Chapter II

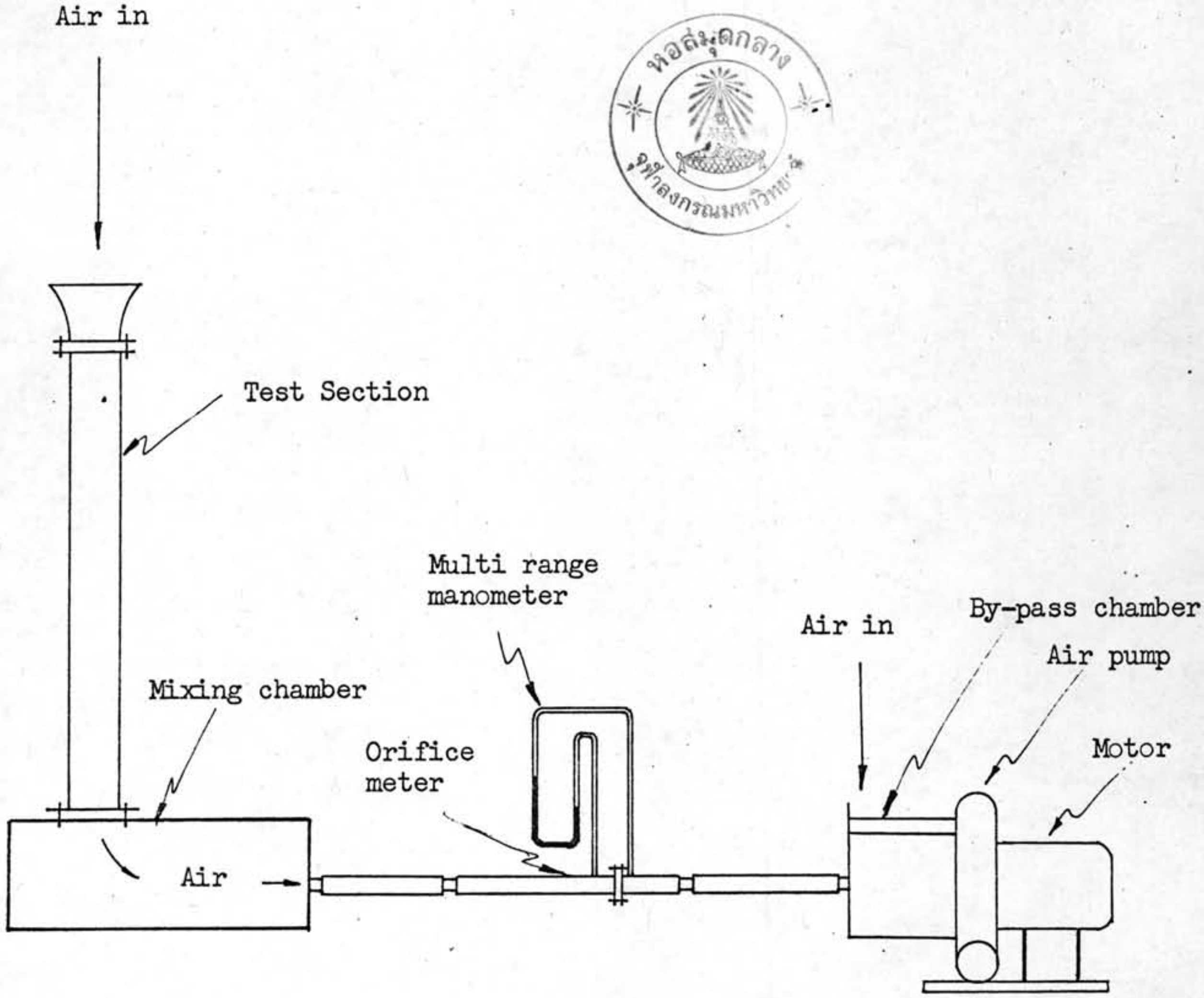
EXPERIMENTAL STUDIES

2.1 Description of apparatus

Fig. 1 shows the general flow diagram of apparatus. The purpose was to provide an apparatus for the investigation of heat transfer phenomena over a number of triangular ducts with different lengths and cross sections. The principal part was the test section, which consisted of a duct, surrounded by a hot water jacket as shown in Fig. 3, to permit the thermal boundary condition of constant wall temperature. In order to obtain such an isothermal wall, the bucket, as also shown in Fig. 3, was maintained at a predetermined temperature. This was controlled by an aqua heating thermostat and contactor relay which operated an electric immersion heater. Heated water was circulated by a centrifugal pump to the hot water jacket. With a discharge valve in service, the quantity of inflow of heated water could be regulated to any required values, if necessary. The test duct was designed with a hydraulically smooth entrance, it was, of course, to ensure that velocities of air at all points on entry plane were equal and the uniform velocity profile was thus established.

