**HYDRAULICS DIVISION**

Technical Note

**DATE:** April 1980 **REPORT NO:** 80-19

**TITLE:** "Evaluation of an Experimental Meter to Measure Lateral Flow Velocities in Peat"

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**REASON FOR REPORT:** This report was prepared jointly with the Scientific Support Division at their request to test their newly developed flow meter.

**CORRESPONDENCE FILE NO:**

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## 1.0 INTRODUCTION

The Engineering Section of the Scientific Support Division is developing a new flow meter for the Lands Directorate of Environment Canada to measure the mass flow in peat bogs. In order to test the performance of this meter, the Hydraulics Division was requested to design and construct the test apparatus. The tests were conducted jointly by the Scientific Support Division and the Hydraulics Division in the Hydraulics laboratory at the National Water Research Institute. This report presents the results of the tests.

## 2.0 DESCRIPTION OF THE FLOW METER

The meter operates on the principle that diodes produce a change in voltage when subjected to a change in temperature. A schematic layout of the meter is given in Figure 1.

The meter consists of two sensing elements, the heat dissipator $S_1$ and the temperature sensor $S_2$. $S_1$ is kept at a higher temperature relative to $S_2$ and this temperature difference provides the basis for the operation of the meter. The sensor $S_1$ is operated with a 30 milliamp (mA) current developing a voltage $E_1$ ($\approx$20 volts at 20$^{\circ}$C), dissipating heat at 600 milliwatts (mW) at 20$^{\circ}$C. The sensor $S_2$ is operated with a 1.3 mA current developing a voltage $E_2$ ($\approx$20 volts at 20$^{\circ}$C) and dissipating heat at 23 mW at 20$^{\circ}$C. Both sensors $S_1$ and $S_2$ have the same thermal coefficient of 10 mV/$^{\circ}$C. Since the sensor $S_1$ is warmer than element $S_2$, the flowing water cools $S_1$ faster than $S_2$ and as a result there is a voltage difference $E=(E_2-E_1)$ which is known to be proportional to the flow rate and this relationship must be obtained by calibration. When the flow rate is zero the voltage difference E is zero. A bridge circuit for sensors $S_1$ and $S_2$ is used for temperature compensation and is powered by a reference potential set at 24.20 volts. The general circuit diagram is given in Figure 2. The resistances $R_0$, $R_1$ and $R_2$ are used for proper current biasing. The resistances $R_4$ and $R_5$ are simply used as voltage dividers and $R_3$ is used to raise $E_2$ to the same value as $E_1$ $(E=(E_1-E_2)=0)$ when the meter is placed in open, fresh water at a temperature of 20$^{\circ}$C.

The meter is very simple to manufacture at low cost, using standard parts and materials.

## 3.0 EXPERIMENTAL EQUIPMENT

### 3.1 Test Facility

In order to evaluate and possibly calibrate the flow meter it was necessary to place the meter into a peat medium, pass a flow through the peat and to measure the mass flow and the flow meter response to changes in the flow rate. A test facility for this purpose was designed and built as shown schematically in Figure 3a and b.

The vertical stand pipe consisted of two sections of clear acrylic pipe with an inside diameter of 20 cm, each about 2 m in length and flanged at both ends. The two sections were bolted together, care being taken that the flange connections were adequately sealed. This provided the capacity for a water column about 4 m in height. The stand pipe was fastened to the laboratory wall using brackets for lateral support but allowing some freedom of movement in the vertical direction.

The test section was made from a short piece of the same acrylic pipe, about 30 cm in length and flanged at one end to facilitate connection to the bottom flange of the stand pipe. The bottom of the test section was enclosed with an aluminum casing which was connected to the plastic pipe wall with a water-tight seal. The aluminum casing had a 5 cm diameter orifice concentric with the acrylic pipe. This orifice was tightly sealed with a circular aluminum plate secured to the casing with six screws. A 1.5 cm hole was drilled through the aluminum plate also concentric with the acrylic pipe and a valve was installed to permit control of the water flow through the test section. In the side of the test section, approximately 15 cm from the bottom a 1/4 inch (0.65 cm) hole was drilled in the wall of the test section and a "swage-lock" fitting was installed. This provided a water tight aperture through which the flow meter could be inserted into the peat. To ensure that there would be no undue movement of water between the peat and the walls of the test section, the latter was made "rough". A coat of varnish was applied to the inside wall of the cylinder and this was covered immediately with finely shredded peat. After the varnish had dried, most of the applied peat remained in place, thus providing a bond between the peat and the container.

Water for the tests was obtained from the domestic water supply line through a standard garden hose. The hose was inserted through the top of the stand pipe until the nozzle was about 30 cm above the test section. This permitted the hose to be used for supplying water and as a siphon to quickly drain the water column by merely disconnecting the hose from the supply valve. The rate of flow through the hose was controlled with a needle valve which permitted fine adjustments in the surface level of the water column.

The pipe column and the test section were supported by a wooden bench which provided the total reaction to the weight of the test apparatus. A photograph of the lower part of the stand pipe, test section and flow meter in place is given in Figure 4.

## 3.2 Instrumentation

The electronic equipment used to operate the flow meter was a voltage reference supply, a digital voltmeter and a strip-chart recorder. The reference voltage supply was a DIGITEC Model 311, the digital voltmeter was a FLUKE Model 86004 and the strip chart recorder a LINEAR INSTRUMENTS Model 142. The schematic layout of the instruments is given in Figure 5.

## 4.0 TEST PROCEDURE

### 4.1 Preparation of the Peat Plugs

After some preliminary testing a standardized procedure was adopted for placing the peat plug in the test section. The first step was to place a snugly fitting reinforced "fly screen" disc in the bottom of the test section. A layer, 8 cm high, of pea gravel having a median diameter of 9 mm was then placed evenly over the screen. The screen ensured that no particles were able to enter the outflow pipe and thus block the flow control valve. Another reinforced "fly screen" was placed on top of the gravel. The peat was then placed over this screen until a plug about 12 cm high was obtained. Another reinforced "fly-screen" disc was placed on top of the peat and finally a perforated brass disc about 1 mm thick was placed on top of the last screen to ensure that the surface of the peat plug remained undisturbed during the tests.

Two kinds of peat identified as "natural" and "commercial" peat were used. The natural peat was obtained from a nearby peat bog by cutting a 40 cm x 40 cm x 40 cm frozen cube. The commercial peat was of the dried and shredded type, normally available from a gardening supplies dealer. Before the peat was placed in the test section, care was taken at all times that it was thoroughly wetted by soaking it in water for at least 24 hours. Three peat plugs were prepared for testing and identified as Peat Plug No's. 1, 2 and 3.

Peat Plug No. 1 was prepared using the natural peat. This material after having been thawed and soaked was taken in small unconsolidated (i.e. loose form) amounts and placed in thin layers in the test section. Light pressure was applied to each layer with a circular wooden disc to obtain a reasonably uniform density and to reduce any extensive settling under pressure of the water column. In placing the peat it was noted that in its natural state it contained isolated pieces of debris such as leafs, roots, etc. This material was removed to ensure a uniform cross section within the peat plug.

Plugs No. 2 and 3 were prepared using the commercial peat. This material was very uniform in texture and was on average finer than the natural peat used in Peat Plug No. 1. In preparing Plug No. 2, the material was placed in the same way as the natural peat. In preparing Plug No. 3, the material was again placed in layers but was compacted much more densely by applying more pressure to each layer with the wooden disc.

After tests on each peat plug were completed, its volume in the test section was measured and the dry weight obtained which was then used to compute the dry density of each peat sample. The dry density for each of the three peat plugs is given in Table 1.

**TABLE 1** **PROPERTIES OF TEST PEAT**

| Test Plug No. | Peat Dry Density $gm/cm^3$ | Permiability Index m | Peat Type |
|---|---|---|---|
| 1 | 0.156 | 0.0042 | Natural* |
| 2 | 0.079 | 0.126 | Commercial** |
| 3 | 0.099 | 0.048 | Commercial** |

* Peat obtained directly from peat bog

** Shredded peat obtained commercially

## 4.2 Calibration of the Flow Meter

Calibration tests were begun with Peat Plug No. 1. Once the test section was secured to the stand pipe, the water column was allowed to rise to a height of about 3 m. In testing Plug No. 1, the control valve at the bottom was left wide open and the flow through the peat was controlled by varying the height of the water column. The water column was preset at a desired height and once this level was stable, the mass flow discharging from the bottom of the test section was collected over a suitable length of time, usually several minutes. The collected water was weighed and recorded as L/min. Each time that a flow measurement was made, the voltage output of the meter in mV was recorded and both flow rate and voltage output were plotted on semilogarithmic graph paper in order to constantly monitor the tests.

The first series of measurements (Set 1A) was made over a range of water column height from 2.85 m to 0.42 m. The peat plug was then left to sit undisturbed for 24 hours under a head of 1.4 m. A second series of measurements (Set 1B) was then made over a range of water column height increasing from 1.4 m to 3.8 m and then decreasing to a head of 0.50 m. When the head was at 3.8 m, it was noted that there was a change in meter output giving values which were not consistent with those from set 1A. This was attributed to higher interstitial pressure created by the relatively large head causing a change in the peat structure around the meter sensor. This, in turn, must have created substantially increased interstitial flow for the same total mass flow rate. This effect can be seen in Figure 6 by the three data points identified as (a), (b) and (c). The measurements were stopped at this point and the peat plug allowed to sit undisturbed for about one hour at a head of about 2 m. Measurements (Set 1C) were continued with the water column height being varied from 2.05 m to 0.50 m. The results showed reasonable agreement with the data from Set 1A and 1B. During these measurements, the water temperature varied between 6.8°C and 18.4°C. The test data for Peat Plug No. 1 are given in Table 2.

