CHAPTER III

EXPERIMENTAL APPARATUS AND PROCEDURE

3.1 Apparatus

Several methods of obtaining laminar flow in a duct are available; for example, the use of a small duct, a low velocity, or a highly viscous fluid. The first choice was not acceptable because of the extreme difficulty in placing pressure taps in the duct wall. The second choice, without use of the third, does not create sufficient pressure drop over a short length of duct which can be measured accurately. On the other hand, most fluids with sufficiently large viscosity exhibit a strong dependence of this property on temperature, requiring very accurate knowledge of the temperature in order to obtain meaningful results. For this reason, water was chosen as the working fluid.

Hagen-Poiseuille's equation indicates that, for constant Reynolds number, the pressure drop in a duct increase with increasing density. Due to constant density, pressure drops which are measurable with a special micromanometer therefore can be obtained in an experiment by controlling a flow through the test section. This was accomplished by using the apparatus shown schematically in Fig.3.1b. The apparatus employed to investigate the flow characteristic in constricted parallel ducts was a close-circuit flow system with water as the working fluid. The essential components encountered along the path of the flow included the following: A head tank, a hydrodynamic development section, a curved rectangular duct, the entrance duct, the rectangular duct test section, an exit section, a rectangular-to-circular transition section, a tank-on-scale, a reservoir and a centrifugal pump with filter. A gate valve located downstream of the rectangular-to-circular transition section was provided for control of the flow rate.

Flow System

To obtain a steady flow, two constant-head reservoirs are used. These are simple overflow devices kept at fixed heights. A diagram of the flow system is shown in Fig.3.1a. The flow passes from the upper head tank through the hydrodynamic development duct, the curved duct, the entrance duct, the test section, the exit duct and the rectangular-to-circular transition section to the gate valve, which serve as flow resistances. The overall flow rate can be changed (by turning the gate valve) without changing the positions of the constant-head tanks. The flow proceeds from this gate valve to the second tank, which is placed on a scale. With the valve between this tank and the reservoir closed, the time necessary to collect a given amount of fluid indicates the mass flow rate and mean velocity in the duct. When weighing measurements are not made, the valve is open and the flow proceeds to the reservoir. From there, a pump returns the fluid through a filter to the first constant-head tank.