From the test section the heated air passed through an insulated mixing chamber which allowed the airstream leaving the test duct to mix evenly. Next the air passed through an orifice meter equipping with a multi range manometer

Fig. 1 General Flow Diagram of Apparatus.



for registering the pressure drop across the orifice plate. The air then passed through a by-pass chamber and a high speed blower. The blower was rightly arranged to permit suction condition of air through all flow passages. With the aid of the by-pass chamber various measurable flow rates could be attained, particularly for low flow rate, namely, Reynolds number not more than 4000. A regulating valve, connecting between the orifice meter and the by-pass chamber (not shown in Fig. 1), was also used to assist the by-pass chamber to regulate as well as retard the flow.

The following subsections would deal with the specific informations of various equipments and instruments.

2.1.1 Test section

There are two kinds of duct geometries involving in this investigation, namely, the equilateral triangular and right-angled isosceles triangular ducts, with opening angles, $2\phi = 60^{\circ}$ and 90° respectively. Both have the hydraulic diameter, d_h, of about 1 in., the lengths being 9 in. and 12 in. approximately. Each duct was made of one strip of copper sheet, about 1 mm. thickness, folded to give the required duct geometry. Both ends of a duct were connected with 4 in.dia. metal flanges. There were a number of thermocouples mounting directly on the surface at each end of a duct. Details of attachment of thermocouples on duct surfaces would be explained in subsection 2.2.2.

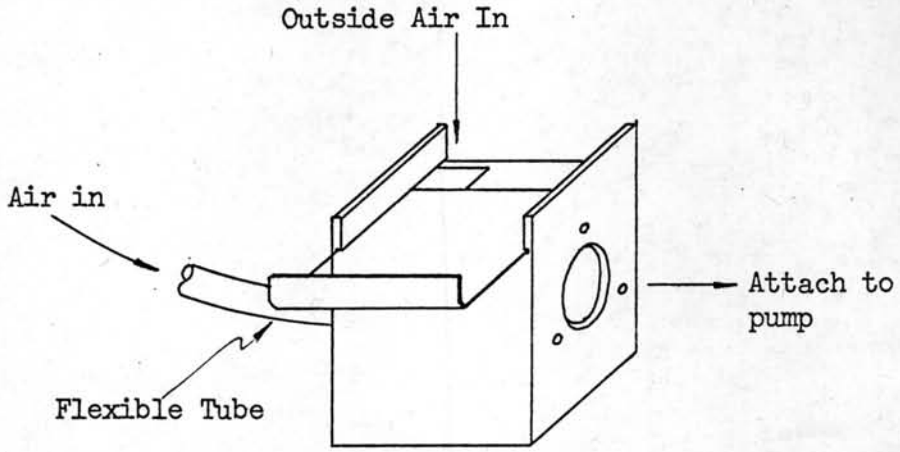


Fig. 2 By-pass Chamber.

