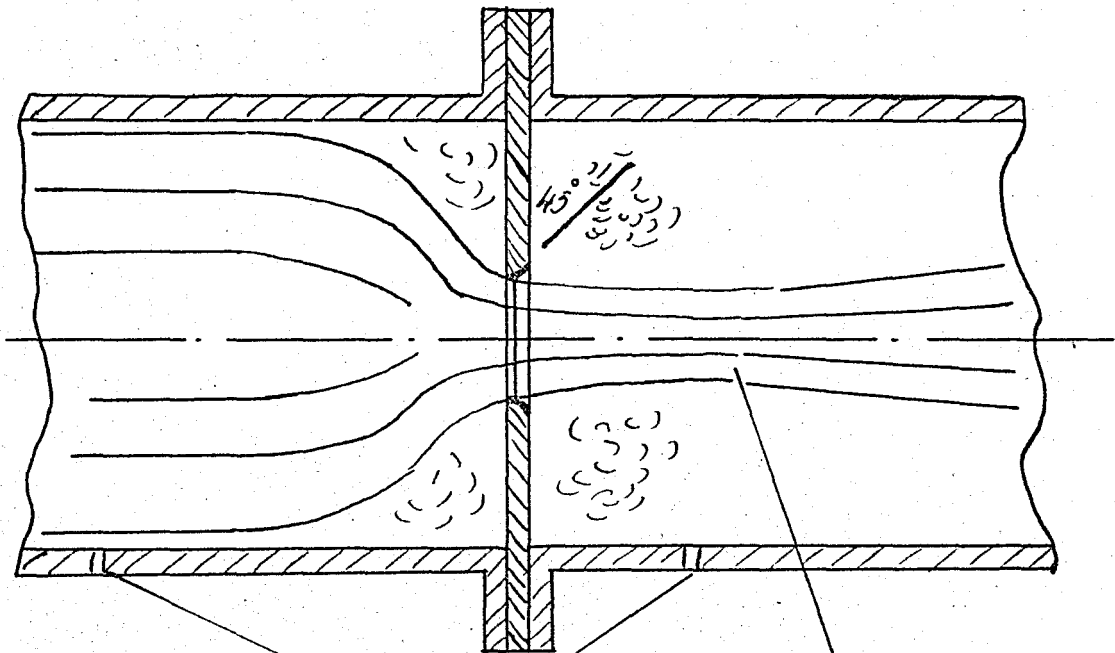
LOW RADIUS NOZZLE FIG:2

FM. EXP: 303

Pressure taps



ISA. NOZZLE



Vena Contracta

Pressure taps

ORIFICE PLATE

VELOCITY and PRESSURE DROP FOR ISOTHERMAL FLOW IN A TUBE

Experiment No: EM. 304

Object: Study of velocity and pressure drop for isothermal flow in a tube.

Theory: A variety of experimental techniques may be used to determine velocity and pressure drop for isothermal flow in a tube. Low pressure drops may be determined very accurately by a micromanometer. A hot - wire anemometer will be used to measure velocity so that fluctuating component may also be obtained. Thus transition phenomena in going from laminar to turbulent flow (and vice versa) may also be demonstrated in this experiment.

Apparatus:

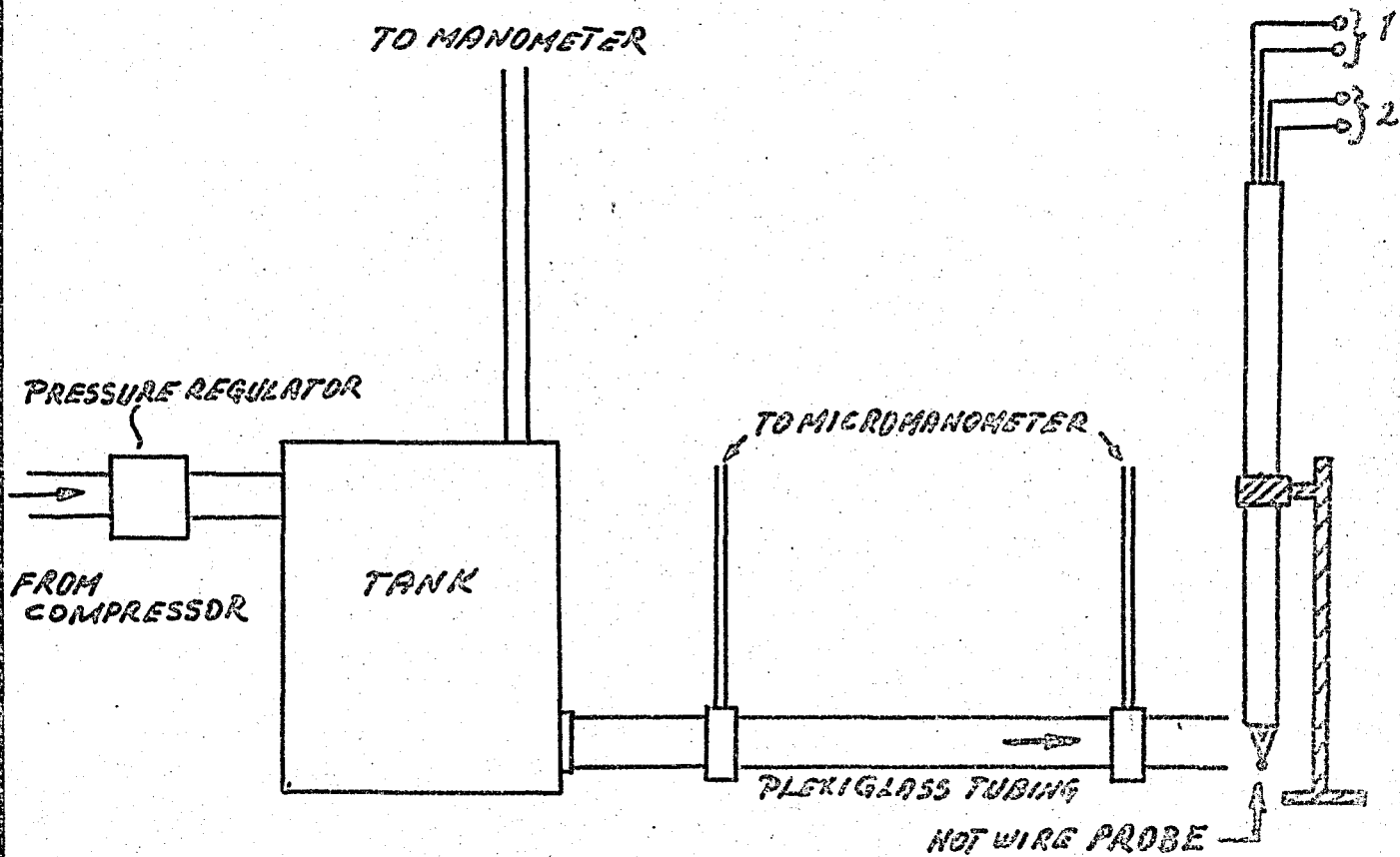
1. Hot wire anemometer
2. Milliammeter
3. Rheostat
4. Wheatstone bridge
5. DC power supply
6. Galvanometer
7. Vacuum tube millivoltmeter
8. AC amplifier
9. Oscilloscope