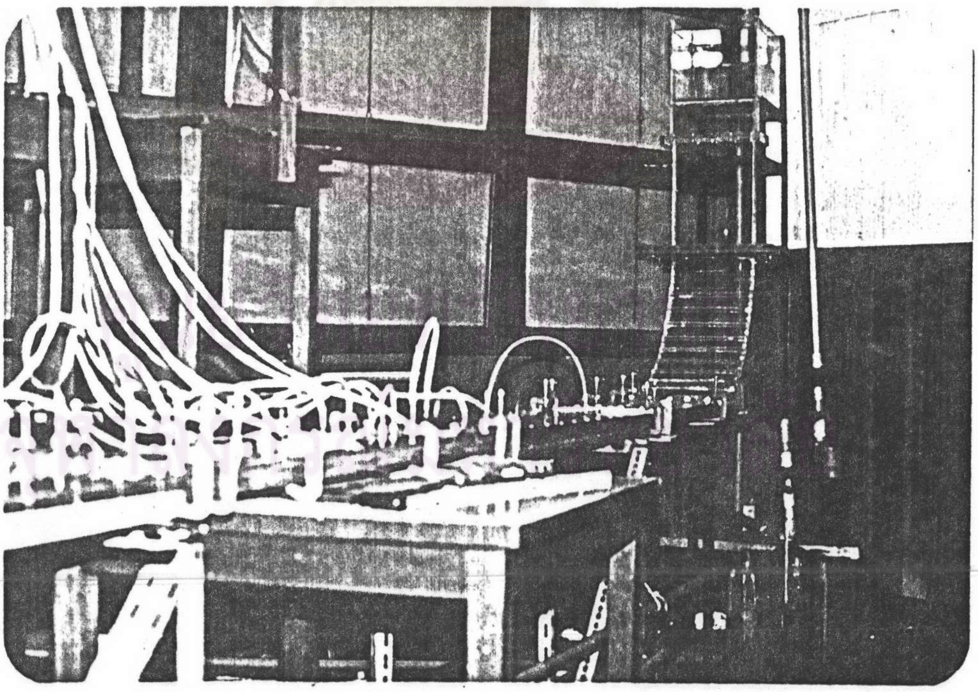


Fig. 3.1 General view of apparatus

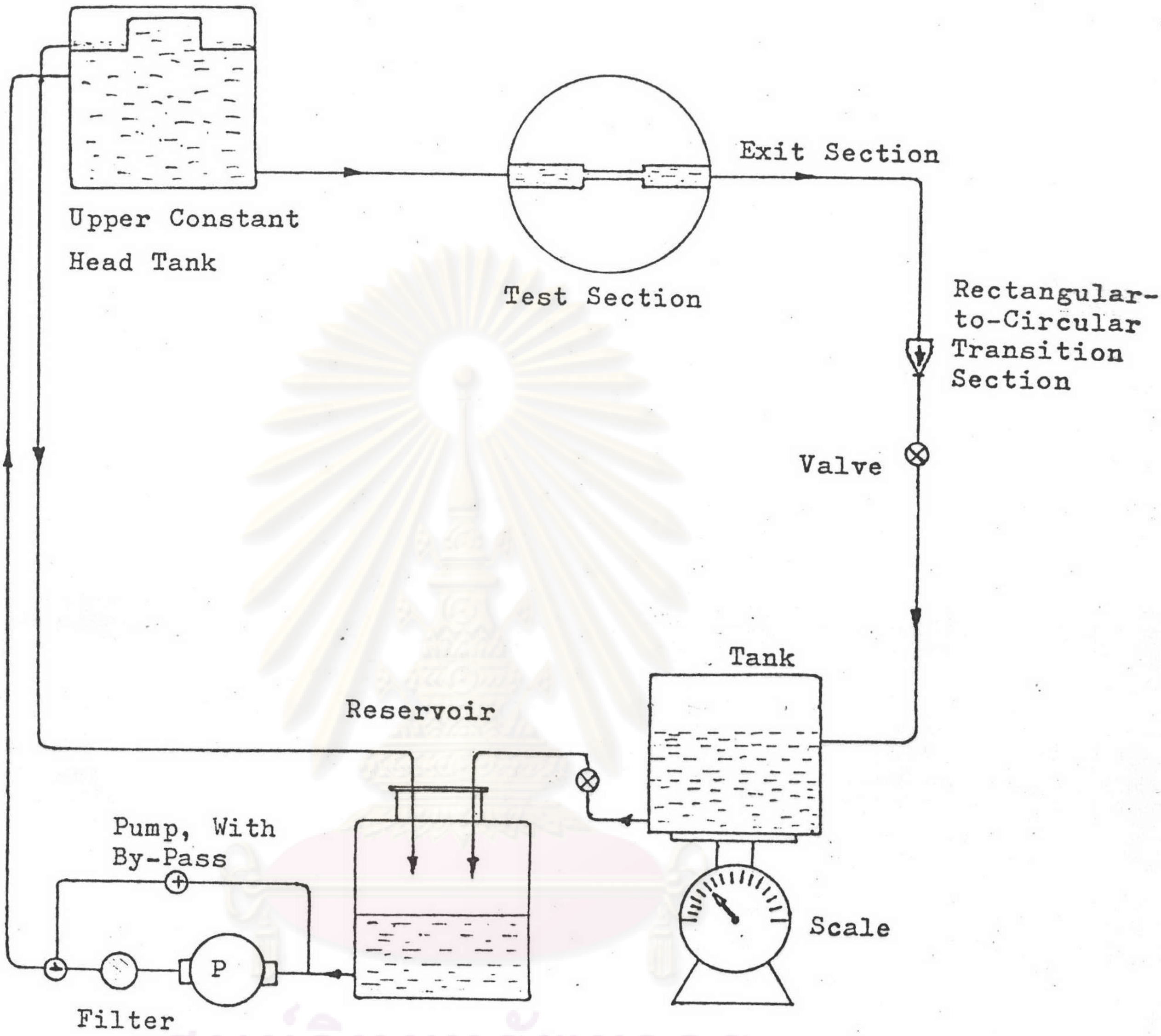
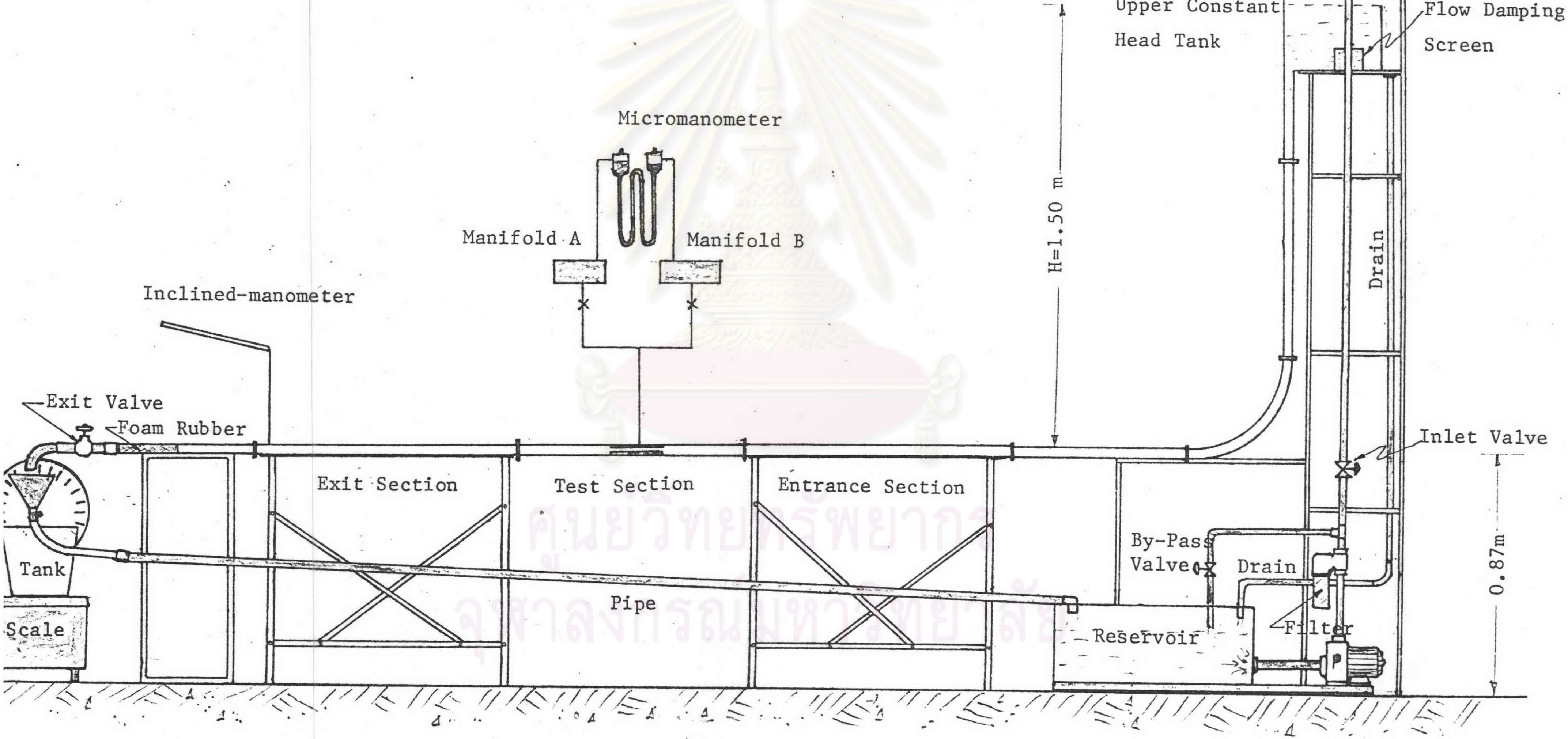