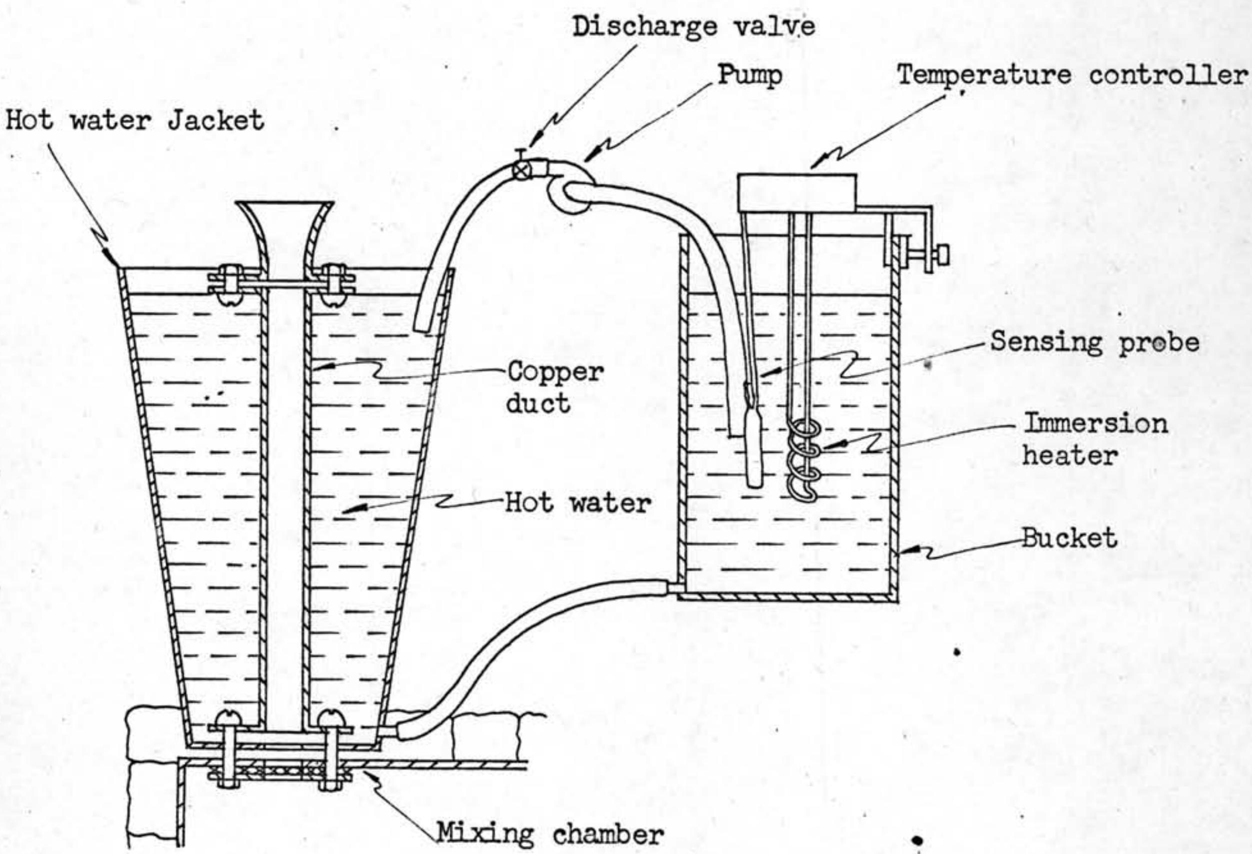


Fig. 3 Test Section for Constant Wall Temperature.

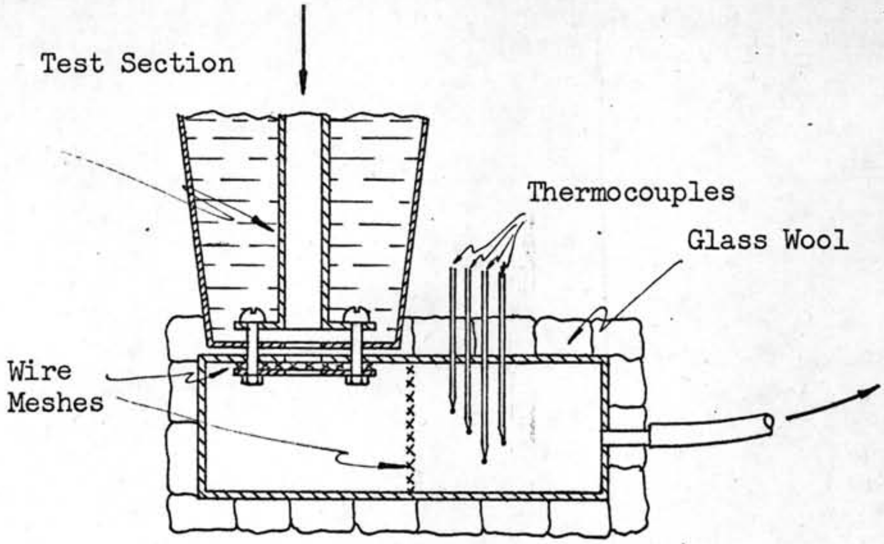


Fig. 4 Mixing Chamber.