Procedure: The resistance, R_e , of the anemometer circuit may be found at room temperature by balancing the wheatstone bridge. This value is read at 1.5 volts. Similarly a value of the anemometer circuit resistance, R , is obtained at 45 volts. The corresponding voltage drop across the hot wire as well as the corresponding pressure drop may be read for different velocities of laminar flow. The average velocity is calculated from the Hagen-Poiseuille equation, and a plot of velocity times ΔP versus voltage drop times current of the hot wire is made for a calibration of the hot wire anemometer. The flow velocity may be increased and the velocity variation may be seen on an oscilloscope to illustrate transition phenomena.

Requirements:

- 1) Plot average velocity versus voltage drop across the hot wire.

- 2) Plot velocity times ΔP versus voltage drop times current of hot wire.
- 3) Plot velocity versus pressure drop.
- 4) Sketch different velocity variations as seen on the oscilloscope.



TYPES OF PIPE FLOW

Experiment No: FL. 305

Object: The object of this experiment is to observe the type of flow in a pipe at various Reynolds numbers which define the transition between laminar and turbulent flow.

Reference: Shames, Mechanics of Fluids, Art. 10-1 to 10-2.

Organization of student groups: Divide the class into groups of 3 or 4

Apparatus:

- 1) Flow equipment
- 2) Thermometer
- 3) Viscosity curve for water (Posted on the Lab. wall)
- 4) Stopwatch
- 5) Bucket and scales

Procedure:

1. Two distinct types of Reynolds number determination are to be used:
 - a) Starting with laminar flow, increase the velocity gradually until turbulence bursts are observed. Take measurements to determine the upper critical Reynolds number at this point.
 - b) Starting with laminar flow, increase the velocity, while vibrating the tube and watching the nature of the flow disturbance to observe whether it grows or is damped. At the highest flow rate for which the disturbance is still damped, take measurements to determine the lower critical Reynolds number.
2. Each group will make as many determinations as time permits.
3. The inside diameter of the tube is the characteristic length to be used in calculating N_{Re} .

Requirements for Report:

- a. Discuss measurement errors and how to avoid them.
- b. Discuss spectrum of states of flow.
 - I. Laminar flow- no disturbance

2. Transition flows - disturbance may be present, but either dies out or is produced only when tube is perturbed.
- c. 3. Turbulent flow - no laminar flow exists.
- c. Describe experimental technique, i.e., bang on pipe.
- d. Calculate N_{Re} , from the data for each value separately.
- (Each student must make his own independent calculation)

General Remarks:

Students will probably have fits with units and with viscosity values. Be prepared to straighten them out.

PIPE FRICTION

Experiment No: FM. 306

Object: The object of this experiment is to obtain data relating pipe friction factor, f , and Reynolds number N_{Re} , for flow of incompressible fluids in smooth pipes.

References: Shames, Mechanics of Fluids, Art. 10-7, 10-12, Binder - Fluid Mechanics, fourth edition, Art. 8-4 to 8-7.

Organization of Student Groups: Divide the class into six groups. Four groups can be occupied on the apparatus, while the remaining two perform calculations. The group can then be cycled. A suggested scheme for six groups listed as A, B, C, D, E and F is :

<i>WATER</i>		<i>AIR</i>		<i>CALCULATIONS</i>
<i>A</i>	<i>B</i>	<i>C</i>	<i>D</i>	<i>E, F</i>
<i>C</i>	<i>D</i>	<i>E</i>	<i>F</i>	<i>A, B</i>
<i>E</i>	<i>F</i>	<i>A</i>	<i>B</i>	<i>C, D</i>

Theory: The plot of friction factor as a function of Reynolds number (fig. 10-22 of Shames) is actually a compilation of many experimental results. In order to gain an understanding and an appreciation of the utility of this plot, you will compare a curve of f vs. Reynolds number obtained in the laboratory with that given in fig. 10-22. This will give you an idea of the magnitude of the experimental effort represented by this plot.

- Apparatus:
1. Air and water flow piping systems
 2. Barometer
 3. Thermometer
 4. Stopwatch
 5. Pail
 6. Steel tape
 7. Scales

Student must provide one sheet of log-log graph paper.

Procedure:

1. Each group is to make two determinations, one on the air flow apparatus, and one on the water flow apparatus.
2. The friction loss for a single pipe length must be calculated from the pressure drop measurements. The average velocity of the air in the pipe is to be determined by measuring the maximum velocity (which will probably be near the center of the pipe) and applying a factor from fig. 8-10, pp. 117 of Binder. In fig. 8-10, V/u_m is plotted versus Reynolds number based on u_m , where u_m is the maximum velocity and V , the average velocity in the tube.
3. The final Reynolds number and friction factor must be calculated with average velocities.
4. Each individual is to prepare a report considering the results of the entire class.
5. Results are to be plotted on log-log paper. Copy the appropriate curve from page 299 of Shames for comparison. Do not draw a curve for the experimental points but compare the values with those indicated by the curve. Plot air and water results on the same sheet using the same coordinates.

This experiment requires the full cooperation of each person involved in order to finish on time and to obtain good results.