The second set of calibration tests was made using Peat Plug No. 2. For these tests it was decided to maintain the water column height fixed at 1.5 m and to use the valve at the base of the test section to control the flow. The column height of 1.5 m was chosen to ensure a high enough flow to cover the operating range of the meter without creating a pressure head high enough to cause flow pattern changes around the meter sensor as was observed with Peat Plug No. 1. The valve was opened to pass a certain rate of mass flow and this was left until a steady state flow was established. Steady state was usually taken to occur when the meter output trace on the chart recorder had reached an approximately constant value in millivolts. At this point, the mass flow was collected as before and the corresponding meter output was recorded. The first series of tests (Set 2A) was begun about two hours after the peat plug was attached to the stand pipe and the results were plotted in Figure 7. The peat plug was then left to sit under the same constant head of 1.5 m for about one hour and the second series (Set 2B) of measurements was made in the same way. These data were also plotted showing considerable change from Set 2A. It was therefore decided to let the peat plug sit under a head of 1.5 m for about 24 hours. The third series of measurements (Set 2C) was then made and also plotted on Figure 7, showing reasonable agreement with Set 2B. Prior to beginning Sets 2B and 2C, the control valve at the base of the test section was closed to obtain zero mass flow and each time the system was left for about 30-45 minutes in an attempt to obtain a stable meter output for zero mass flow (i.e. zeroing the meter). It became apparent that the meter output was approaching a constant base voltage asymptotically and it was therefore decided to record the values at the end of this waiting time. When Set 2C was completed, the water column was

TABLE 2 CALIBRATION DATA - TEST PLUG NO. 1

| Meter Output mV | Flow L/min | Average Velocity cm/s | Water Head m | Water Temp. °C | Comments | Data Set |
|---|---|---|---|---|---|---|
| -13.2 | 0.735 | 0.0390 | 2.85 | 8.9 | Flow controlled by water head | |
| -11.8 | 0.746 | 0.0396 | 2.85 | 8.9 | | |
| -20.0 | 0.612 | 0.0325 | 2.45 | 6.8 | | |
| -21.0 | 0.600 | 0.0319 | 2.45 | 6.8 | | |
| -26.0 | 0.513 | 0.0272 | 2.10 | - | | |
| -22.0 | 0.508 | 0.0270 | 2.10 | - | | |
| -35.2 | 0.338 | 0.0179 | 1.50 | 9 | | |
| -48.0 | 0.185 | 0.0098 | 1.0 | 12.7 | | 1A |
| -51.0 | 0.184 | 0.0098 | 1.0 | 12.7 | | |
| -50.8 | 0.182 | 0.0097 | 1.0 | 12.7 | | |
| -67.0 | 0.087 | 0.0046 | 0.53 | 12.7 | | |
| -68.0 | 0.085 | 0.0045 | 0.51 | 12.7 | | |
| -69.5 | 0.082 | 0.0044 | 0.50 | 12.7 | | |
| -73.0 | 0.071 | 0.0038 | 0.44 | 12.8 | | |
| -74.5 | 0.066 | 0.0035 | 0.42 | 13.5 | | |
| -62.5 | 0.144 | 0.0077 | 1.4 | 18.4 | After sitting under water | |
| -50.8 | 0.212 | 0.0113 | 2.0 | 14.6 | about 24 hrs. | |
| -43.8 | 0.298 | 0.0158 | 2.5 | 14.0 | | |
| -35.5 | 0.394 | 0.0209 | 3.0 | 11.6 | | |
| -36.0 | 0.399 | 0.0212 | 3.0 | 11.6 | | 1B |
| - 1.5 | 0.629 | 0.0334 | 3.8 | 8.1 | Higher flows at probe due | |
| 0 | 0.665 | 0.0353 | 3.8 | 8.1 | to the high head. | |
| - 6.0 | 0.464 | 0.0246 | 3.0 | 8.1 | | |
| -49.0 | 0.227 | 0.0121 | 2.05 | 13.5 | After sitting under water | |
| -51.5 | 0.223 | 0.0118 | 2.04 | 13.5 | for 1 hr. after previous | |
| -60.0 | 0.152 | 0.0081 | 1.50 | 15.0 | test. | |
| -56.0 | 0.149 | 0.0079 | 1.50 | 15.0 | | 1C |
| -70.5 | 0.085 | 0.0045 | 1.0 | 15.5 | | |
| -84.0 | 0.042 | 0.0022 | 0.55 | 15.8 | | |
| -87.0 | 0.040 | 0.0021 | 0.50 | 16.3 | | |

lowered to a height of 0.50 m and the discharge control valve removed to permit a free out flow. When the flow at this condition had stabilized, the mass flow was measured. This test was made to attempt to define a permeability index given by v/h (v=velocity, h=water column height above base of test section) for relative comparison of different types of peat plugs. The permeability index was computed and is given in Table 1. Immediately after the permeability test, the control valve was replaced and the water column brought again to a height of 1.5 m. The next test was to assess the effect of removing the velocity probe and then replacing it in the exact same location of the peat plug. This was done by carefully removing the probe and quickly sealing the aperture in the wall of the test section. During the brief time (i.e. 1-2 seconds) before the aperture could be sealed, a weak jet emerged transporting minute pieces of peat. The meter was replaced after about two hours and a final series of measurements (Set 2D) was made and also plotted on Figure 8. During all the tests with Peat Plug No. 2, the water temperature varied from 12.8$^{o}$C to 19.3$^{o}$C. The data for the four sets of measurements are given in Table 3.

For the calibration of Peat Plug No. 3, the mass flow was again regulated with the control valve and a water column height of 1.5 m was used. After the test section was secured to the stand pipe, the peat plug was left for about 48 hours under a head of 3.8 m. The water level was then lowered again to 1.5 m and the first series of measurements (Set 3A) taken and plotted on Figure 8. A permeability test was then made using the same procedure as for Peat Plug No. 2. The permeability index was computed and recorded. The system was returned to a water column height of 1.5 m and the second series of measurements (Set 3B) was made and recorded on Figure 8. It was noted that data for Sets 3A and 3B appeared to follow two different curves. The peat plug was therefore left to sit undisturbed for about one hour and a third series of measurements (Set 3C) was taken and plotted on Figure 8. After five measurements in Set 3C were taken, a large gas bubble was observed to rise from the top surface of the peat plug directly above the flow meter. The next three measurements in Set 3C when plotted on Figure 8 demonstrated a meter output which was too high for the corresponding mass flow. This indicated that some kind of change had taken place around the flow meter sensor, causing it to sense a higher local velocity then before. The peat plug was left undisturbed for about one hour and some more measurements (Set 3D) were made and also plotted on

Figure 8. These data showed better agreement with results from previous sets. At the end of Set 3D, the flow meter was moved back and forth several times and then secured again in its original position. After being left for 24 hours under a head of 1.5 m the final series of measurements (Set 3E) was made and plotted on Figure 8, indicating reasonable agreement with data from Sets 3A, 3C and 3D. Another permeability test was made and the permeability index computed. The average permeability index for Peat Plug No. 3 was then determined and entered in Table 1. Prior to each set of measurements, the control valve was shut off and a flow meter reading for zero flow taken with the water column height at 1.5 m. During the tests with Peat Plug No. 3, the water temperature varied from 15.0°C to 22°C. The data for the five sets of flow measurements are given in Table 4.

## TABLE 3 CALIBRATION DATA - TEST PLUG NO. 2

| Meter Output mV | Flow L/min | Average Velocity cm/s | Water Head m | Water Temp. °C | Comments | Data Set |
|---|---|---|---|---|---|---|
| -70.0 | 0.104 | 0.0055 | 1.5 | 13.5 | Constant head tests. Tap controlled. Start 2 hrs. after plug prepared. | 2A |
| -88.5 | 0.048 | 0.0026 | 1.52 | 14.3 | | |
| -65.6 | 0.147 | 0.0078 | 1.49 | 13.5 | | |
| -59.7 | 0.222 | 0.0118 | 1.50 | 12.8 | | |
| -51.3 | 0.323 | 0.0172 | 1.50 | 12.8 | | |
| -38.0 | 0.667 | 0.0354 | 1.50 | 14.0 | | |
| -41.7 | 0.675 | 0.0358 | 1.50 | 13.0 | | |
| -33.6 | 0.981 | 0.0521 | 1.50 | - | | |
| -90.7 | 0 | 0 | 1.50 | - | After sitting underwater about 1 hr. | 2B |
| -83.4 | 0.029 | 0.0015 | 1.50 | 15.0 | | |
| -67.9 | 0.077 | 0.0041 | 1.50 | 15.2 | | |
| -49.6 | 0.179 | 0.0095 | 1.50 | 14.6 | | |
| -34.5 | 0.418 | 0.0222 | 1.50 | 15.4 | | |
| -38.0 | 0.414 | 0.0220 | 1.50 | 15.4 | | |
| -32.0 | 0.621 | 0.0330 | 1.50 | 16.2 | | |
| -91.0 | 0 | 0 | 1.50 | 18 | After sitting underwater about 24 hrs. | 2C |
| -80.9 | 0.047 | 0.0025 | 1.50 | 18.4 | | |
| -61.3 | 0.129 | 0.0069 | 1.50 | 18.5 | | |
| -60.5 | 0.135 | 0.0072 | 1.50 | 18.5 | | |
| -69.5 | 0.075 | 0.0040 | 1.50 | 18.8 | | |
| -71.0 | 0.074 | 0.0039 | 1.50 | 18.8 | | |
| -53.0 | 0.180 | 0.0096 | 1.50 | 19.0 | | |
| -56.0 | 0.168 | 0.0089 | 1.50 | - | | |
| -44.0 | 0.294 | 0.0156 | 1.50 | 18.4 | | |
| -31.0 | 0.529 | 0.0281 | 1.50 | 18.6 | | |
| -33.0 | 0.512 | 0.0272 | 1.50 | 18.6 | | |
| -18.1 | 0.927 | 0.0492 | 1.50 | 18.2 | | |
| -24.6 | 0.746 | 0.0396 | 1.50 | 17.9 | | |
| -28.0 | 0.722 | 0.0383 | 1.50 | - | Permeability Test. | 2D |
| - 8.0 | 1.356 | | 0.50 | - | | |
| - 9.0 | 1.290 | | 0.50 | - | | |
| - 9.0 | 1.200 | | 0.50 | - | | |
| -33.3 | 0.116 | 0.0062 | 1.50 | 19.0 | After probe was removed and the replaced in plug. 1 hr. wait after replacement. | |
| -13.6 | 0.230 | 0.0122 | 1.50 | 19.3 | | |
| - 5.0 | 0.330 | 0.0175 | 1.50 | - | | |
| - 6.5 | 0.342 | 0.0182 | 1.50 | - | | |
| -55.5 | 0.055 | 0.0029 | 1.50 | - | | |
| -55.7 | 0.057 | 0.0030 | 1.50 | - | | |