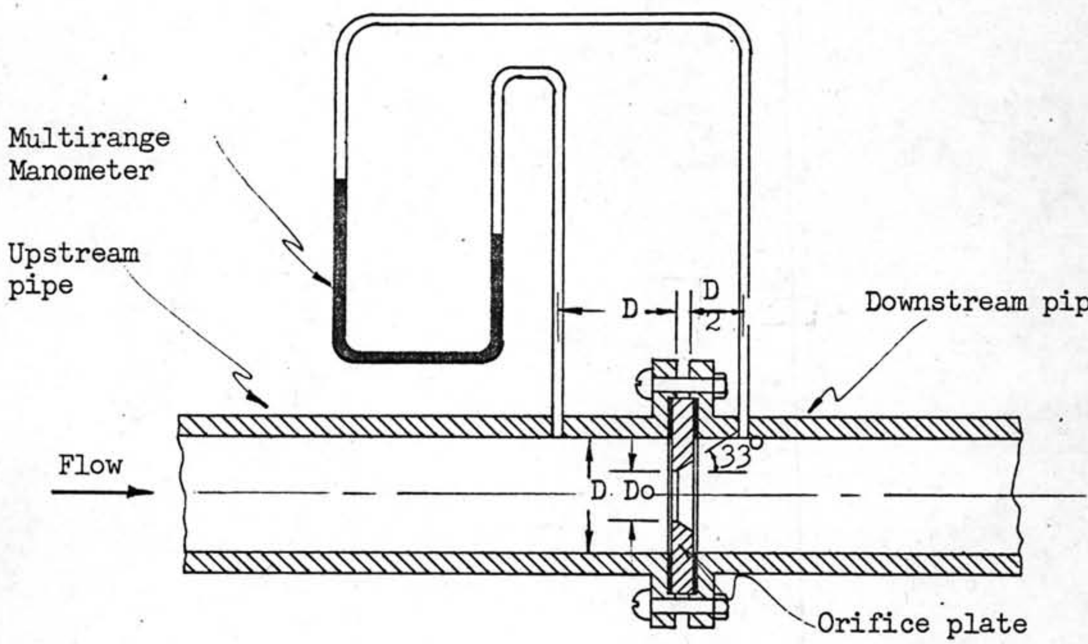


Fig. 5 Orifice Meter Assembly.

D - Inside pipe diameter

Do - Orifice diameter

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A vertical mounting of the duct was chosen so that the temperature profile of heated air would not be distorted due to natural convection as in the case horizontal mounting.

Fig. 3 illustrated the test section associated with several equipments arranging to achieve the constant wall temperature condition over the entire length of the duct. There were 1.5 gallons hot water jacket, 2.0 gallons bucket, centrifugal pump[1] equipping with a discharge valve, 1500 watts electric immersion heater, 100° - 240° F aqua heating thermostat with contactor relay and a circuit breaker.

2.1.2 By-pass chamber

The detail of the by-pass chamber, dimensions of which are 8 x 8 x 6 $in.^3$, was shown in Fig. 2. The chamber was made of ordinary ply wood with 3/8 in. thickness. A sheet metal by-pass opening, at the top, might be slided to fully opened position or fully closed one which meant that there was no flow or maximum one respectively through the orifice meter. There was a 3 in. dia. hole at one side, being firmly attached to the inlet of the high speed blower.[2]

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[1]Centrifugal pump, 50 cycles/sec., 220/240 volts, 1-phase electric motor, 720/150 G.P.M., 10/45 Ft-Hd, (Stuart Turner Ltd.)

[2]Electric blower - 3 in. dia., driven by 1/4 H.P., 50 cycles/sec., 220 volts, 1-phase electric motor at 3600 rpm, (Matsushita Co. Ltd.).

2.1.3 Mixing chamber

A 6 x 12 x 4 in.[3] mixing chamber was shown in Fig. 4. It was made of ordinary ply wood with 3/8 in. thickness, being insulated most outside surfaces with glass wool at least 1 in. thickness. The upper side, with 2 in. dia. hole of which the centre was aligned to the test duct axis, could be removed or opened by immediately loosing the screws provided. Such preparation and construction the test duct could be alternately replaced if required. Besides four thermocouples were provided to sense the final air temperature at different points. Furthermore, two pieces of wire meshes, with 25 meshes per in., were also provided to even the flow after leaving test section.

2.1.4 Orifice meter

The assembly of VDI orifice meter was shown in Fig. 5. Such an orifice design, which may be found in many fluid mechanics textbooks, e.g.[3,4] and the like, adapted from NACA Tech. Mem. 952. The brass orifice diameter (D_o) is exactly 0.45 in. with 0.11 in. thickness. The upstream pipe as well

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[3]Daugherty R.L., and Franzini J.B., "Fluid Mechanics with Engineering Applications," (6th ed., New York: McGraw-Hill, Inc., 1965), pp. 356-59.