Questions and requirements of report:

- a) Discuss Moody diagram on pp. 299 of Text, and curve of V/u_m in Binder.
- b) Discuss apparatus and demonstrate .
- c) Discuss log-log plot and comparison of experimental points to published curve for smooth pipes.
- d) Why f decreases with increasing Reynolds number ?
- e) Why loss values are not the same in air and water pipes ?
- f) Why head loss is constant along the pipe ?
- g) Errors such as : small range of N_{Re} , small number of tests, varying water head , varying pipe diameter , etc.
- h) For the water and air flow units the first static pressure tap was placed several feet from the pipe inlet. What is the reason for this? Explain the why behind the reason.

i) Which assumption is (probably) responsible for the difference between your results and those of fig. 10-22 ? Indicate whether the assumptions will tend to increase or decrease your f values with respect to those of fig. 10-22 .

k) It is known that a large head loss is associated with turbulent as compared to laminar pipe flow . Explain.

LIMITING PIPE FLOW

Experiment No: FM. 307

Object: The object of this experiment is to study limiting flow in pipes, and to compare the pressure gradients of incompressible and compressible flows.

Reference: Shames, Mechanics of Fluids, Art. 13-9, 13-17

Organization of student groups: This experiment is conducted with the entire group. With the help of the instructor, one student manipulates all of the valves and reads the manometers. Another student will record values and post them for the class.

Apparatus:

- 1) Pipe with a nozzle at the inlet and with pressure taps being 7 in number and each 28 in. apart
- 2) Vacuum pump
- 3) Manometers

Procedure:

- a) Control all valves slowly.
- b) Demonstrate limiting flow by varying the receiver pressure below limiting pressure in the pipe. The pressure distribution along the pipe will continue to change with the receiver pressure until the limiting condition is reached.
- c) Obtain data showing the pressure distribution in the pipe for the case where the flow can be treated as essentially incompressible.
- d) Observe the change in the pressure distribution along the pipe as the receiver pressure is reduced. Record the pressure distribution for limiting flow in the pipe, i.e., for the case of minimum receiver pressure.
- e) Record the data necessary to fill in the data sheet.
- f) The students should analyze the method for finding the temperature at the exit. It is obviously not an isentropic expansion.
- g) No temperature correction is needed for the barometric reading.
- i) P_1 and T_1 are at the pipe entrance, and not room conditions. Assume the flow through the nozzle is isentropic.

Questions and requirements of Report:

- a) Explain the arrangement of the equipment .
- b) Explain the use of manometer boards.
- c) Assuming reversible adiabatic flow through the inlet nozzle, calculate the inlet Mach number and Reynolds number for the case of limiting flow in the pipe.
- d) Assuming the pipe to be smooth, calculate, for the minimum flow condition, the friction factor based on the inlet Reynolds number.
- e) For the condition of minimum receiver pressure, calculate $f^{k/H} L$ value for each station. Use the friction factor based on the inlet Reynolds number.
- f) Assuming adiabatic flow, plot the Mach number distribution along the pipe.
- g) Plot the ratios of pressure along the pipe to the inlet pressure vs. distance along the pipe for the actual case as measured. Use data for the case of minimum receiver pressure.
- h) For comparison, assume incompressible flow and plot, on the same graph as in part (g), the pressure ratio based on the pipe inlet conditions.
- i) Assuming adiabatic flow with friction, calculate the temperature of the air at the exit of the pipe.

1. For the case of incompressible flow in a pipe, under what conditions will the pressure distribution be linear ?

2. Explain the observed change in the pressure distribution which resulted from decreasing the receiver pressure .

3. The friction factor calculation is based on the inlet Reynolds number, yet f is assumed constant along the pipe. Is this assumption reasonable ?

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FM. EXP: 307

DATA SHEET

Date _____

Barometric Pressure _____ in. Hg.

Temperature _____ °F

Observed Data:

Distance between pressure taps is 28 in.

Absolute Receiver Pressure	Manometer Readings, in. of Hg							Receiver Pressure in. Hg. Vac.
	1	2	3	4	5	6	7		Atm
non-limiting pipe flow								
limiting pipe flow								

Calculated Results:

Receiver Pressure Condition	Absolute Pressure, in. of Hg							Receiver Pressure in. Hg. Abs.
	1	2	3	4	5	6	7	
limiting pipe flow								

Ma_1 _____ N_{Re1} _____ f _____

Station	1	2	3	4	5	6	7
$f \frac{K}{H} L$							
M							
$\frac{P}{P_1}$							

Exit Air Temperature _____ °F.

PIPE FLOW AND FLOW MEASURING

Experiment No: FM.308

Object:

- 1) To find the friction factor, f , for various lengths of pipe at three different discharge rates.
- 2) To find the friction factor, K , for various pipe fittings, at the same three discharge rates.
- 3) To compare these values with values determined by the estimate method of the textbook.
- 4) To plot the energy diagram for the pipe line.

References: Prandtl, Essentials of Fluid Dynamics, PP.161-171
Munzaker and Wrightaire, Engineering applications of Fluid Mechanics, Chapter 8.

Introduction:

This experiment provides a means of studying two fundamental problems associated with the flow of liquids through pipes, first, that obtaining an accurate and continuous measure of average velocity or mass flow, and second, that of predicting energy losses due to viscous friction. Both are basic to the branch of applied fluid mechanics, known as Hydraulics.

It is standard practice in hydraulics to derive the desired information from standardized obstructions to the flow, known as venturi, meters, flow nozzles or orifice plates. This is done by relating the mass flow measured in some other way to the static pressure difference between the upstream flow and the section of contracted flow. These meters have no moving parts, are efficient to operate, and give a good measure of average quantities.

Due to the high viscosity of liquids as compared to gases, the question of friction losses occupies a position of far greater importance in hydraulics than in ventilation engineering. It is usual to correlate information on losses in pipe flow in terms of a dimensionless friction factor, f , which is defined as the ratio of the pressure drop per unit length to the dynamic pressure, multiplied by the diameter.

$$f = \frac{\Delta p}{l} \cdot \frac{2}{\rho V^2} \cdot D$$

Dimensional analysis shows that f , should be a function only of the Reynolds number $\frac{vD\rho}{\mu}$ of flow, if the pipe is smooth. What this function is of course, can not be predicted from dimensional analysis, but experimental results show two distinct regions, corresponding to laminar and turbulent flow as observed in the Reynolds experiment, and logical theories can be derived to account for the form of, F vs Re in each region (though not in between). The value of f in the turbulent region is critically dependent on wall roughness inside the pipe.

Apparatus:

Pump, pipes apparatus, pressure gages, water and mercury manometers, venturi meter, flow nozzle, metering orifice.