TABLE 4 CALIBRATION DATA - TEST PLUG NO. 3

| Meter Output mV | Flow L/min | Average Velocity cm/s | Water Head m | Water Temp. °C | Comments | Data Set |
|---|---|---|---|---|---|---|
| -108.0 | 0 | 0 | 1.5 | 20 | After peat sitting for 48 hrs. under head of 3.8 m. | |
| -58.4 | 0.321 | 0.0171 | 1.5 | 20.8 | | |
| -64.0 | 0.268 | 0.0142 | 1.5 | 21.1 | | |
| -50.8 | 0.552 | 0.0293 | 1.5 | - | | 3A |
| -54.0 | 0.560 | 0.0297 | 1.5 | - | | |
| -36.0 | 0.818 | 0.0434 | 1.5 | 22.0 | | |
| -71.2 | 0.208 | 0.0110 | 1.5 | 21.5 | | |
| -71.3 | 0.198 | 0.0105 | 1.5 | 21.5 | | |
| -85.0 | 0.097 | 0.0052 | 1.5 | - | | |
| -86.0 | 0.097 | 0.0052 | 1.5 | 21.0 | | |
| -50.8 | 0.452 | 0.0240 | 0.5 | - | Permeability Test | |
| -51.0 | 0.445 | 0.0236 | 0.5 | 21.7 | | |
| -91.8 | 0.039 | 0.0021 | 1.5 | 19.8 | | |
| -94.7 | 0.038 | 0.0020 | 1.5 | - | | 3B |
| -63.5 | 0.108 | 0.0057 | 1.5 | 20.8 | | |
| -65.5 | 0.108 | 0.0057 | 1.5 | - | | |
| -55.2 | 0.202 | 0.0107 | 1.5 | 21.1 | | |
| -105.0 | 0 | 0 | 1.5 | - | Reading taken 1 hr. after previous reading. | |
| -84.0 | 0.089 | 0.0047 | 1.5 | 15.7 | | |
| -64.0 | 0.204 | 0.0108 | 1.5 | 15.0 | | |
| -26.5 | 0.723 | 0.0384 | 1.5 | 15.2 | | |
| -44.6 | 0.447 | 0.237 | 1.5 | 16.0 | | 3C |
| -53.0 | 0.347 | 0.0184 | 1.5 | 16.0 | | |
| + 3.0 | 0.603 | 0.320 | 1.5 | 16.8 | Large gas bubble released above probe. | |
| -11.0 | 0.340 | 0.0181 | 1.5 | 16.2 | | |
| -25.0 | 0.374 | 0.0199 | 1.5 | 15.7 | | |
| -106.0 | 0 | 0 | 1.5 | - | Reading taken 1 hr. after previous reading | |
| -65.0 | 0.135 | 0.0072 | 1.5 | | | |
| -46.7 | 0.279 | 0.0148 | 1.5 | 16.9 | | |
| -37.0 | 0.557 | 0.0296 | 1.5 | 16.8 | | |
| -29.4 | 0.856 | 0.0455 | 1.5 | 17.8 | | 3D |
| -61.0 | 0.214 | 0.0114 | 1.5 | 17.8 | | |
| -71.0 | 0.202 | 0.0107 | 1.5 | - | | |
| | | | | | Probe moved back and forth in peat plug. | |
| -113.0 | 0 | 0 | 1.5 | - | After peat sitting for 24 hrs. under head of 1.5 m. | |
| -75.6 | 0.132 | 0.0070 | 1.5 | 20.0 | | |
| -59.6 | 0.250 | 0.0132 | 1.5 | 20.6 | | |
| -50.5 | 0.431 | 0.0229 | 1.5 | 20.8 | | 3E |
| -36.0 | 0.295 | 0.0422 | 1.5 | 20.1 | | |
| -87.0 | 0.096 | 0.0051 | 1.5 | 19.9 | | |
| -33.7 | 0.950 | 0.0504 | 1.5 | 21.0 | | |
| -58.5 | 0.386 | 0.0205 | 0.5 | - | Permeability Test. | |
| -60.0 | 0.385 | 0.0204 | 0.5 | - | | |
| -118.0 | 0 | 0 | 0.8 | - | | |

## 5.0 DATA ANALYSIS

### 5.1 Preliminary Data Summary

In plotting Data Sets 1A, 1B and 1C in Figure 6, it was noticed that the three sets of data showed reasonably good agreement, except for three isolated points. These points identified as (a), (b) and (c) showed too high a value of meter output for the measured mass flow. This meter response was observed immediately after the height of the water column was taken up to the maximum of 3.8 m. This effect indicates that in some way conditions around the meter sensor were changed so as to create a higher local flow velocity. Once the head was reduced and the peat left undisturbed, conditions appeared to return to normal as evidenced by the location of the data points for Data Set 1C. This problem should not occur in the field where pressure heads are very low. Instead, it is a problem of calibration and can be avoided by maintaining lower heads. Therefore, the three data points (a), (b) and (c) in Figure 6 should be removed from further consideration and the remaining data can be used to define the calibration curve for Peat Plug No. 1.

In comparing Data Set 2A and 2B for Peat Plug No. 2, in Figure 7, one notes that each set represents a distinctly separate curve with the meter output in Data Set 2B being always higher for the same mass flows. When Data Set 2C was plotted the points approximated a curve which virtually coincided with the data from Set 2B. These results indicate that a certain "settling" time is required in order for the peat to obtain some state of equilibrium. It is most likely that after a test is begun and flow is passed through the peat, certain structural adjustments take place within the peat plug and a certain minimum time is required to achieve this. When Set 2A was measured, no flow had passed through the peat plug prior to that and hence there was no time for any internal adjustments. Data Set 2B was taken after the peat plug had been undisturbed for about one hour with a small flow passing through it all the time. The plotted points showed a clear departure from Set 2A. The fact that Data Set 2B and 2C are in such good agreement further support the argument for a minimum waiting time to obtain equilibrium within the peat plug. Data Set 2C was taken 24 hours after Data Set 2B. This would indicate that a minimum waiting time of about one hour is sufficient to obtain repeatable results. Data Set 2D in Figure 7 was begun one hour after the meter had been replaced in the peat plug. In spite of the one hour waiting time, the data set indicated a much higher meter output than observed during Sets 2B and 2C. The data points, however, approximated a curve which had a similar trend to the curves of Sets 2B and 2C. The higher meter output indicates a higher local flow velocity but it's not clear how this is obtained. Nevertheless, these results show that removing and replacing the meter in the same location in the peat, should be avoided.

The review of the plotted data sets in Figure 6 for Peat Plug No. 2 has shown that Data Sets 2A and 2D should be removed from further consideration. Data Sets 2B and 2C can be used for further analysis to obtain a calibration curve for the meter.

There were five data sets obtained for Peat Plug No. 3 and these are shown in Figure 8. Set 3A was obtained after a 48 hour waiting and one can expect that the data from this set should be representative of the calibration curve for this peat plug. Data Set 3B plotted considerably above Data Set 3A and this is most likely due to the fact that the measurements were made immediately after the permeability index tests, for which the control valve was removed to permit unrestricted flow at a heat of 0.50 m. Data Set 3C was obtained after a waiting period of one hour and based on experience with previous peat plugs this data should coincide with that of Set 3A. Examination of Figure 8 shows that this is the case for all but the last three points which plotted much higher than any of the data points in the five sets. These three points were obtained immediately after a large gas bubble was observed to escape from the surface of the peat, directly above the axis of the meter. Presumably, the gas bubble originated at or very near to the meter sensor and its departure may have altered the peat structure, thereby changing the local flows or it may have caused a change in the heat conductivity around the probe. It is not possible to state the exact effect of this gas bubble, and indeed any other bubbles, but it is clear from the results that these bubbles must be avoided in future calibrations. In fact, the existence of gas bubbles in natural peat in the field may cause problems by distorting the meter output signal. Data Set 3D was obtained after a waiting period of one hour. The first two points plotted higher than expected on Figure 8 considering the one hour waiting period, whereas the remaining points of Set 3D were in reasonable agreement with the data from Set 3A and 3C. It is not clear why the two points should not be in better alignment with the other points in the same set. Finally, it can be seen that Data Set 3E also shows good agreement with the data from Sets 3A and 3C. Prior to taking this last set, the meter was moved back and forth (but not withdrawn) and data 3E obtained after waiting 24 hours. The good agreement of the data indicate that there was no long lasting effects of disturbing the probe in the peat. The data which were found to be unsuitable are removed from further consideration and the remaining measurements used for developing a calibration equation for the flow meter in Peat Plug No. 3.

Another factor which might have affected the flow measurements is water temperature. Pedrosa (1) conducted some tests in still, fresh water in a circular vessel 56 cm in diameter and 15 cm deep to assess the effect of water temperature on the flow meter. The meter was dragged through the water in a circular path with the water being kept at a constant temperature. Tests were conducted to produce a family of curves, one curve for each constant temperature, Figure 9. The curves showed a clear dependence of the meter on water temperature and this effect increased with velocity, although the curves are not clearly defined for velocities below 0.05 cm/s which were measured in the peat tests. This effect of temperature, however, was not noted in the peat tests. This may be partly due to the fact that in peat the internal temperature of the sensing elements is much higher than in water, resulting in lower sensitivity to temperature changes. However, it is also clear from these tests that as flow conditions in peat approach those of clear water (i.e. channels) then temperature change becomes important.