[4]Streeter V.L., "Fluid Mechanics, (4th ed., New York: McGraw-Hill, Inc., 1966), p. 431.

as downstream one is 1.1 in. inside diameter (D). The pressure taps were tapped at two sections across the orifice plate, one at upstream being about one pipe diameter (D) and another at vena contracta being approximately one-half pipe diameter (D/2). A multi range manometer[5] fitting to the orifice meter at the aforementioned sections was provided for registering the differential pressure. This manometer could be oriented at positions 12.5, 25.0, 50.0, and 125.0 mm. H_2O. The 0-25.0 cm. H_2O column, filled with the red oil (specific gravity, $\gamma = 0.784$ at $20^{\circ}C$), could be accurately measured within 0.01 cm. H_2O. Details for calibrating the orifice meter would be found in subsection 2.2.1.

2.2 Flow calibration, and temperature measurements

2.2.1 Air flow calibration

An arrangement of the apparatus used for calibrating the orifice meter, which recorded the rate of flow with Reynolds number upto 4000, was shown in Fig. 6. A "Parkinson Cowan Measurement" gas meter was used as a standard meter accurately measuring within 10 in. WG pressure. The flow rate in litres per hour was determined by recording the total

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[5]Multi Range Manometer for Ricardo Alcock Viscous Flow Meter No. 461 H, Serial N o. N 15536.

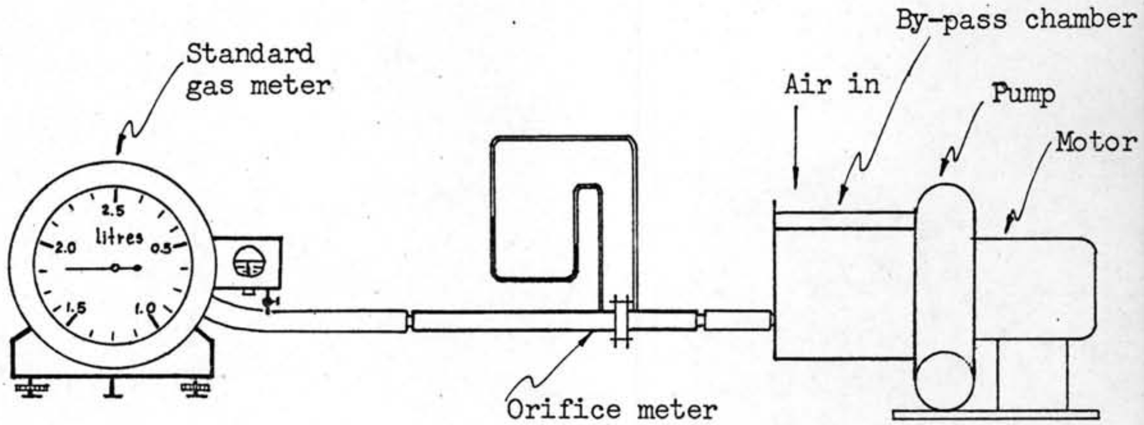

Fig.6 The Assembly of Apparatus for Calibrating Orifice Meter.