Procedure:

- 1) Calibrate any two of the metering devices provided, by measuring drops for at least five velocities, using the volumetric tank to determine mass flow.
- 2) Three rates of discharge are to be used, to complete set of data being taken at each rate. During each of these runs it will be necessary to measure, the discharge rate, water temperature, and the various pressure differences at the different taps as listed on the data sheet of experiment FM. 03 of Part I.

Requirements of report:

- 1) Plot calibration curves for the flow meter studied, and compare them regarding efficiency, and closeness of approach to ideal flow relations
- 2) Make the necessary calculations to fill the blanks in the sheet given.
- 3) Plot the energy diagram without using experimental data
- 4) Plot the energy diagram, using the experimental data, to show discrepancies.

VISCOSITY MEASUREMENTS

FM 4CI : Measurement of water viscosuty by the capillary
tube method

VISCOSITY MEASUREMENT

Experiment No: ME . 401

Object: The object of this experiment is to measure the viscosity of water by the capillary tube method.

Reference: Shames, Mechanics of Fluids ,Art. 10-9.

Organization of student groups: Divide the class in groups of five.

Theory: The viscosity of water is going to be measured by the capillary tube method. In the calculations the Hagen-Poiseuille law is used.

$$\mu = \frac{\Delta P D^2}{32 L V}$$

$$\mu = \frac{\pi \Delta P D^4}{128 Q L}$$

or

where: Δp = pressure difference, lb/ft².

L = length of tube ,ft.

D = internal diameter of tube ,ft.

V = average velocity in tube , ft/sec.

Q = volume rate of flow ,ft³/sec.

μ = dynamic viscosity ,slug/ft-sec.

This law is valid only for laminar flow. The type of flow can be determined by calculating the Reynolds number. An accepted value of viscosity should be used in the Reynolds number calculations.

Several factors can have a marked influence on the readings obtained, and can be the cause for poor agreement between experimental and published results. These include :

1. Fluctuations in head reading, this may be minimized by keeping the water flowing into the overflow cup as far from the capillary inlet as possible.

2. Vibrations and surges or other unsteadiness of flow may be due in part to the surface tension of water in the overflow cup.

3. Temperature gradients through the apparatus.

4. Laminar flow not fully developed. Even though the Reynolds number indicates the apparatus is operating in the laminar flow regime, it may not be fully developed, giving an error in results.

5. Turbulent flow will obviously give gross error in result. The Reynolds number should be calculated with a published viscosity value to avoid misleading conclusions regarding the flow regime observed.

6. The following conversions are for quickly checking results. It is best to let the student struggle with his own conversions :

$$0.204 \text{ lb/ft}^2 = 1 \text{ mm water}$$

$$3.53 \times 10^{-5} \text{ ft}^3/\text{sec} = 1 \text{ cm}^3/\text{sec}.$$

$$\frac{\pi D^4}{128 L} = 2.55 \times 10^{-10} \text{ ft}^3$$

$$\mu = \frac{h(\text{in mm}) \times 0.204 \times 2.55 \times 10^{-10}}{Q(\text{cm}^3/\text{sec}) \times 3.53 \times 10^{-5}} \frac{\text{slug}}{\text{ft-sec}}$$

$$\mu = \frac{h(\text{mm})}{Q(\text{cm}^3/\text{sec})} (1.475 \times 10^{-6}) \text{ slug/ft-sec}$$

$$\text{or } \mu = \frac{h(\text{cm})}{Q(\text{cm}^3/\text{sec})} (1.475 \times 10^{-5}) \text{ slug/ft-sec}.$$

Thus, h/Q should be about 1.3 sec/cm^2 to obtain a viscosity of about $1.3 \times 10^{-5} \text{ slug/ft-sec}$, which is an appropriate value for water at room temperature.

Caution : Be especially careful that the lines are purged of air at all times. The readings to be taken are quite small and any carelessness in their measurement will result in a sizeable error.

The water used must be distilled water.

Apparatus: For each viscometer a 60 vcc of graduate

Two catch beakers

Thermometer

Stopwatch

manometers

Procedure: Collect data to fill the data sheet

The measurements and calculations of each group will be reported on the blackboard.

Requirements of report:

- A) Briefly discuss the apparatus, pointing out :
1. that water must be in lines at all times.
 2. that distilled water must be used .
 3. that a constant overflow must be maintained.
- B) Discuss how the results obtained by your class compare with the published data.

FM. EXP: 401

DATA SHEET

Data and Results:

Date _____

Group Number _____

Temperature _____ °F

Right Manometer _____ mm. H₂O

Volume _____ cm³

Left Manometer _____ mm. H₂O

Time _____ sec.

Pressure Drop _____ mm. H₂O

Tube Length 15 in.

Tube Diameter 0.128 in.

Composite Results

Group Number	<i>h</i> (cm. H ₂ O)	Temperature (°F)	Reynolds Number	Viscosity (slug/ft-sec. x 10 ⁵)	Percent Error
1					
2					
3					
4					
5					
6					
7					
8					
Average					

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MOMENTUM STUDY

FM 501 : Jet deflection

FM 502 : Force on elbow

JET DEFLECTION

Experiment No: FM. 501

Object: The object of this experiment is to make a momentum study of the deflection of a water jet caused by the partial insertion into the jet of (1) a thin plate and (2) a cylinder.

Reference: Shames, Mechanics of Fluids ,Art. 5-3 to 5-5.

Organization of student groups: Divide the clas into groups of 3.

Apparatus: Jet deflection equipment

Basins

Stopwatch

Scales

Procedure:

1. The flow system should be flushed to remove air before the experi - ment.

2. With the knife edge inserted into the jet so that all of the water which is deflected directly by the knife edge leaves the jet in a direc - tion normal to the original jet axis, measure the flow rates of the two resulting streams. From these measurements, calculate the deflection angle of the principal stream and compare the calculated value with the measu - red value.

3. Water for the jet is taken from the building water supply in which there are occasional pressure fluctuations. If such a fluctuation occurs during a measurement, this measurement should be repeated.

4. Insert the cylinder partially into the jet and observe the nature of the jet deflection.

5. Use the largest deflection obtainable with two-well defined stre - ams coming from the knife edge.

Caution:

a) it is easy to get wet, for the student, if the supply valve is open - ed too far.

b) Air bubbles and line pressure variations must be watched for.