## 5.2 Calibration Curves

The screened data were plotted on cartesian coordinates as meter output in mV, versus average flow velocity in cm/s. The average flow velocity was obtained by dividing the measured mass flow rate by the cross-sectional area of the peat plug perpendicular to the flow direction. The computed velocities are given together with the other data in Tables 2, 3 and 4. The plotted data are given in Figures 10a, 10b and 10c. Smooth curves were drawn through the points to define preliminary calibration curves and these are identified as Curves 1, 2 and 3 for Peat Plugs 1, 2 and 3 respectively. The scatter of the data about the average curves is in keeping with what can be expected with this type of measurement.

The meter output for zero flow (zeroing the meter) could not be adequately determined from direct measurement because the meter output did not reach a constant value when the flow was shut off, even after a waiting time of greater than 45 minutes. Values obtained after about 45 minutes were plotted for Curves No. 2 and 3. In both cases, the average calibration curves agreed reasonably well with the measured values. This indicates that the meter in each case may have been close to "zero" and that the value of the meter output can be obtained by extrapolating the calibration curve back to zero flow velocity. This value of the meter output, say, $E_o$ is fundamental to the definition of any calibration curve. The curves for the different peat plugs indicate that there is a unique value of $E_o$ for each peat condition. Therefore, the indicator of flow velocity in each case must be the meter output in excess of $E_o$, say $E_n$. Values of $E_n$ were therefore obtained by taking values of meter output for even values of flow velocity from the smoothed curves in Figures 10a, 10b and 10c. The resulting values of net meter output $E_n$=E-$E_o$ (E=measured meter output) were then plotted as a function of flow velocity in Figure 11. The curves cover a range from zero velocity to about 0.05 cm/s. Since for each peat plug the value of $E_o$ has been taken into account, all three curves have a zero meter output for zero flow velocity. All three curves are non linear with the change in velocity for a constant change in meter output increasing as velocity increases. The shape of the three curves indicates that the meter has a satisfactory sensitivity and resolution for velocities $\leq$0.02 cm/s. For velocities greater than 0.02 cm/s the meter output became nearly independent of velocity as this increased.

The curves in Figure 11 were obtained for peats of different properties. Curve No. 1 was obtained for "natural" peat whereas Curves No. 2 and No. 3 were obtained for the "commercial peat". Curve No. 3 represents a peat of greater dry density than that for Curve No. 2 (see Table 1) and this is reflected in the relative positions of the curves. The curves indicate that for a given meter output the curve of lower density will pass more flow. This observation is confirmed by the values of the permeability index also given in Table 1. The "natural" peat plug represented by Curve No. 1 had the greatest dry density and consequently one would expect to find Curve No. 1 above Curve No. 2 and No. 3 in Figure 10. However, the "natural" peat had a coarser texture and density alone may not be a stringent indicator of peat condition on meter performance. On the other hand, examination of the permeability index, indicates that the "natural" peat had a value (0.0042 cm/s/m) much lower than the denser of the two "commercial" peat plugs (0.048 cm/s/m). These two criteria of density and permeability index taken together seem to indicate that as the peat becomes more compact, the effect of peat texture seems to be of less importance especially at the lower end of the operating range of the meter. The effect seems to increase as the velocity increases as indicated by the gradual diversion of Curves No. 1 and No. 3. This contention, however, is not conclusive from these tests and further experiments using peat from different sources (ecosystems) (2) should be conducted. If the above indications can be confirmed, that is, peat texture is of minor importance, then it is possible that a single calibration curve may be sufficient. Nevertheless, as indicated by the plots in Figure 10a, 10b and 10c a value of $E_o$ will have to be determined for each type of peat. The value of $E_o$ can be readily obtained in the field. One simply pushes a length of plastic pipe (say 60 cm) of large enough diameter (say 7.5 cm) into the peat. This creates a zone of zero flow inside the pipe walls at the ambient peat bog temperature. The meter is placed into the peat and left until a stable value of $E_o$ has been obtained. Such a procedure can be conveniently carried out at each measurement location.

## 6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 The tests have shown that the flow meter is sensitive and repetitive for the same peat conditions for velocities less than 0.02 cm/s. For velocities greater than 0.02 cm/s, the meter output becomes nearly independent of velocity as this increases.

6.2 The meter does not appear to be significantly affected by the water temperature in the peat. However, the tests indicated that besides flow rate the meter may be affected by the folowing factors:

a) peat texture and degree of uniformity of peat.
b) gas bubbles in the peat interstitial spaces.
c) density.

Further tests are required to assess the relative significance of these factors.

6.3 The effect of gas bubbles, if found to be a significant factor, could present a serious problem in the field, where their presence may not be known nor can it be controlled. These bubbles appear to act as insulators and as such their effect is equivalent to a systematic error.

6.4 The tests have indicated that due to the "artificial" flow conditions set up in the calibration facility, a settling time of at least one hour and preferably as much as 24 hours after preparing a peat plug is required to obtain consistent correlation between meter output and measured flow rate. Long settling times are required when the peat has been substantially disturbed.

6.5 The present analysis indicates that the flow meter will have a unique output $E_o$ for zero flow velocity for each peat condition. These values of $E_o$ can be readily determined in the field. The values of $E_o$ are fundamental to the determination and the use of the calibration curves for the meter.

6.6 The flow meter is insensitive to temperature change when the sensor is firmly surrounded by peat. However, if flow conditions approach those of clear water (i.e. channels in the peat) temperature effects become important.

6.7 In order to further study and account for the effects of the factors in section 6.2 with the objective of developing standard calibration curves, the following is recommended.

6.7.1 Build three new meters with longer (3 cm-4 cm) heat dissipators. The dissipators should be of the same diameter as the supporting shaft and should not be recessed as in the meter used for these tests. This will ensure more uniform contact with the surrounding peat medium and produce a better averaging effect.

6.7.2 Conduct further tests using undisturbed, natural peat plugs, representative of the type of peat in which the meter will be used. The plugs should be cut horizontally so that the flow through the peat is the same as in the natural state.

6.7.3 Tests should be made with all three meters placed in the peat plug simultaneously at suitable but different locations, measuring the flow independently. The separate meter outputs can then be used to evaluate the flow conditions at different locations in the peat. In addition one can also determine if there is any advantage to using the average response of several meters. Prior to using the three meters in the peat tests, they should be separately calibrated in clear water to determine their relative performance characteristics.

6.7.4 Tests to obtain $E_o$ for each peat sample should also be made in an effort to better define the factors affecting $E_o$.

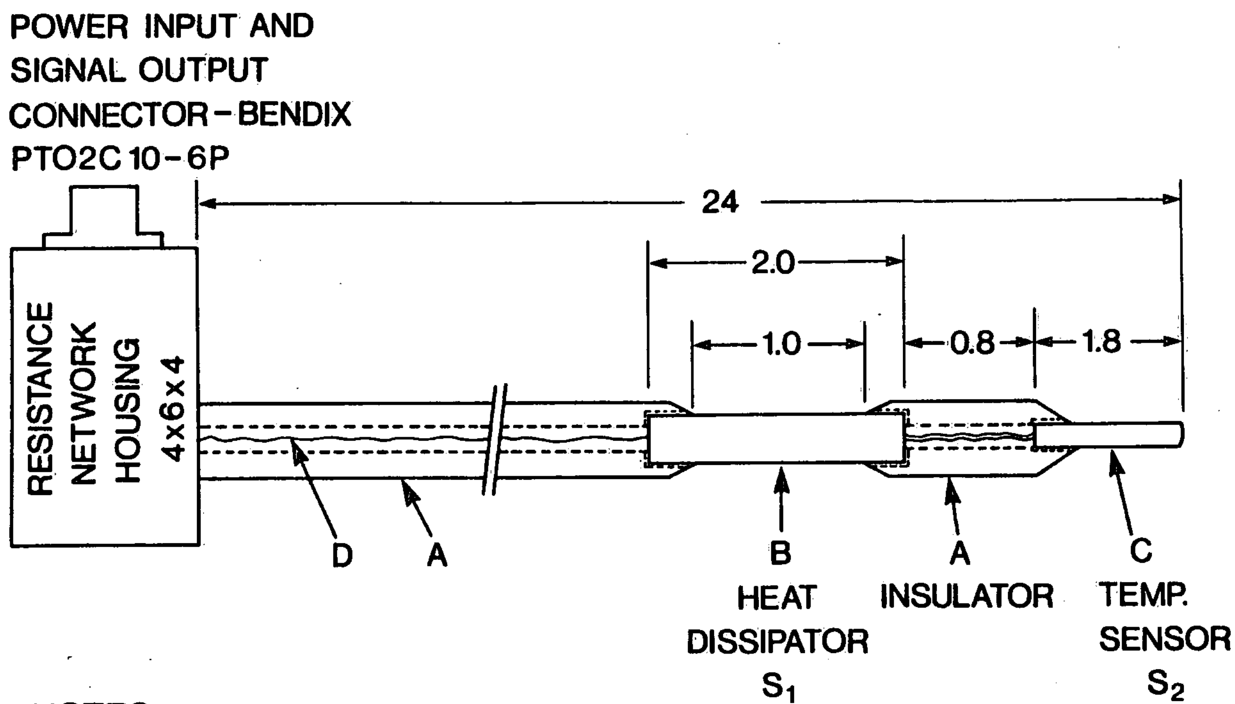
## REFERENCES

(1) Pedrosa, M. Personal Communication.

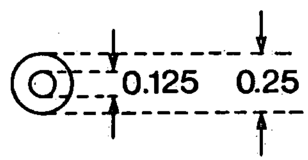
(2) Wickware, G. M. Personal Communication

## ACKNOWLEDGEMENTS

The writers wish to express their appreciation to Mr. Frank Dunnett who constructed the test facility and assisted in the measurements.