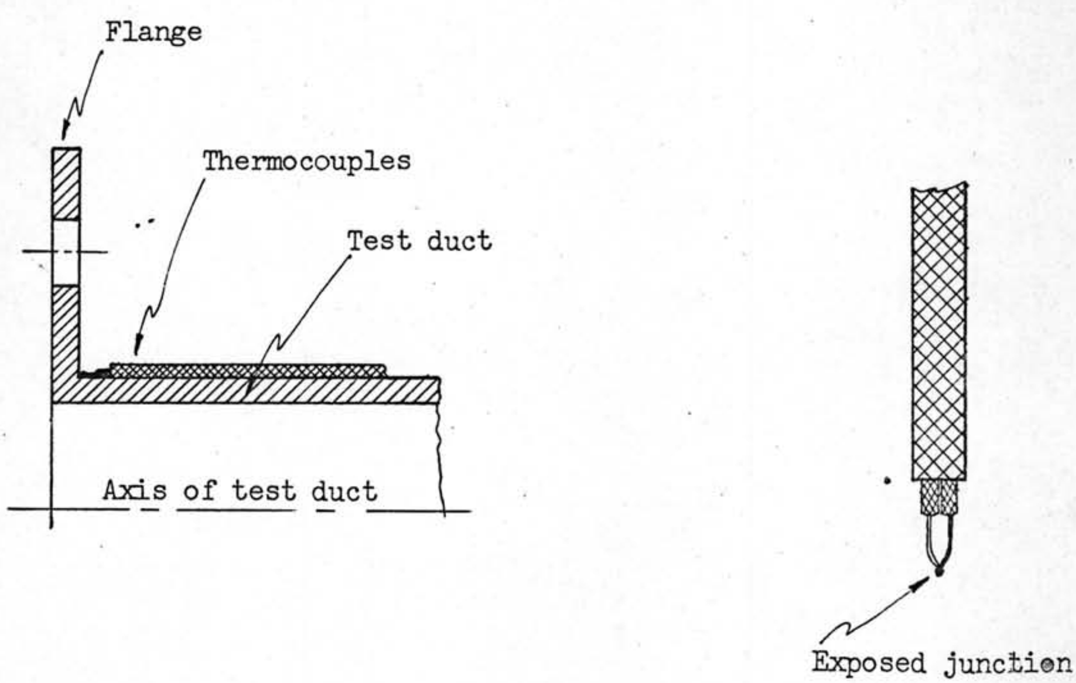

Fig. 7 Thermocouples and Method of Attachment on Surface.

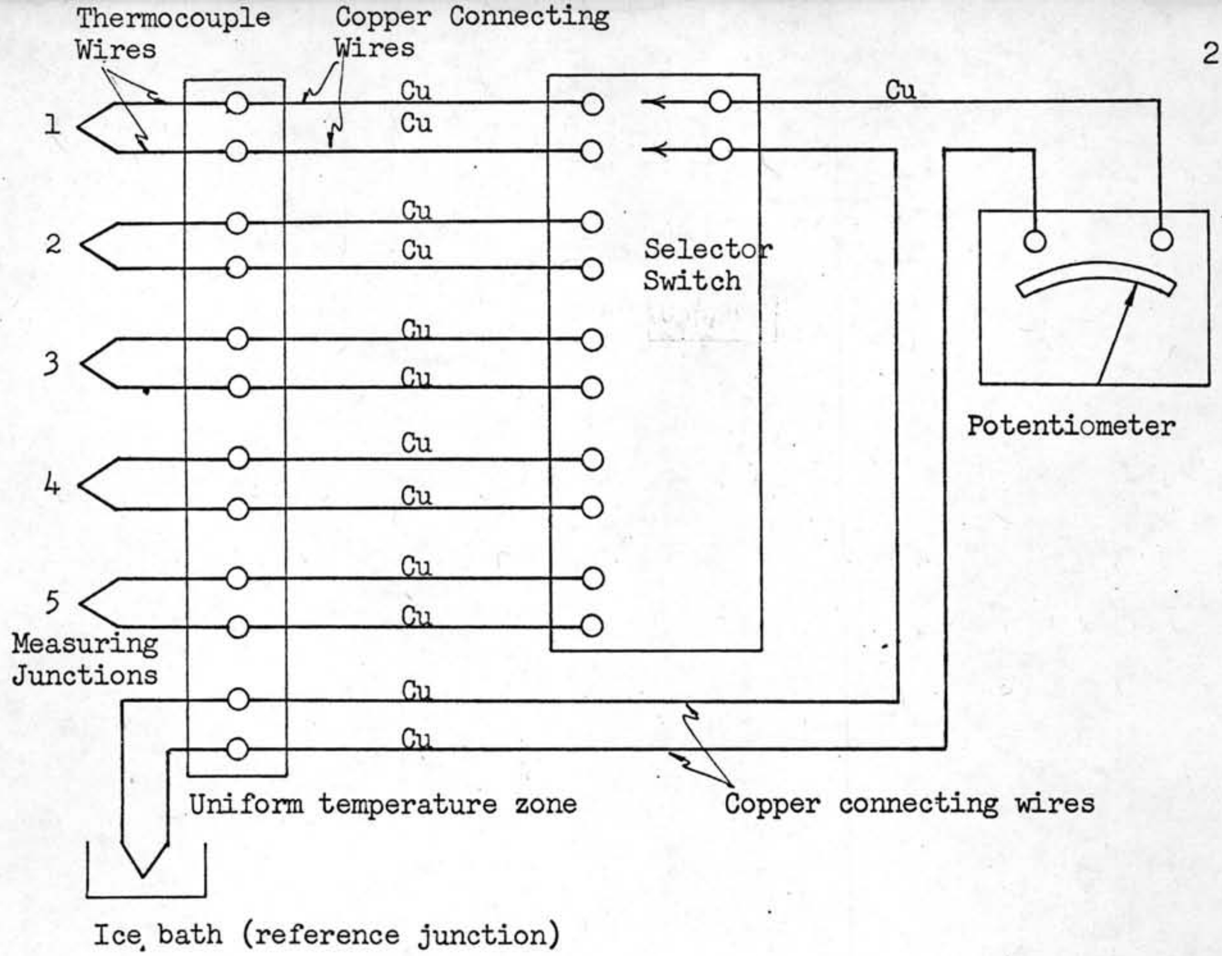

Fig. 8 A zone-box circuit involving one reference junction.