Requirements of Report:

1. Show all calculations, listing all assumptions.
2. Discuss possible errors introduced by these assumptions.
3. Discuss sources of error in the experimental measurements.
4. Explain why the cylinder deflects the stream as it does.
5. Explain water hammer and the reduction of water hammer by the use of air chamber. Point out:
 - a) the serious problem posed by water hammer in a high - head hydraulic power plant when the electrical load is suddenly dropped.
 - b) the methods that have been used to solve the problem.
 - c) the possibility of deflecting the turbine jet by means of a knife edge or cylindrical deflector.
6. Explain the use of basic momentum equation. Discuss some of the assumptions which are useful in analyzing the flow.

FORCE, ON ELBOW

Experiment No: FM. 502

Object: The object of this experiment is to apply the linear momentum equation to the calculation of a " bend force " and to compare the calculated value, with one determined experimentally .

Reference: Shames, Mechanics of Fluids, Art. 5-3 to 5-5 .

Organization of student groups: Divide the class into groups of 3.

Apparatus: Elbow with spring arrangement
1000 ml. beaker
Set of scale weights
Stopwatch

Procedure:

- I. Each group will experimentally determine the water flow rate required to produce a certain reaction force on the elbow .
 - a) The maximum force which can be applied to the apparatus will be determined.
 - b) The maximum force for each apparatus will be posted on the board for the use of groups performing calculations.
 - c) The water flow rate which gives a deflection equal to that produced by the force determined in (a) will be measured.

2. Each student will calculate the water flow required to produce the force determined in (1a).

3. The weights are in rather large increments, and this is why the weights are established and the flow rate is adjusted instead of vice versa.

Questions and requirements of Report :

1. Discuss the general arrangement of the apparatus, and point out that most of the calculations can be made before the experiment is run.
2. Make a comparison and discussion of the calculated and measured flow rates.
3. What assumptions involved in the calculations may not be fully justified ?
4. What assumptions or approximations are involved in the measurements?

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FM. EXP: 502

DATA SHEET

Observed data and calculated values for determining flow rate:

Trial Number	Tare Weight	Gross Weight	Tare Weight (lb)	Gross Weight (lb)	Net Weight (lb)	Flow Rate (lb/sec)

Inside tube diameter = _____ in.
Amount of weight used on pan = _____ lb.
Measured mass rate of flow m_{meas} = _____ lb/sec.

WIND TUNNEL AND COMPRESSIBLE FLOW EXPERIMENTS

- FM 601 : Wind tunnel velocity measurements
- FM 602 : Pressure distribution around a cylinder
- FM 603 : Drag measurements
- FM 604 : Boundary layer study
- FM 605 : Compressible flow in a converging nozzle
- FM 606 : Schlieren study

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WIND TUNNEL VELOCITY MEASUREMENTS

Experiment No: FM. 601

Object: The object of this experiment is to measure the air velocity in the test section of a wind tunnel at several fan speeds and to determine the velocity profile at one speed.

Organization of student groups: Divide the class into groups of 4.

Apparatus: Vertical traversing Pitot tubes (permanently mounted to wind tunnels)
Inclined tube manometers
Thermometer (for air temperature measurement)

Procedure:

1. Obtain Pitot tube readings at the center of the tunnel for each speed setting.
2. Make a vertical Pitot tube traverse of the tunnel at one speed setting.
3. Observe barometric pressure and room air temperature.
4. The velocity profiles observed in the tunnels should be quite flat. The lowest velocity should not be less than about 90 % of the average value. The tunnel centerline velocities should be approximately:

Position 1	35 fps
Position 2	45
Position 3	55
Position 4	60

Requirements of Report:

1. Discuss the arrangement of the wind tunnel and the desirability of a flat velocity profile in the test section.

2. Derive the Pitot tube equation, and exhibit and describe the sample pitot tube from the supply cabinet.

3. A graph indicating the velocity profile for the test section.
Plot square root of pitot tube vs. position.

4. Discuss the plot of results, pointing out that $\sqrt{\Delta P} \sim V$,

where:
$$\Delta P = P_{total} - P_{static}$$

5. Discuss the arrangement of the Pitot tube traversing mechanism.

FM. EXP: 601

DATA SHEET

Speed Setting	Pitot Tube Reading at Centerline (in. of water)	Velocity (ft/sec)	Velocity Profile for Speed Setting		
			Pitot Tube Position (in)	Pitot Tube Reading (in. of water)	Square Root of Pitot Tube Reading
1			+6	Top	Wall
2			+5		
3			+4 1/2		
4			+3		
Corrected Barometer Reading: _____ in. Hg. Temperature _____ °F.			+1 1/2		
			Center Line		
			-1 1/2		
			-3		
			-4 1/2		
			-5 3/4		
			-6	Bottom	Wall

PRESSURE DISTRIBUTION AROUND A CYLINDER

Experiment No: EM. 602

Object: The object of this experiment is to determine the values of the critical angle and the pressure distribution around a cylinder at one Reynolds number, and to compare the total pressure in the test section of the wind tunnel with the barometric pressure.

Reference: Shames, Mechanics of Fluids, Art. 5-15 to 5-17, 8-16.

Organization of student groups: Divide the class into groups of four. each group should experiment with pitot tube and cylinder assembly before taking readings.

Apparatus: Cylinder assembly
Pitot tube
Inclined tube manometer
Thermometer
Barometer

student must supply one sheet of polar graph paper.

Procedure:

1. Determine the pressure distribution around a cylinder at one air velocity (velocity pressure approximately 0.5 in. of water)

2. Make a polar plot of the pressure coefficient. The graph must be titled and the flow direction and velocity indicated.

The pressure coefficient is defined as:

$$C_p = \frac{P_c - P_o}{1/2 \rho V_o^2}$$

where:

P_c = Pressure at a point on the surface of the cylinder

P_o = Static pressure of undisturbed air stream

ρ = Density of air

V_o = Velocity of undisturbed air stream
 C_p = Pressure coefficient, dimensionless

3. Check alignment of pointer by making sure that maximum pressure reading occurs at 0 degrees.

4. Check interference effect of pitot tube upstream by varying position while reading pressures at cylinder.

Caution:

In comparing the total pressure in the tunnel with the barometric pressure, the cylinder and cylinder manometer should be used. The rubber tubing connections to the cylinder may be altered.