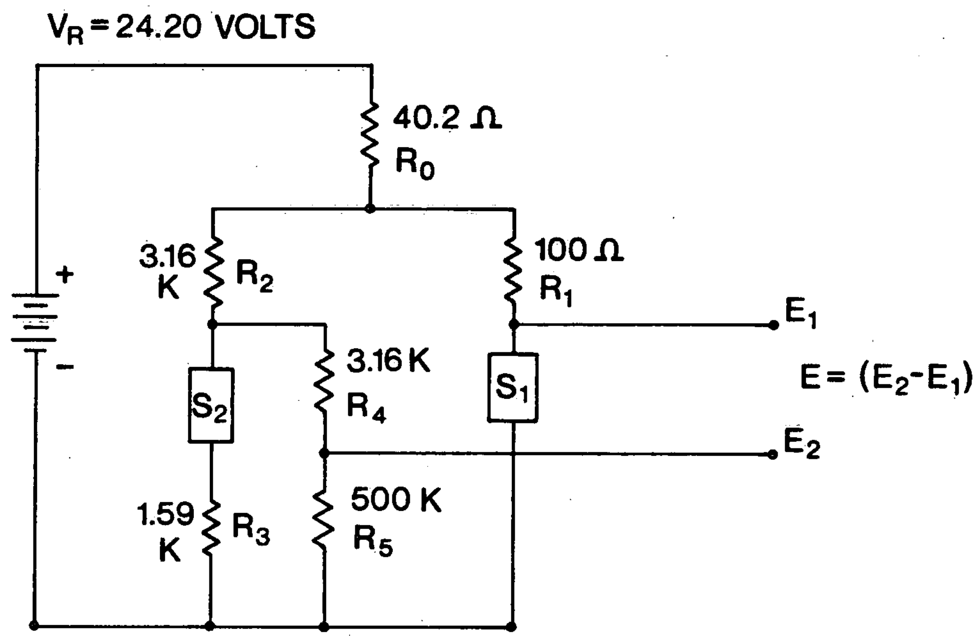



NOTES:

1. A-ACRYLIC TUBING 


2. B-BRASS TUBING 0.156 EXT. DIAM.
3. C-BRASS TUBING 0.125 EXT. DIAM.
4. D-4 LEADS-2 FOR HEATER, 2 FOR TEMP. SENSOR
5. ALL DIMENSIONS IN cm