Fig.3.1a Schematic diagram of the flow system

Fig. 3.1b Schematic diagram of apparatus



Entrance Section and Exit Section:

The key component of the apparatus is the rectangular duct, a schematic diagram of which is presented in Fig.3.2. Two ducts were employed during the course of the experiments, both of which were of the same general construction and dimensions. The top and bottom walls of the duct constituted the long sides of the rectangular cross section. The duct axis was positioned horizontally during all experiments. The ducts were fabricated from flat plates of plexiglass that had been carefully selected for straightness and transparent property. All side walls of the duct were 1.0 cm. thick. Prior to fabrication, all surfaces in contact with the flow were cleaned to a high luster.

Six wall pressure taps were centrally distributed along the top surface of the ducts. The holes for the taps were 0.25 cm. diameter. Particular care was taken in polishing the wall in the neighborhood of the taps. The distance of each tap was 20.0 cm. apart. Inspection of each tap under a magnifying sight glass verified the absence of burrs or other irregularities.

Both entrance and exit sections are 122.0 cm. long, and have internal cross section dimensions of 28.4 by 2.0 cm. (equivalent diameter = 3.74 cm.). Therefore, in terms of the equivalent diameter, the lengths of the two sections are 32, with the aspect ratio being 14:1. It is well established that the length of run x_{fd} required to achieve hydrodynamically developed conditions is proportional to the equivalent diameter D_h and to the Reynolds numbers Re; that is

$$x_{fd} \approx D_h . Re \approx D_h^2 . V \qquad \text{.............(3.1)}$$

in which V is the mean velocity of the flow. The constant of proportionality may well be a function of the aspect ratio but to an extent that has not been heretofore established.

Hydrodynamic Development Section:

The hydrodynamic development section was of similar construction and dimension to the entrance and the exit sections except that the length was 82.0 cm. or 22.0 in term of the equivalent diameter. However, there was not pressure-tappings provided along the section.