Requirements of Report:

- a) Discuss apparatus
- b) Define pressure coefficient and critical angle.
- c) Discuss possible errors in the experiment due, among other things, to wall effects, cylinder diameter effect, pitot tube presence, and other factors
- d) Discuss energy equation as applied to the comparison between total pressure in the tunnel and ambient pressure.
- e) Discuss the polar plot and the amount of data to be taken. Increments of 10 degrees out to 180 degrees with a check of the other half of the cylinder are satisfactory.

Questions:

1. Why velocity head at pitot tube differs from that at cylinder?
2. Why critical angle measured experimentally is different from that predicted by potential flow?
3. Why total pressure in tunnel is different from atmospheric pressure?

DRAG MEASUREMENTS

Experiment No: FM. 603

Object: The object of this experiment is to determine drag coefficients for several different objects at various Reynolds numbers.

References: Shames, Mechanics of Fluids, Art. II-9, II-10
 Binder, Fluid Mechanics, 4th. edition, Art. 10-1 to 10-6
 pp. 165 - 173
 Streeter, Fluid Mechanics, 3rd. edition, Art. 5-5, 5-6
 pp. 205 - 210.

Organization of student groups: Divide the class into groups of two or three.

Theory:

The Reynolds number and drag coefficient are defined by the relations

$$N_{Re} = \frac{\rho \bar{V} d}{\mu} \quad ; \quad C_d = \frac{F_d}{\frac{1}{2} \rho \bar{V}^2 A}$$

where:

- ρ = Fluid density, slug/ft³
- \bar{V} = Average fluid velocity, ft/sec.
- d = Characteristic length, ft.
- μ = Dynamic viscosity, slug/ft-sec.
- F_d = Drag coefficient, lb.
- A = Projected area of object normal to the stream, ft².

Apparatus: Drag model support mechanism
 Scale
 Weights
 Thermometer
 Barometer
 Calipers
 Ruler
 Drag models

Procedure:

1. Each group is to make two drag measurements on a particular model in the wind tunnel, one at a low velocity and one at a high velocity.
2. The results of each group will be posted on the blackboard.
3. On the results sheet a space is provided to list C_d values obtained from the references. These should be determined at the proper Reynolds number. Be sure the text refers to the same shape and orientation. Note that Shames' Fig. II-14 is not correct for a sphere.
4. The complete report form as indicated in the General Notes should be followed.
5. This experiment will be performed with a minimum of instruction by the instructor. Be sure to make a careful force analysis of the model support mechanism.

Requirements of Report:

- a) Take necessary measurements to fill the data sheet.
- b) Calculate U_{Re} and C_d .
- c) Plot c_d versus N_{Re} .
- d) Compare the measured values of C_d with those from published data.

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BOUNDARY LAYER STUDY

Experiment No: Fl. 604

Object: The object of this experiment is to observe and analyze the velocity profile in the boundary layer at several positions along the wall of a diffuser. The static pressure gradient along the diffuser wall will also be measured and the effect on the boundary layer growth noted.

Reference: Shames, Mechanics of Fluids, Art. II-1, II-2, II-7.

Organization of student groups: Divide the class into groups of 5.

Apparatus: Masonite diffuser sections installed in wind tunnel
Boundary layer probes and traverses
Manometers
Barometer
Thermometer
Inclined manometer bank

Each student must supply 2 sheets of graph paper.

Procedure:

1. Each group will make a traverse of the boundary layer at one station. Readings should be taken starting from the wall and proceeding outward into the stream until the full boundary layer has been traversed. Read also all static pressures.

2. One complete set of readings of the static pressures at the six positions should be taken. These pressures should be read as nearly simultaneously as possible.

3. At a certain speed of the wind tunnel fans, stations 1, 3 and 5 should be used for boundary layer traverses, with readings taken every 0.05 in. (0.05 in. = 1 turn of lead screw)

- a) Care must be given when moving the traverse mechanism from one station to another. The scale may have to be adjusted so that it reads zero in. with the probe hole bisected by the wall.

- b) The static pressure connections through the brass tee must be correctly changed when the pitot tube is moved to a new station.
- c) The manometer for static pressures contains oil, but is inclined to read in in. of water.

4. Each group will record the dynamic pressure profile for its station and post the values on the board.

5. Each student will make a copy of the results for the wind tunnel used by his group.

Requirements of Report:

1. The complete report form, as indicated in general notes, should be followed.

2. Explain the relationship between dynamic pressure and velocity

3. Plot the dynamic pressure profiles for the tunnel.

4. Plot static pressure in in. of water gage vs. distance along the test section wall.

5. Calculate axial pressure gradient. (A sketch of test section will be required indicating the shape of the channel). Is the pressure gradient positive or negative?

6. Calculate the free stream velocity in the tunnel.

7. Discuss and explain whether the wall shear stress increases or decreases along the tunnel wall.

Appendix to FM.EXP. 604

It is suggested that a water table demonstration of diffuser separation and the viscous sublayer be made while other groups work on the wind tunnel. The following are some of the concepts which can be demonstrated and discussed.

a) Diffuser separation:

- 1) Widen first one side of the diffuser and then the other to demonstrate how a region of fixed stall attaches itself to the wall with the largest diffusion angle.
- 2) With a symmetrical but large diffusion angle it is difficult to predict which side will stall, the stall pattern can oscillate from side to side.

b) The laminar sublayer; the viscous sublayer, and the transition phenomenon may be illustrated using a narrow diffusion angle.

- 1) Laminar sublayer - Make a dye trace across the bottom of the channel ahead of the contraction. Notice how the dye spreads out smoothly across the surface of the glass channel bottom.
- 2) Viscous sublayer - Make a dye trace across the bottom of the channel well downstream of the contraction. Notice how the dye forms small vortices whose axis line up in the streamwise direction.

c) Transition region :

Make dye traces just downstream of the contraction on the bottom of the channel. You should be able to inject dye into regions of local stall such that the dye will flow upstream against the main current. This illustrates the action of the adverse pressure gradient on the laminar sublayer, i.e. the fluid next to the wall is brought to a halt and then is reversed in direction causing a small stall region. The boundary layer then attaches a short distance downstream.