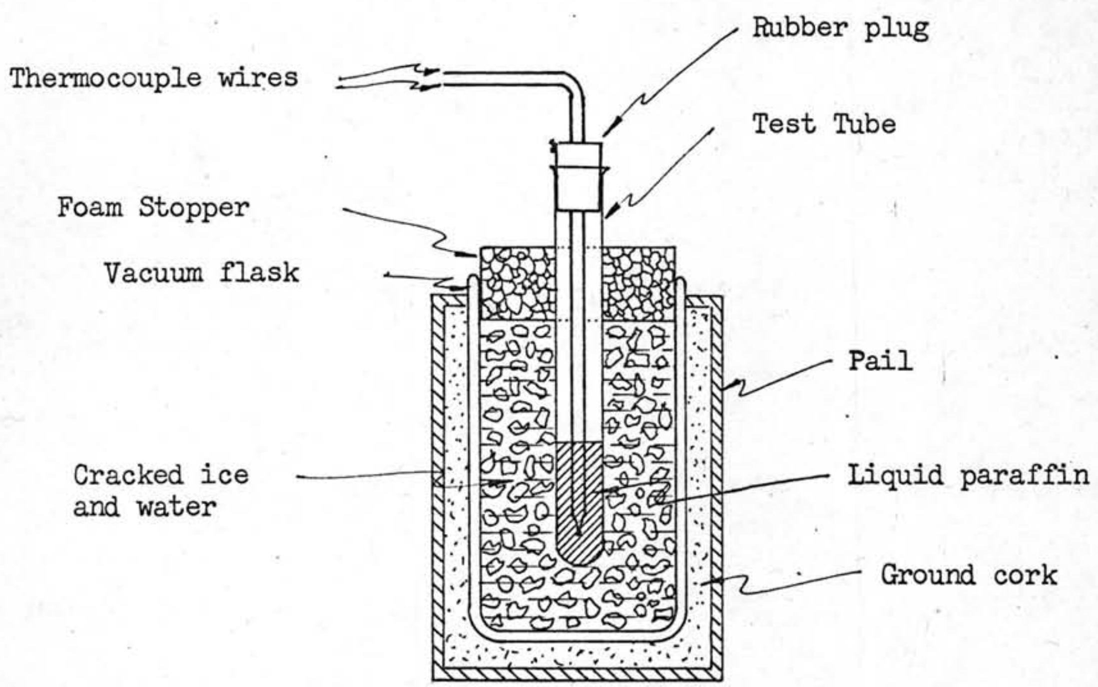

Fig. 9 An ice bath for Reference Junction.

times required for one or more revolutions of the handle of the meter.

Because the differential pressure was so small readings on a vertical scale were not sufficiently accurate, the column of manometer was then inclined so as to magnify the readings. Then by installing the column at 25.0 mm. H_2O on vertical scale which is identical to 25.0 cm. H_2O on inclined one, the orifice was then calibrated successively by regulating the rate of flow step by step, with 1.0 cm. H_2O increment, from no flow (0 cm. H_2O) upto the rate of flow about 3500 litres per hour (13 cm. H_2O) or Reynolds number about 1500. In order to attain Reynolds number about 4000, the column was oriented a little steeper at 125.0 mm. H_2O on vertical scale being identicall to 250.0 mm. H_2O on inclined one. The orifice was then calibrated as the same procedure as above.

2.2.2 Temperature measurements

There were three positions where temperature distributions were measured, that is, (1) before the entrance, (2) after the outlet section (inside mixing chamber), and (3) around the surfaces at the inlet and outlet sections, of the test duct. To measure inlet air temperature distribution, two thermocouples were situated before the entrance of the test duct to ensure that they did not alter the uniform velocity profile at the entrance. And then the average value of the two readings were determined. Thermocouples for inlet air temperatures had been shielded with insulating material such as foam to avoid the effect of natural convection of heated water. The final air temperature distribution after leaving the test duct were measured by four thermocouples and their average value was obtained. The wall temperature distributions were measured by a large number of thermocouples mounting directly around the perimeters at the inlet and outlet sections. There were three and seven thermocouples mounting directly on the surface at each end of an equilateral and a right-angled isosceles triangular ducts, respectively. On account of the fact that the thickness of the duct is so small and copper is a good conducting material, its resistivity may be ignored. In other words, the temperature gradients across the duct wall are negligible. It can be assumed that temperatures measuring on outside duct surface equalled temperatures on the inside surface.