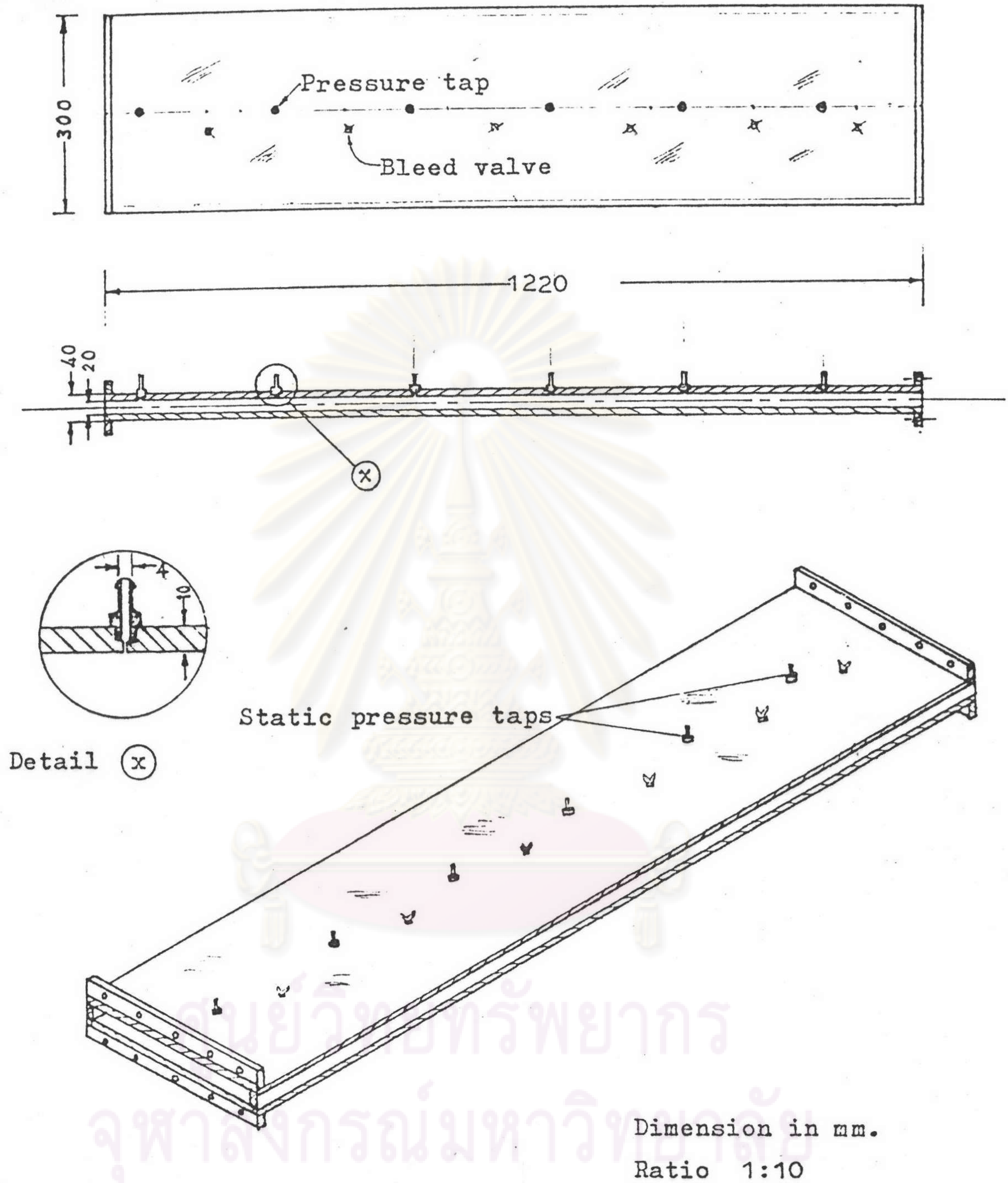


Fig.3.2 Schematic of entrance section and exit section

Test Section:

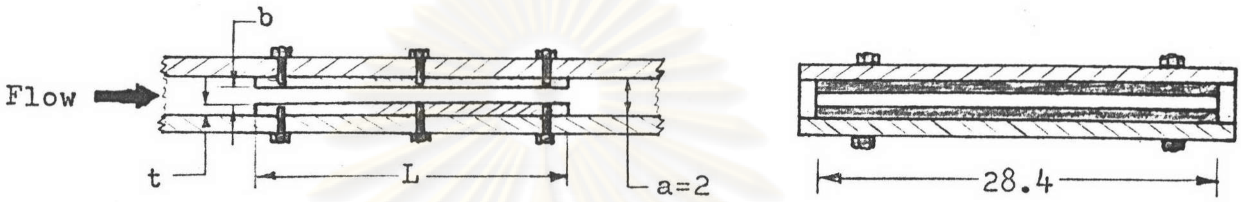
The test section, which formed the heart of the apparatus, was designed and fabricated in the same way as the entrance section or the exit section, was provided with a slat-type blockage to form entrance constriction. The length and thickness of the constriction can be varied by unscrewing and changing a new plate-type as required. The blockage or constriting elements were fabricated from a plexiglass sheet, with a width of 28.0 cm. Some of these features can be seen in the schematic side view of the constriction element shown in Fig.3.1b. Certain dimensional characteristics of the constricting elements are listed in Table 3.1. For each of seven elements and with area ratios of 2/3, 1/2 and 1/4 respectively, the table gives the slat or plate length L (relative to the duct diameter D_h) and the thickness,t. Water was delivered to the test section by the long hydrodynamic development length and the long entrance length. The entrance length and the test section were colinear and horizontal, as was the exit length situated downstream of the test section. These components were identical in internal cross section 28.4 by 2.0 cm., with length of 32 equivalent diameter. The mating of the sections was accomplished by means of flanges.

In case of a long constriction or large L/D_h ratio, the short vertical side of rectangular cross section was reduced by half or 1.0 cm. and as a result the thickness and length of constricting plates were also reduced by half, while the aspect ratio of the duct was increased to 28:1.

Pressure taps were installed both upstream and downstream of the constriction. Including those along the constriction, there were a total of twenty tapping stations whose locations will be evident from the pressure distributions to be pressented later. Since the most rapid pressure variations were expected to occure just downstream of the constriction, the taps were concentrated in that region. After the pressure taps, which the holes for the taps were 0.25 cm. dia., were installed, the bores were carefully honed to remove burrs. The pressure signals from the taps were conveyed via 5.0 cm. dia. plastic tubing to inclined multi-tube-manometer and to a pressure selector switch, where the output of the switch was sensed by a micromanometer with smallest scale reading of 0.02 mm. H_2O, for marginally pressure difference.

Painstaking bleeding of air from the system was required as a prerequisite for a successful data run, and numerous bleed valves were installed for this purpose.

Table 3.1 Characteristics of the constricting elements in the test section.



$$D_h = 4A/p = 4(w \times b)/2(w + b) = 2(28.4 \times b)/(28.4 + b)$$

$$\sigma = b/a \quad \text{and } t = (a-b)/2 = 1 - \sigma$$

Thickness, t

σ	2/3	1/2	1/4
t	0.333	0.5	0.75

Length of the constriction elements, L

σ / L/D_h	2/3	1/2	1/4
100	254.7	193.2	98.27
75	191.1	144.9	73.7
50	127.4	96.6	49.13
25	63.67	48.3	24.57
10	25.47	19.3	9.83
5	12.73	9.6	4.91
2	5.09	3.9	1.96

All dimensions in centimeter.

Head Tank:

The detail of upper constant head tank, dimensions of which are 30 x 49 x 30 cm^3, was shown in Fig.3.3. The head tank was fabricated from plexiglass with 1.0 cm. thickness. There was a partition plate (1.0 cm. thick.) for overflow of water, thus forming a constant head inside the tank. This overflow was drained through a 2.5 cm. dia. hole which was connected to a PVC pipe at the bottom of tank enroute to the reservoir. The water entering test section was delivered from the tank via a plexiglass duct.

Reservoir:

A 30 x 60 x 30 cm^3 open-top reservoir was shown in Fig.3.4. It was made of plexiglass plates with 1.0 cm. thick plate. There was a 2.5 cm. dia. hole at one side, being firmly connected to the inlet pipe of a high speed centrifugal pump.

Curved Duct:

A 90 degree curved rectangular duct was fabricated from plexiglass sheets with a 70 cm. radius of curvature. The top and bottom walls of the curved duct were 0.3 cm. thick, while the thickness of the side walls was 1.0 cm.. A schematic diagram was presented in Fig. 3.5.

Rectangular-to-Circular Transition Section:

The rectangular section was fabricated from plexiglass sheets with the circular part made of PVC pipe. At the downstream end of the rectangular duct, it was filled with foam rubber which served to dampen flow pulsations. The gradual decreasing in rectangular shape was of the order of 30 degree to the downstream end of the duct as shown in Fig.3.6.

Multi-tube-manometer:

Twenty glass tubes have been used to measure the static pressure of a fluid in motion when the velocity is undisturbed. All glass tubes are about 50 cm. long and 0.5 cm. inside diameter. The back plate of manometer can be tilted to an any degree as presented in Fig.3.7.