Note: A further discussion of the regions of flow listed above may be found in the paper by S.J. Kline and P.W. Runstadler, "Some preliminary results of the visual studies on the flow model of the wall layers of the Turbulent Boundary Layer" in Trans. ASME, series E, Journal of Applied Mechanics, vol. 26, no. 2, June, 1959, pp. 166 - 170.

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DATA SHEET

Date _____ Speed Setting _____ Tunnel No. _____

Distance from
wall, in.

Station _____
($P_T - P_0$)
in. of water

Station _____
 $P_T - P_0$
in. of water

Station _____
 $P_T - P_0$
in. of water

0.05			
0.10			
0.15			
0.20			
0.25			
0.30			
0.35			
0.40			
0.45			
0.50			
0.55			
0.60			
0.65			
0.70			
0.75			
0.80			
0.85			
0.90			
0.95			
1.00			

Static Pressure

Station	Atm.	1	2	3	4	5	6
Reading in. of water							
Ga. Press. in. of water							

COMPRESSIBLE FLOW IN A CONVERGING NOZZLE

Experiment No: FM. 605

Object: The object of this experiment is to observe the pressure in a converging nozzle with fixed inlet pressures and variable receiver pressure, and to compare the critical pressure ratio with the predicted ratio.

Reference: Shames, Mechanics of Fluids, Art. 13-2, 13-5, 13-14.

Organization of student groups: This experiment is conducted with the entire group. The instructor manipulates all of the valves and a student reads the manometers while another student records and posts them on the blackboard.

Apparatus:

- Converging nozzle mounted to the wind tunnel
- Manometers
- Vacuum pump
- Thermometer
- Barometer

Procedure:

1. Ample time is available in the laboratory period to run through the experiment several times for effect before taking data.
2. Control all valves slowly
3. Operate the equipment while readings are recorded by each student on the data and results sheet.
4. One set of readings will be taken with the receiver pressure well above the critical pressure.
5. Note carefully the behaviour of the throat pressure with decreasing receiver pressure.
6. A final set of readings will be taken with the lowest receiver pressure attainable.
7. Note that no temperature correction need be applied to the barometer reading.

Requirements of report:

- a) Explain the arrangement of apparatus.
- b) Take necessary data to fill the data sheet
- c) Make the necessary calculations to fill the results sheet.
- d) Discuss sources of error, accuracy of results, give reasons for deviations.

FM. EXP: 605

DATA SHEET

Date _____ Group _____

Data and Results:

Room Temperature _____

Barometric Pressure _____ (Inches of Mercury at room temperature)

Gage Readings _____ (Units)

Receiver Pressure Condition	Manometer Readings			
	Inlet	Throat	Receiver	Atmosphere
Above Critical				
Below Critical				

Absolute Pressures _____ (Units)

Receiver Pressure Condition	Atmos. P_a	Inlet P_1	Throat P_t	Receiver P_2	Ratios	
					P_1/P_a	P_2/P_a
Above Critical						
Below Critical						
Calculated Critical Pressure Ratio for $K = 1.4$						

SCHLIEREN STUDY

Experiment No: FM. 606

Object: The object of this experiment is to observe some of the optical methods of flow visualization. The schlieren system will be demonstrated with a reflecting and with a refracting optical system.

Reference: Shames, Mechanics of Fluids, Art. 13-12 to 13-13 and Appendix A-7, pp. 528 - 535 .

Organization of student groups: Divide the class into two groups.

Apparatus: Vacuum wind tunnel system
Models
Other schlieren apparatus

Procedure:

1. The instructor will operate the equipment.
2. Flow around one or more models in the two-dimensional supersonic nozzle will be demonstrated.
3. Free jet flow from a converging nozzle will be demonstrated.

Suggestions: The students should look for the following points in the schlieren images:

1. Two-dimensional nozzle
 - a) Attached shock Mach angle
 - b) Detached shock
 - c) Disturbances in wake
 - d) Separation in nozzle
 - e) Expansion waves.
 - f) Standing normal shocks when model "blocks" the flow.
2. Free jet
 - a) Repetitive pattern (compare with fig. 13-23 in Shames)
 - b) Effect of varying nozzle inlet pressure.

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Requirements of Report:

1. Draw a simple sketch of the two optical systems used.
2. Make a rough estimate of the Mach number at the leading edge of the diamond shaped model. Note that the included angle of the leading edge is 15 degrees.

General Remarks:

It is advisable to experiment with the equipment before running the experiment to secure well defined flow patterns.

FLOW IN OPEN CHANNELS

EM 701 : Flow in open channels

(Measurements in open channels and hydraulic jump)

FLOW IN OPEN CHANNELS

Experiment no: FM. 701

Object: The object of this experiment is to familiarize the student with measurements in open channel flows and hydraulic jumps.

Reference: Streeter, Fluid Mechanics, pp. 119-120, 387-393 on hydraulic jumps.
pp. 220, 323, 324, on V-notch weirs

Theory:

Introduction: The measurement of flow discharges in rivers, irrigation ditches, flumes and spillways involves the use of such devices as weirs, depth gages, and total head tubes. Sluice gates are used to control the flow in open channels branching off a main flow or a reservoir. Approximate theories of the operation of these measurement and control devices are fairly simple, but only moderately successful. They are often used with empirical corrections in engineering calculations. Precise and detailed theories are very complicated (when available). By use of the weighing tank and a stop watch it is possible to "calibrate" the weirs, i.e. make the empirical corrections mentioned above. Another check, can be made by surveying the flow cross-section with the total head tube, either upstream or downstream.

Hydraulic jumps are waves in channel flow across which a rapid increase in depth occurs. The flow velocity ahead of the "jump" is greater than (c) , the speed of small surface gravity waves ($c = \sqrt{gh}$, where $h = \text{depth}$), and downstream the velocity is less than the local wave speed. Hydraulic jumps are analogous to shock waves in gases where the velocity is supersonic ahead, subsonic behind the shock wave.