All thermocouples used for measuring temperatures at various points were copper-constantan.

Fig.8 shows a certain circuit suitable for measuring temperatures at a large number of points. Such a circuit is required only one reference junction which is known in Bureau of Standards publication as a zone-box circuit.[6] This circuit

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[6]Benedict R.H., "Fundamentals of Temperature, Pressure, and Flow Measurements" (New York: John Wiley & Sons, Inc., 1969), pp. 67-70.

is composed of several measuring junctions, one reference junction, copper connecting wires, a selector switch, and a potentiometer. In this investigation, fortunately, extended copper wires were in the uniform temperature zone, which was at room temperature, changing not more than 1 deg.F. The reference junction was kept at 32 deg.F. in an ice bath as shown in Fig.9. The potentiometer[7] was provided for measuring electromotive force (emf) upto 1.8 volts. By selecting the lowest multiplier the potentiometer could precisely measure within microvolts. The emf was later linearly converted into Fahrenheit temperature scale.[8]

The method of attachment[9] of thermocouple wires on the surface so as to measure wall temperature was shown in Fig.7. Thermocouple wires were held to the surface by soldering and located as close to the surface as possible. The ends of the thermocouple wires were twisted together and welded with silver. This type of thermocouple junction, which is so called as exposed junction,[10] was also shown in Fig.7.

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[7] Portable D.C.Potentiometer-Type P3, No. 18195, (Croydon Precision Instrument Co.).

[8] Benedict, <u>op. cit.</u> pp. 84-94.

[9] <u>Ibid</u>. pp. 177-179.

[10] <u>Ibid.</u>

2.3 Experimental procedure

In this experiment the procedure employed might be simply classified into two parts, namely, (1) for Reynolds number ranging between 450 and 1500, and (2) for Reynolds number ranging between 1500 and 4000.

Part 1 The flow characteristics and heat transfer through the equilateral triangular duct, 9.04 in. in length, was first investigated. The assembly of apparatus was identically shown in Fig.1.

Prior to start the experiment, the potentiometer was standardized against internal standard cell following to manufacturer's recommendation.

The blower or centrifugal pump was next switched on with the by-pass opening fully opened. This meant that there was no flow passing through the orifice. The multi range manometer, its column being oriented at 25.0 mm. H_2O (just as the same position as already mention in subsection 2.2.1), was next set to zero. Then the by-pass opening was gradually closed until the manometer was at 10 mm. H_2O. When this had been done the water pump was switched on with the discharge valve closed. When the pump had reached its rated speed, then the discharge valve was gradually opened to circulate water to hot water jacket until the level of water in the jacket was so high that its surface nearly touched the lower part of inlet flange of test duct. The valve was then stopped opening. Next the heater was switched on with thermostat setting about 160 deg.F.

If might take at least 45 minutes to heat up water to the required temperature. Furthermore, it also took about two hours or more to attain steady conditions. When such conditions were possible, the following observations could then be taken:-

(1) Ambient air temperature.

(2) Pressure drop across the orifice plate.

(3) Thermocouple readings on the test section.

(4) Thermocouple readings before the test section.

(5) Thermocouple readings inside the mixing chamber.

Again, the by-pass opening was gradually closed until the manometer reading was at 15 mm. H_2O. If steady state was obtained, similar observations could then be taken. With 5 mm. H_2O increment, the procedure was repeated step by step till the manometer reading was 70 mm. H_2O. The experiment was then complete for the equilateral triangular duct with a length of 9.04 in.

The test duct was then replaced by the equilateral triangular duct, 11.97 in. in length. The tests were carried out successively in a similar procedure as the previous case.

By the same procedure as those for the equilateral triangular duct, the right-angled isosceles triangular ducts with lengths of 8.99 and 11.98 in. were then investigated respectively.

In order to cover a wide range of Graetz numbers, the equilateral triangular duct with a length of 9.04 in. and the right-angled isosceles triangular duct with a length of 8.99 in. were later shortened to 4.92 and 5.09 in. respectively. The same procedure as those described above was successively performed.

Part 2. Test equipments and the procedure were the same as those in Part 1 except the column of manometer was oriented at 125.0 mm. H_2O.