FIGURE 1. DESCRIPTION OF FLOW METER




NOTE 1. ALL RESISTORS 1%

FIGURE 2. FLOW METER CIRCUIT SCHEMATIC

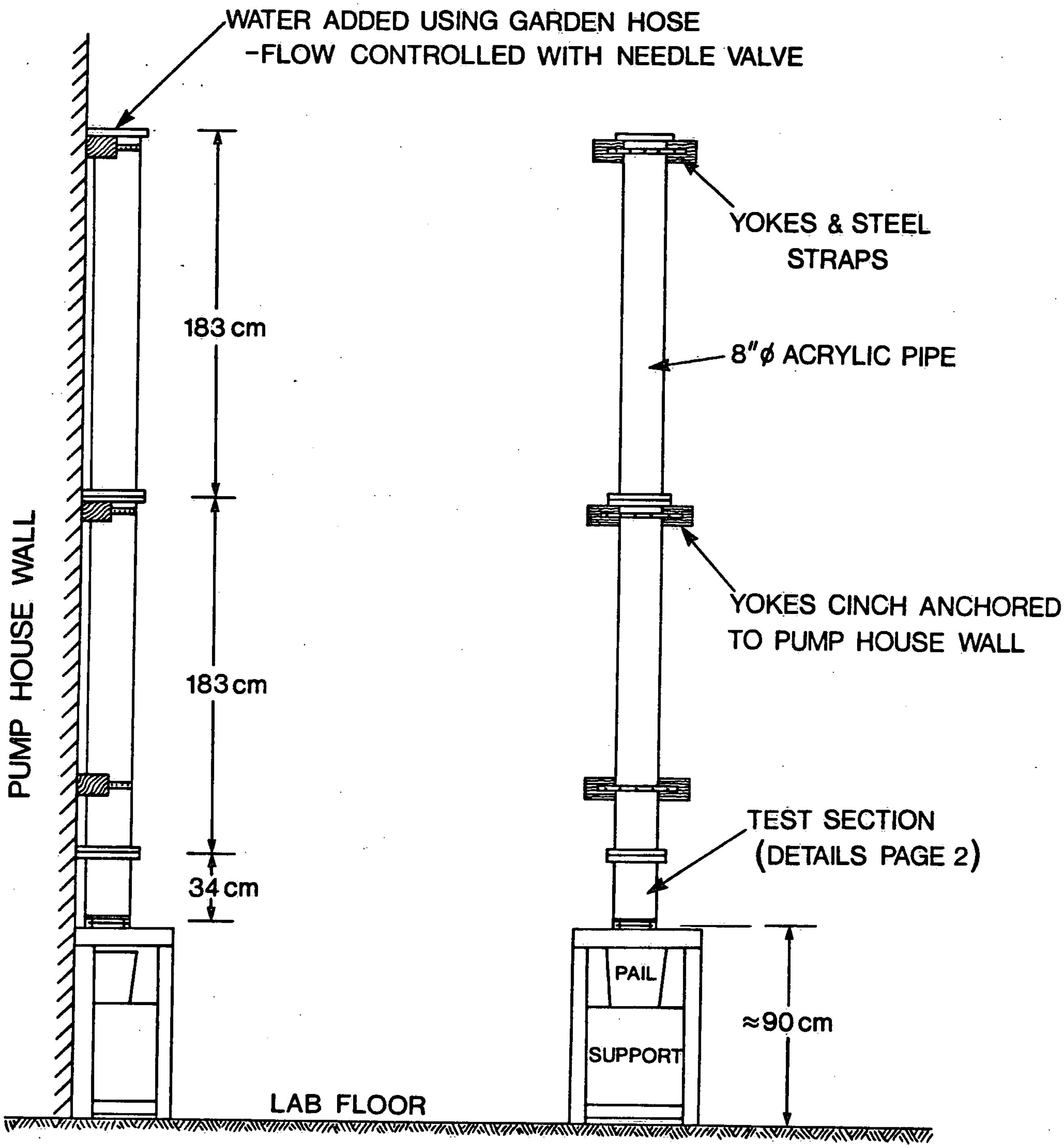



FIGURE 3a. GENERAL LAYOUT OF TEST FACILITY

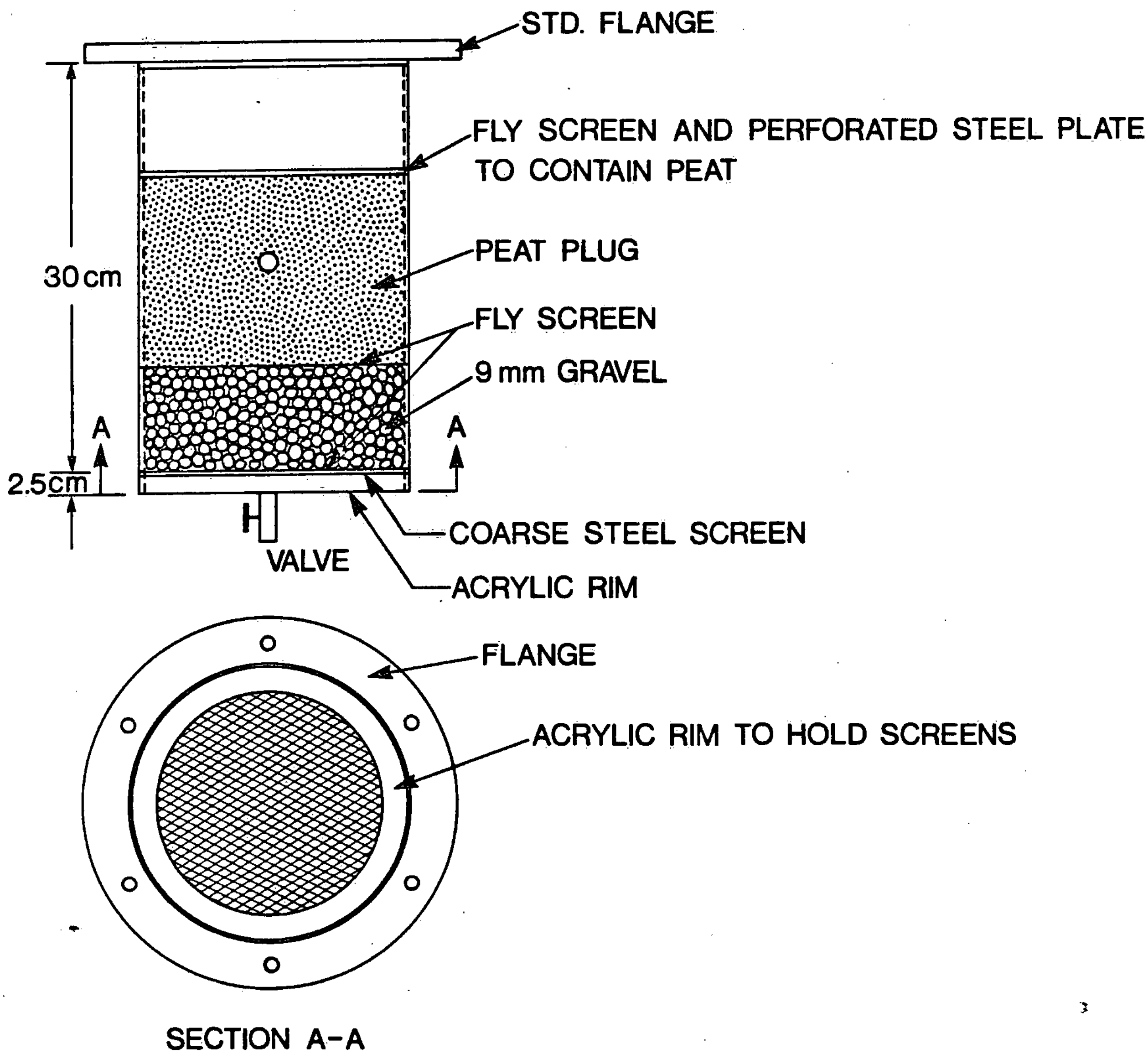



FIGURE 3b. DETAILS OF TEST SECTION

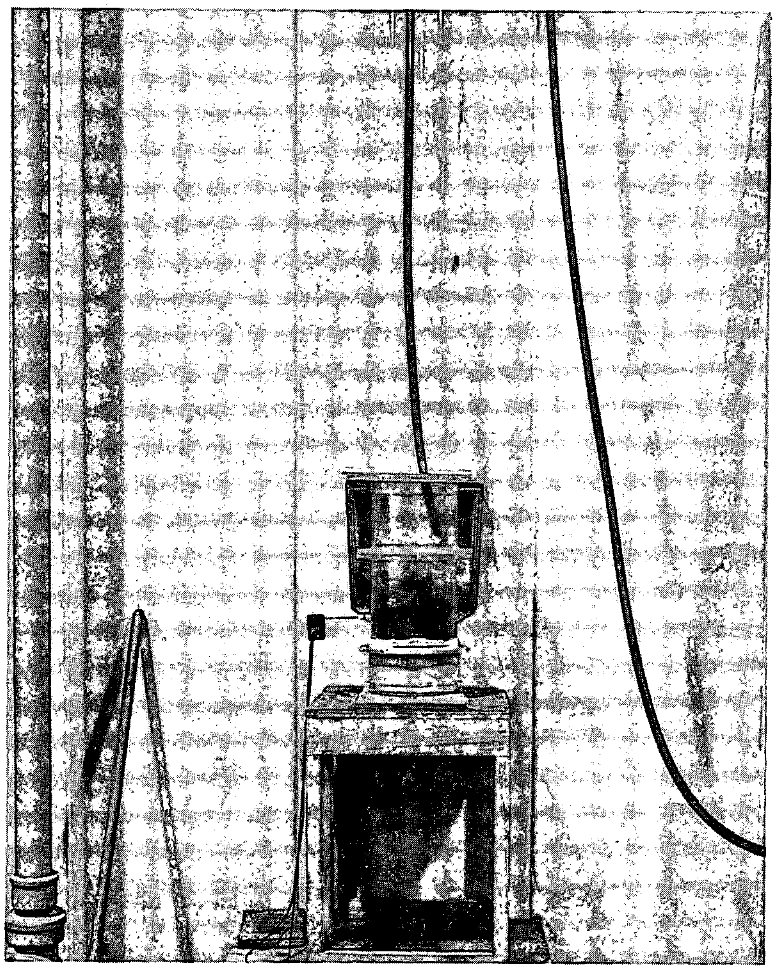


FIGURE 4. LOWER PART OF THE TEST FACILITY

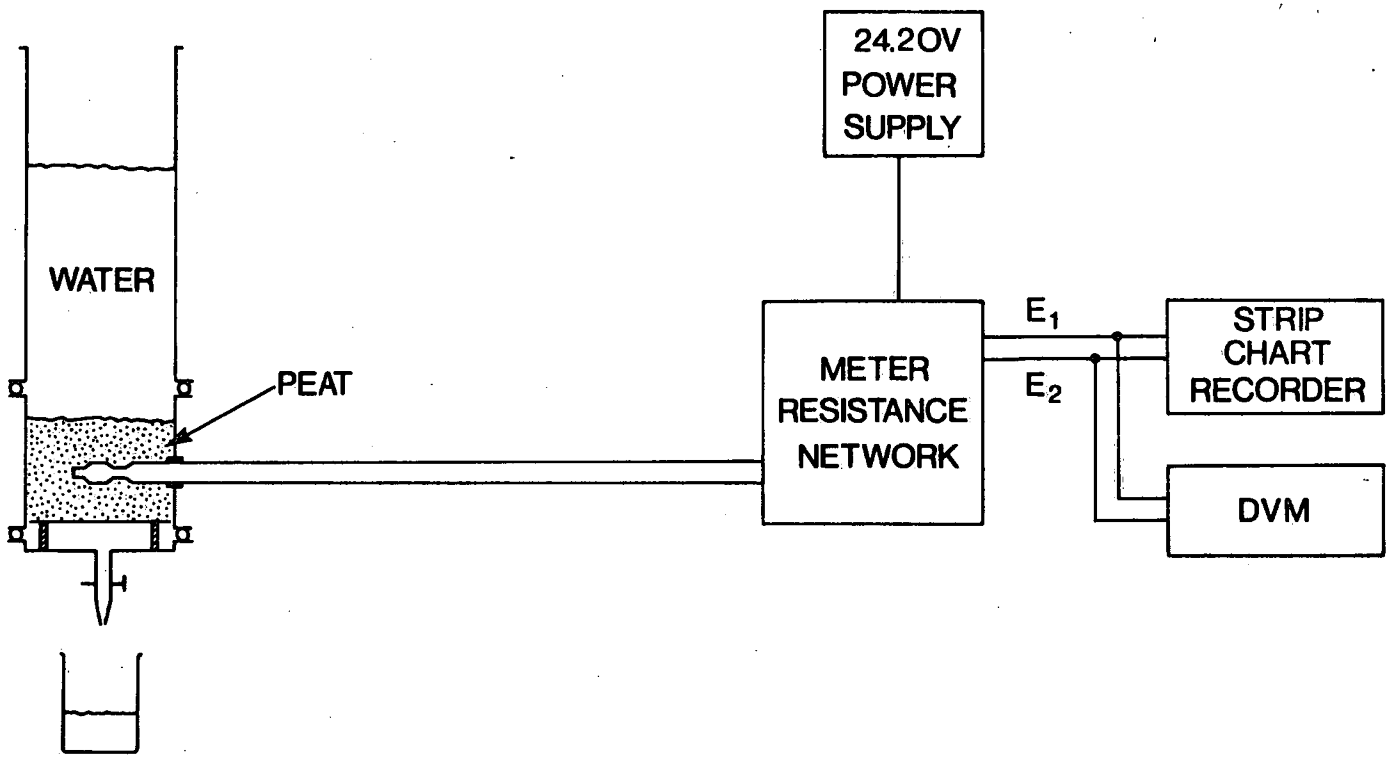



FIGURE 5. SCHEMATIC LAYOUT OF FLOW METER AND INSTRUMENTATION

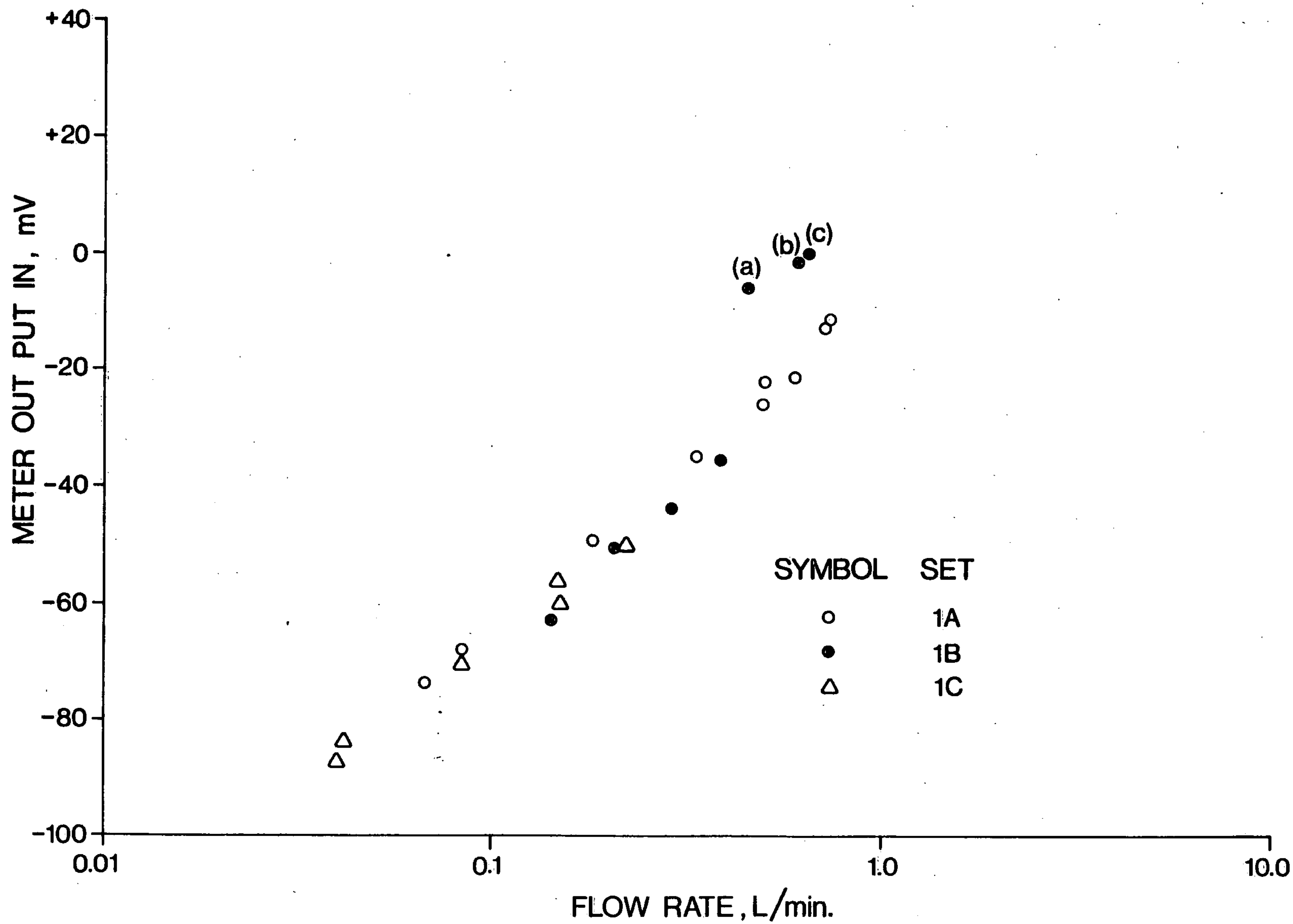



FIGURE 6. TESTS WITH PEAT PLUG No.1 (Natural)