Apparatus: Flume, recirculating circuit, weighing tank
90 deg. triangular weir
Depth gage
Total head tube
Pressure taps in floor of flume
Manometers, stopwatch
Sluice gate

Smooth "bump" on bottom of flume

Procedure:

a) Flow over a weir

1. Set up a steady flow in the flume with the 90 deg. triangular weir in place.
2. Measure the height of the water above the apex of the weir.
3. Measure the flow rate by determining the time to fill weighing tank by a certain amount.
4. Vary the flow rate and take sufficient data to plot a curve of mass flow vs. head on the weir.

b) Hydraulic Jump

1. Remove weir and install upstream sluice gate. For two upstream sluice gate settings at constant flow rate adjust downstream sluice gate so that a stationary hydraulic jump is obtained.
2. Measure the flow rate and the depth and total head ahead and behind the hydraulic jump.
3. Raise downstream sluice gate so that jump is "washed away" and make a depth and total head survey at two downstream positions so that the flow may be calculated.
4. Repeat (2) for another flow rate.
5. Vary the head on the sluice gate and the flow rate and observe the possible forms of the hydraulic jumps. Use the wave making paddle and note relation of wave speed to strength of jump.

Requirements of Report:

- a) Plot mass flow vs. head on the weir and compare with "weir formulae" from references.
- b) Compare your depth and total head measurements across the hydraulic jump with the inviscid theory of the jump. Briefly discuss your observations of (b5).

FLUID MACHINERY

- FM 801 : Test of an air compressor
(same as presented in experiment FM.05, Part I)
- FM 802 : Test of a triplex pump
(same as presented in experiment FM.06, Part I)
- FM 803 : Test of radial fan with forwardly curved blades
(same as presented in experiment FM.07, Part I)
- FM 804 : Test of a Pelton wheel model runner

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TEST OF A PELTON WHEEL MODEL RUNNER

Experiment No: EM .804

Object: To obtain characteristic curves of the model runner, under varying conditions of head, discharge and load and to determine the efficiency of the runner.

Reference: Hunsaker and Rightaire PP. 341 - 345

Theory: The effective head for impulse wheels (assuming the nozzle as part of the wheel) is :

$$h = \frac{V_i^2}{2g} + \frac{P}{w}$$

i.e. approach velocity head plus pressure head. Looking upon the turbine wheel as a kind of orifice, the discharge would follow the laws of discharges through orifices under variable head. Consequently,

$$Q = CA\sqrt{2gh} \quad \text{ft}^3/\text{sec.}$$

where, C varies with the value of φ , the speed ratio. Other means of measuring discharge than this formula are usually used in tests.

The power input to the wheel will be:

$$WHP = \frac{Q \cdot w \cdot h}{550}$$

The linear velocity, u of the runner corresponding to its nominal diameter, D (to centerline of buckets for impulse wheels) may be expressed in terms of the velocity corresponding to the effective head, h , (theoretical jet speed) by:

$$u = \varphi \sqrt{2gh}$$

where: φ is the speed ratio or relative speed coefficient ranging between 0.45 and 0.47 for the impulse wheel. This speed ratio will be

$$\varphi = \frac{\pi DN}{60 \cdot 12 \sqrt{2gh}} = \frac{1}{1840} \cdot \frac{DN}{\sqrt{h}}$$

where: n is RPM., and D is in inches. Evidently there will be a best value of φ , corresponding to the speed and gate (discharge) which gives the highest wheel efficiency, η (i.e., the full load point).

Based upon the foregoing relations, general formulae for speed,

discharge and power of a wheel may be written :

$$(1) \quad N = 7840 \varphi \frac{\sqrt{h}}{D} = N_u \frac{\sqrt{h}}{D}$$

Hence, speed coefficient $N_u = \frac{ND}{\sqrt{h}}$.

$$(2) \quad Q = Q_u D^2 \sqrt{h}, \quad Q_u = \frac{Q}{D^2 \sqrt{h}} \quad (\text{discharge coefficient})$$

$$(3) \quad HP = P_u D^2 h^{3/2}, \quad P_u = \frac{HP}{D^2 \cdot h^{3/2}} \quad (\text{power coefficient})$$

An inspection of the three coefficients, assigning unit values to h and D , shows that N_u , Q_u and P_u , are the speed, discharge and power for a 1 inch wheel, acting under a 1 ft. head. There are evidently an indefinite number of values of N_u , Q_u , and P_u , for a given wheel, depending on gate and speed. Their ranges as usually given for a type of wheel. Refer to the full gate (maximum power) rather than the full load point. (gate setting for best efficiency).

These coefficients are of great importance in the design of turbines. The ranges of these values for efficient operation, being known from tests for each type or "series" of wheels. Equation (1) is used to select the size of wheel required for a given value of N . Equation (3) to select the size of wheel to give a certain HP. By combining these equations, a single relation may be obtained taking into account both speed and power as follows:

$$\text{from (1)}, \quad D^2 = N_u^2 \frac{h}{N^2}$$

$$\text{from (3)}, \quad HP = P_u D^2 h^{3/2} = P_u N_u^2 \frac{h^{5/4}}{N^2}$$

$$\text{Therefore, } N \frac{\sqrt{HP}}{h^{5/4}} = \sqrt{P_u} \cdot N_u = N_s \quad (\text{specific speed}).$$

Assigning unit values to HP and h , $N_s = N$. This means that the specific speed is the speed of a hypothetical wheel of the series when delivering 1 HP and a 1 ft. head. It is a constant for any given turbine wheel.

For the impulse wheel, the coefficients for efficient operation should have values (at full gate point) in the following ranges:

$$N_u = 800 - 1000$$

$$Q_u = 0.0002 - 0.0005$$

$$P_u = 0.00002 - 0.00005$$

$$N_s = 3 - 6$$

In testing a model runner under conditions not corresponding to such as would be held in practice to indicate the choice of that type of turbine, the values found in tests may well fall outside these ranges, showing that for this test conditions another wheel type would have been selected to be correspondingly lower than normal.

Requirements of report:

- 1) Discuss apparatus used, including the surge tank and results.
- 2) Using the data obtained (heads between 110 and 150 ft., discharges varied for each constant head, load varied for each discharge), plot N_u against Q_u .

3) At each given head, and for each discharge used under this head, Q will be constant (vertical line), but several values of N_u will be obtained on that vertical line, depending on the varying speed N . At each point obtained, mark the efficiency calculated for this point. (

$$\text{efficiency} = \frac{\text{BHP}}{\text{WHP}}$$

Plot lines of equal efficiency by interpolation. If possible find the region or point of best efficiency from the graph, and determine N_u , Q_u , BHP, efficiency, speed ratio, N_s , P_u at this point.

- 4) Repeat the above procedure for each new head, and see whether the graphs can be combined into one.

Nominal wheel diameter : _____

Brake arm : _____