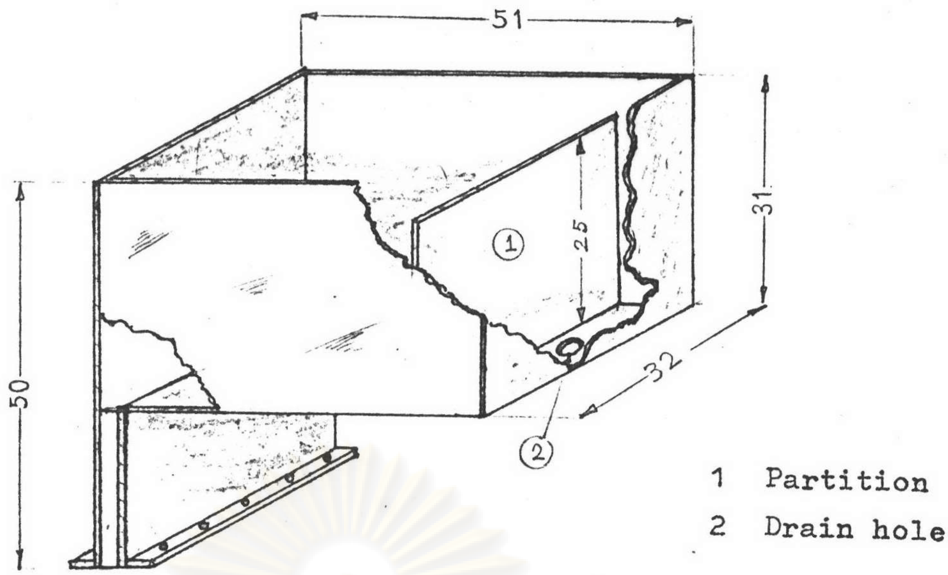


Fig.3.3 Schematic of head tank

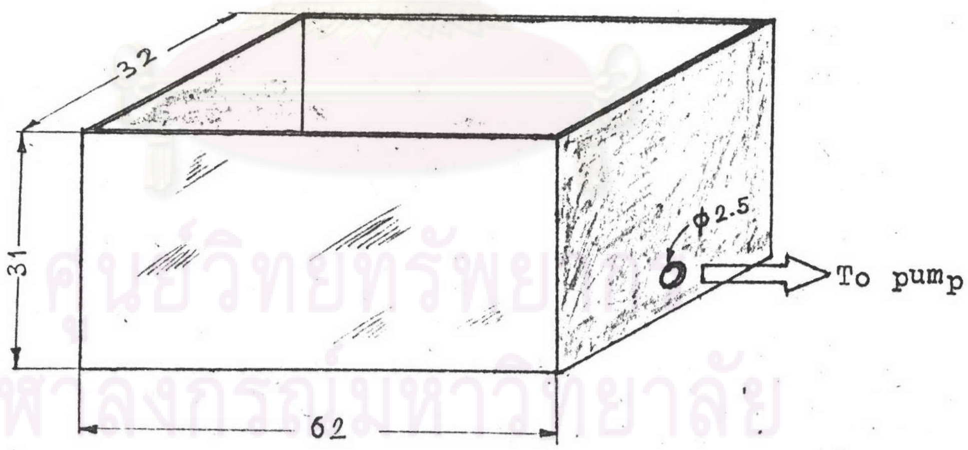


Fig.3.4 Schematic of reservoir

All dimension in cm.