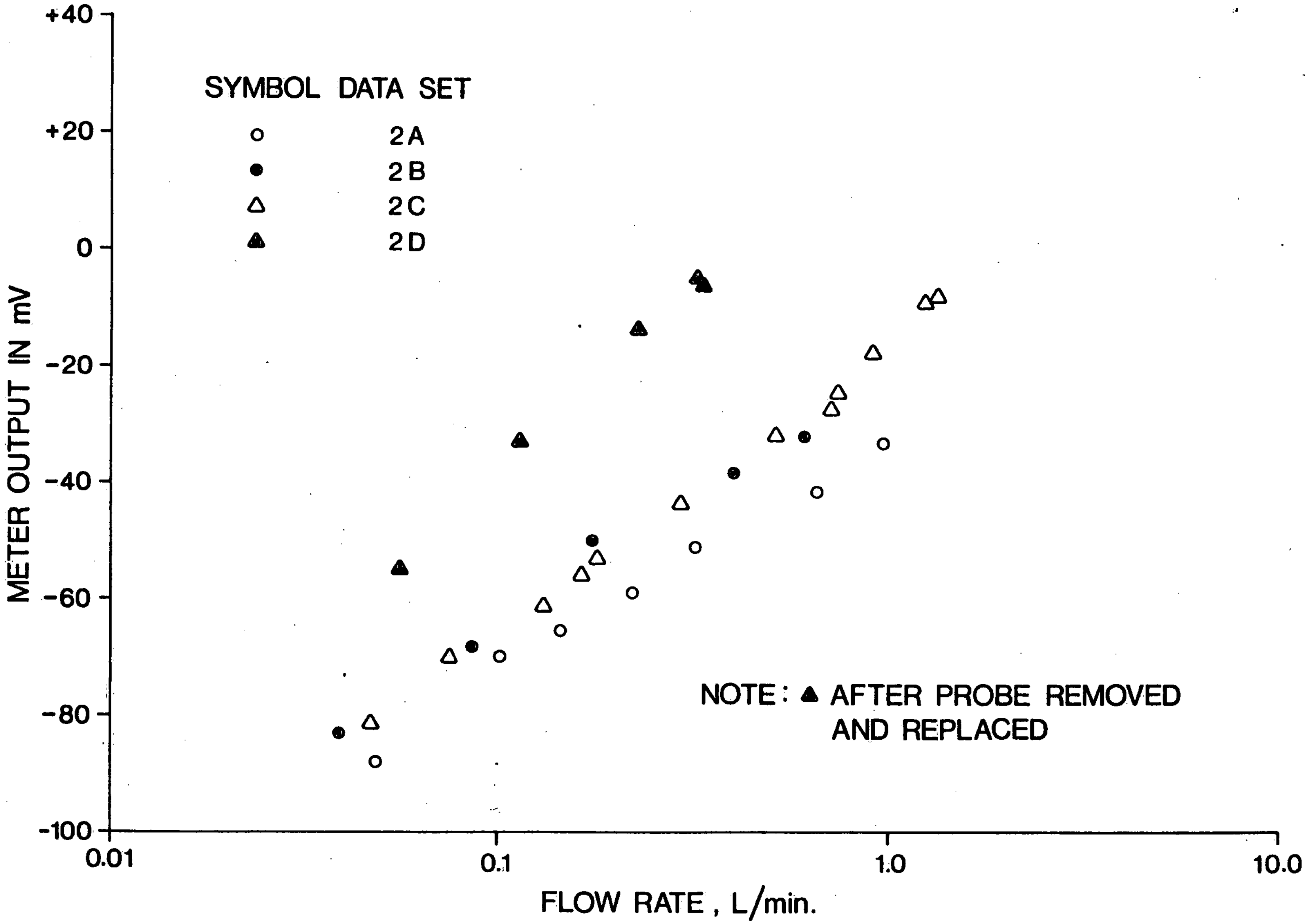



FIGURE 7. TESTS WITH PEAT PLUG No. 2 (Commercial)

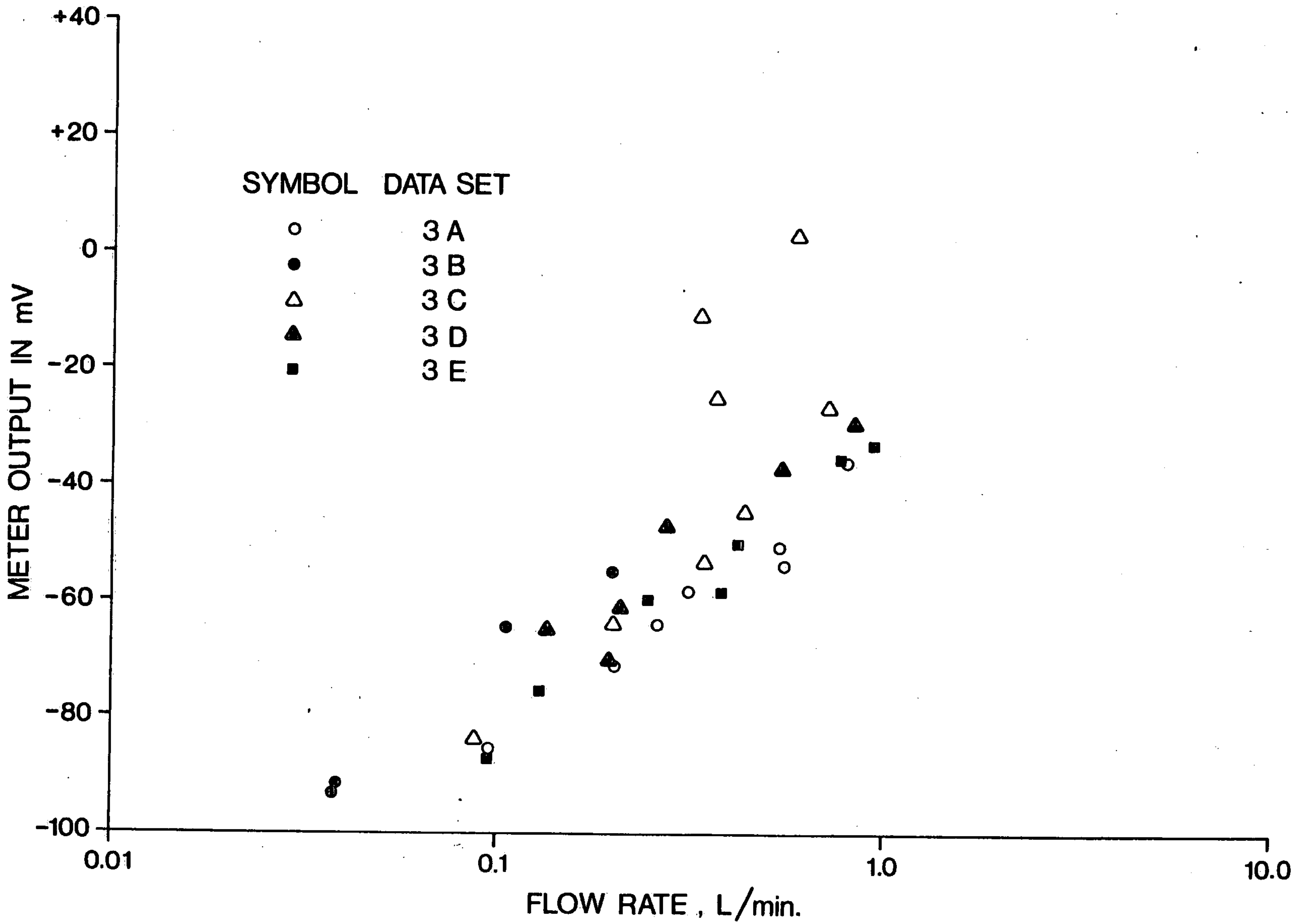



FIGURE 8. TESTS WITH PEAT PLUG No.3 (Commercial)