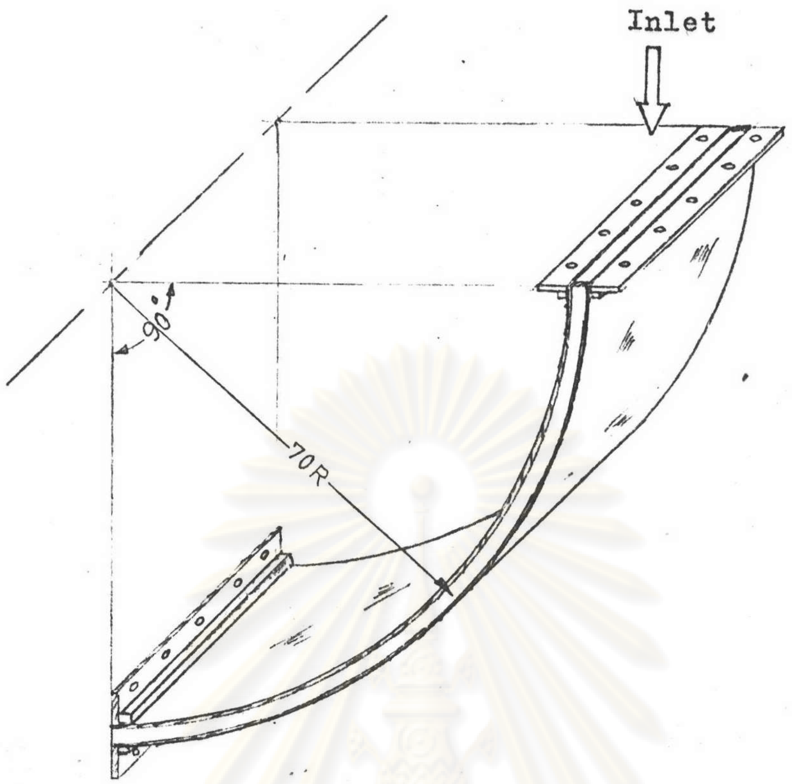
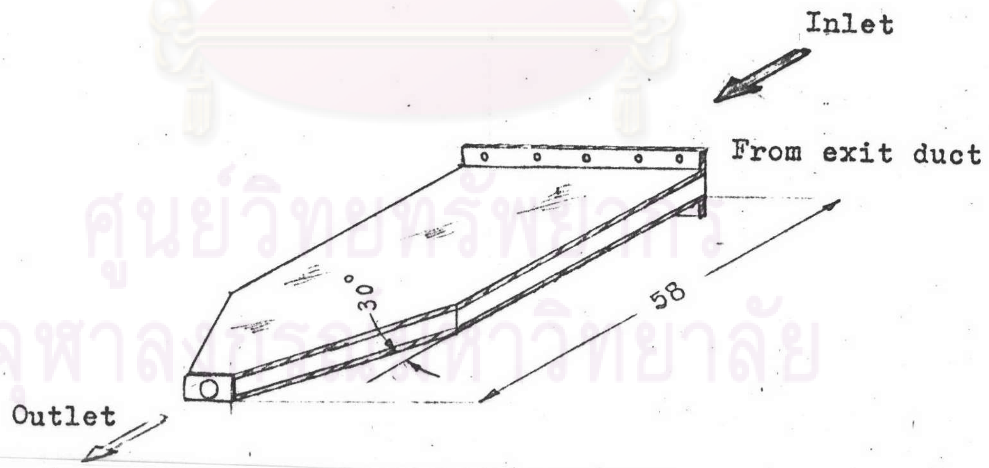


Fig.3.5 Curved duct



All dimension in cm.

Fig.3.6 Rectangular-to-circular transition section

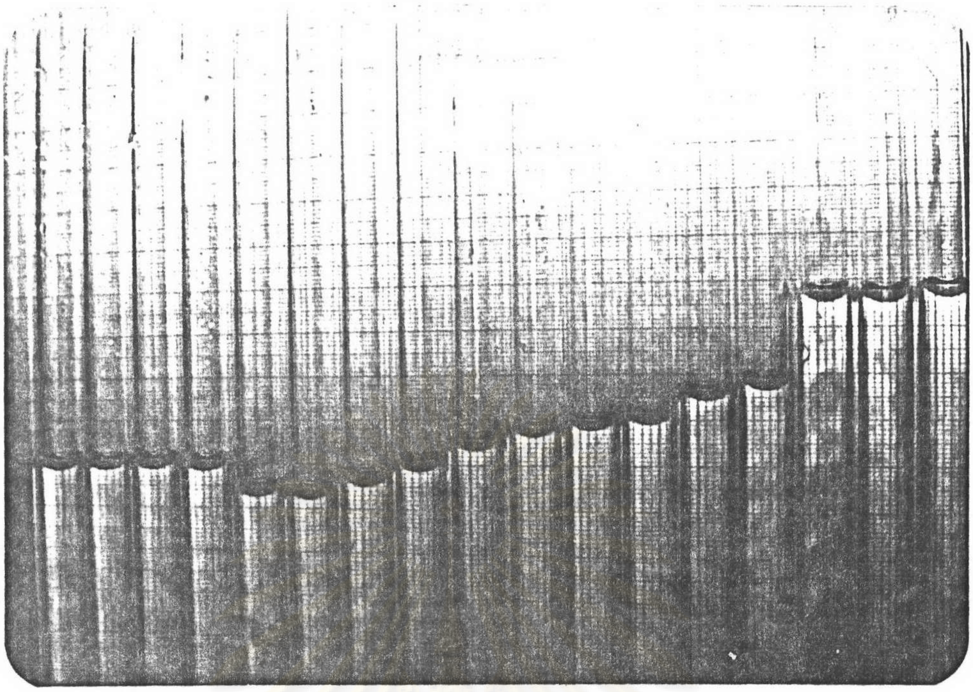


Fig. 3.7 Multi-tube-manometer

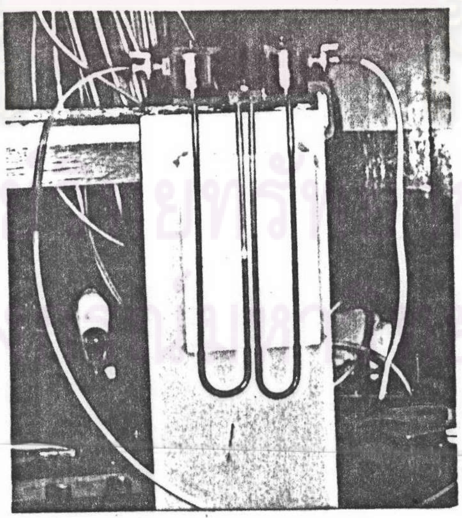


Fig. 3.8 Micromanometer

Micromanometer

The pressure differences associated with the measurement of the static pressure distribution ranged from 0.001 to 1.0 cm. of water. Differential-pressure measurements for the upstream, constriction and downstream regimes, were made with a sensitive micromanometer capable of measuring differences as small as 0.002 cm. of water (approximately 2 microns of mercury) with an accuracy of 5 percent. This instrument was designed and construte in the Department of Mechanical Engineering's Workshop. In essenc the micromanometer is of two connecting concentric U-tubes as shown in Fig. 3.8. It was constructed using the principle of the micromanometer with two gage liquids [22] , immiscible in each other and in the fluid to be measure, a large gage difference on U-tubes may be produced for a small pressure difference. The liquids are water and aniline [7] with specific weight of 1 and 1.022, respectively. A detailed description of this manometer is exhibited in Appendix B.

Others Components

There are as follows:

Centrifugal Pump:

The specifications of pump are, 0.5 H.P., 220 Volts, 2.5 Amp., 50-60 Hz., 1-Ø, 2850 rpm., 1.0 in. dia. (inlet and exit) (ADDA CO. LTD.)

Water Filter:

"BADU Schutzfilter", with filtration up to 20 micron, & pressure max. 10 bar, (SPECK CO. LTD.).

Mechanical Scale:

The range is 0-10 Kg. with 10 gm. resolution (Berkel Co. Ltd.

Thermometer:

Mercury type of thermometer was used to measure fluid temperature while flowing through the constricted duct.

3.2 Procedure

The flow characteristics through the duct without constriction was first investigated. The assembly of apparatus was as shown in Fig. 3.1. Prior to starting the experiment, the inlet valve was completely opened while the outlet valve and the by-pass valve were closed. The centrifugal pump was next switched on after filling water into the reservoir. The outlet valve was fully opened when overflow of constant head tank took place. Bleeding of air from the duct system was done via numerous bleed valves. When air pocket was eliminated, the exit valve was closed. The multitube-manometer and micromanometer which were connected with taps along the duct and across test duct respectively, were next set to zero (with reference to atmosphere for inclined multi-tubemanometer). Then the exit valve was gradually opened until the micromanometer registered a 2 mm. difference. Data for pressure drop across the test duct were taken for a range of Reynolds numbers from 300 to 4000. The following observations were made:

(1) Fluid flow temperature.

(2) Pressure drop across test duct

(3) The time to collect a given amount of fluid.

Time up to five minutes, after each new adjustment, was allowed to insure steady condition before taking data and observations made. With 2 mm. increment, the procedure was repeated step by step until either reaching the limit of manometer or maximum pump capacity. The running of overflow fluid from the constant head tank has been observed at all times, thus, ensuring that a constant head fluid was entering the test section. The experiment was then completed for flow through the test duct of 360 cm. long without constriction.

The test section was then modified to become a duct with constriction where $\sigma = 1/4$ and $L/D_h = 100$. In order to use a single micromanometer, a double-chamber manifold system was used. Each pressure-tap line was connected to a tee connector-one leg of which being connected to one manifold and the remaining leg connected to the other manifold. This arrangement allows measurement of the pressure differences between any two taps as well as checking for leakage and relaxation times of the instrument. All lines from the pressure taps to the tees were of minimum and equal length to minimize and equalize the relaxation times, which is important whenever a new reading was to be made. This was also true for all lines connecting the tees and the manifolds. The entire system was checked carefully for leakage before any data were obtained. The tests for duct with constriction were carried out successively using similar procedure as the previous case but it was perhaps more difficult to measure axial pressure distribution along the constriction duct. The entrance-region, axial pressure distribution was obtained by measuring pressure differences between an entrance duct tap located 100 cm. from the test section inlet and successive taps situated along the duct. After reaching the limit of the manometer, using this procedure, readings at remaining stations were taken with respect to taps already referenced to the entrance duct. In this manner, the readings of presure difference between the entrance and all tap locations on the duct were obtained. Overlapping measurements were made for each run by using various pressure-tap combinations to serve as a check. By the same procedure as aforementioned, tests with constricted duct of varying σ's and L/D_h's as tabulated in Table 3.1 were investigated respectively.