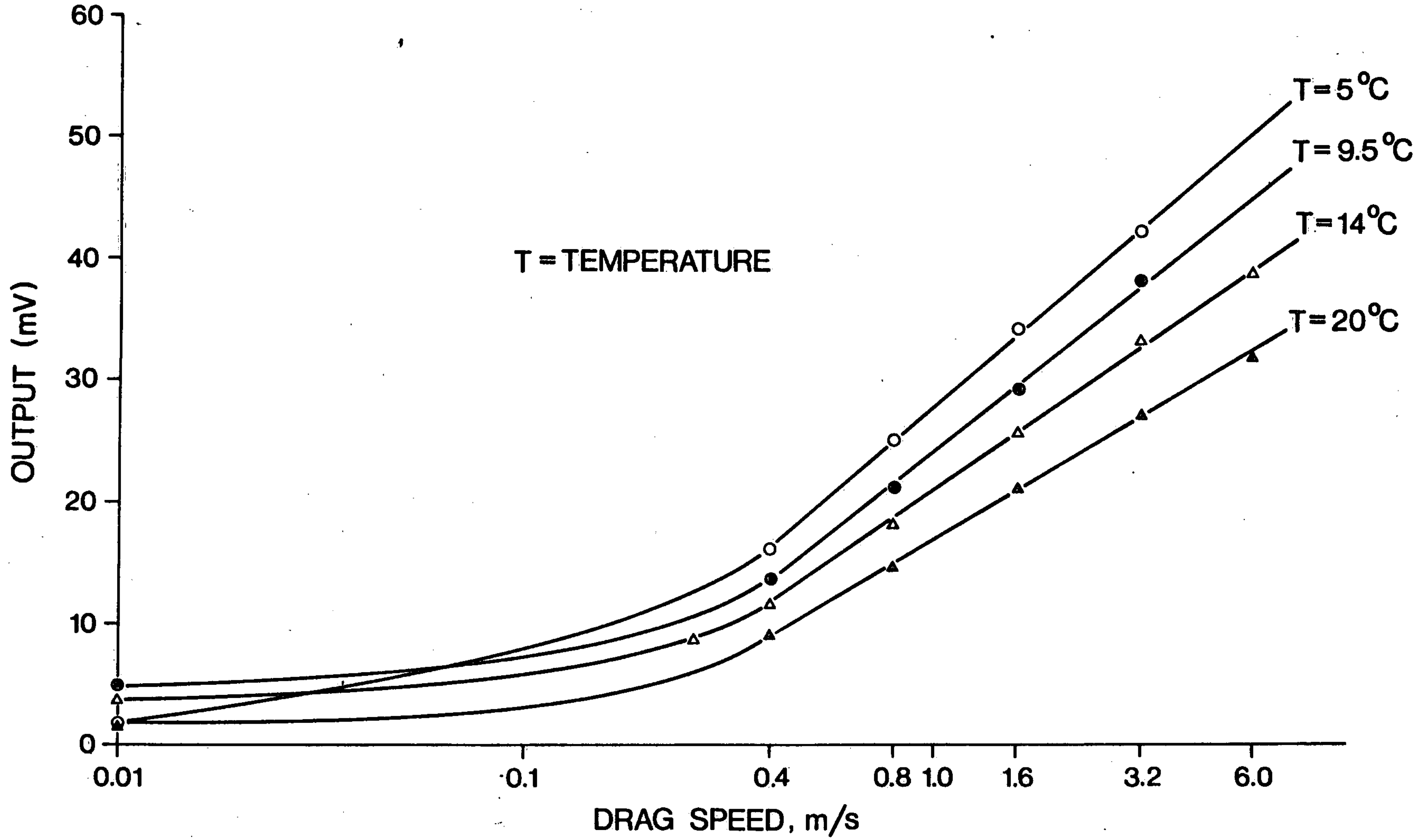



FIGURE 9. CALIBRATION CURVES FOR CLEAR WATER (Pedrosa)

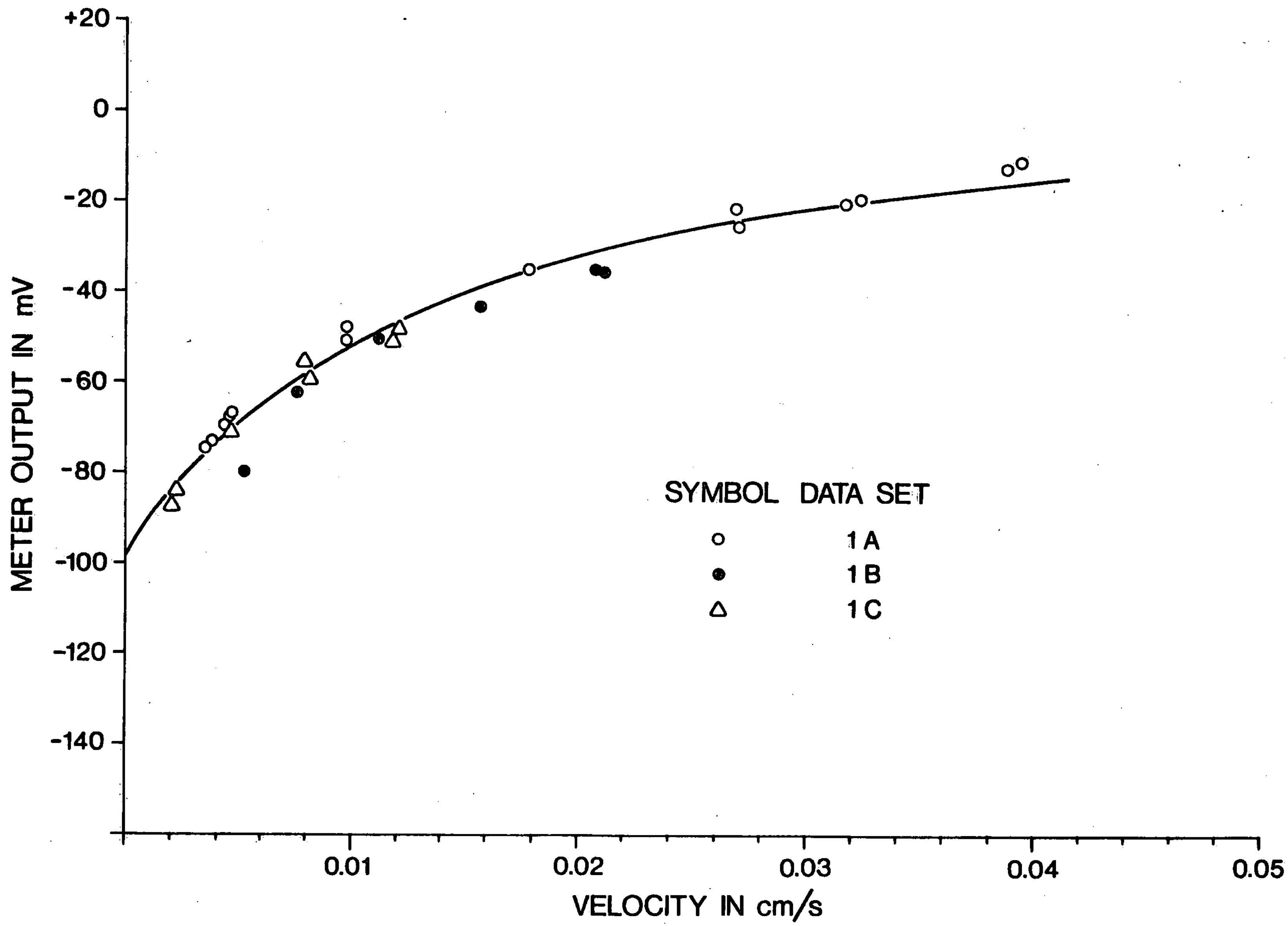



FIGURE 10a. CALIBRATION CURVE WITH PEAT PLUG No.1 (Curve no.1)

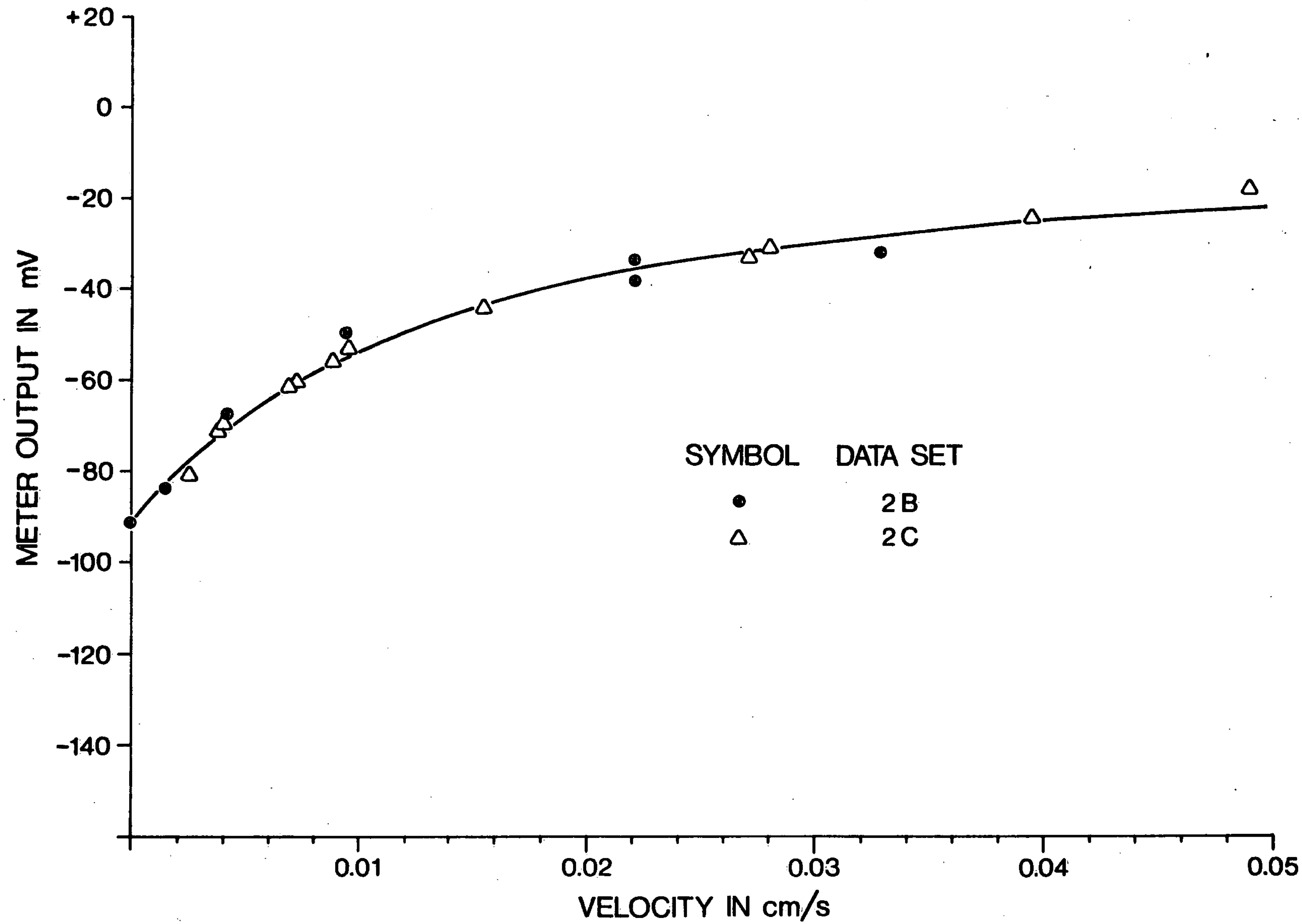



FIGURE 10 b. CALIBRATION CURVE WITH PEAT PLUG No. 2 (Curve no. 2)

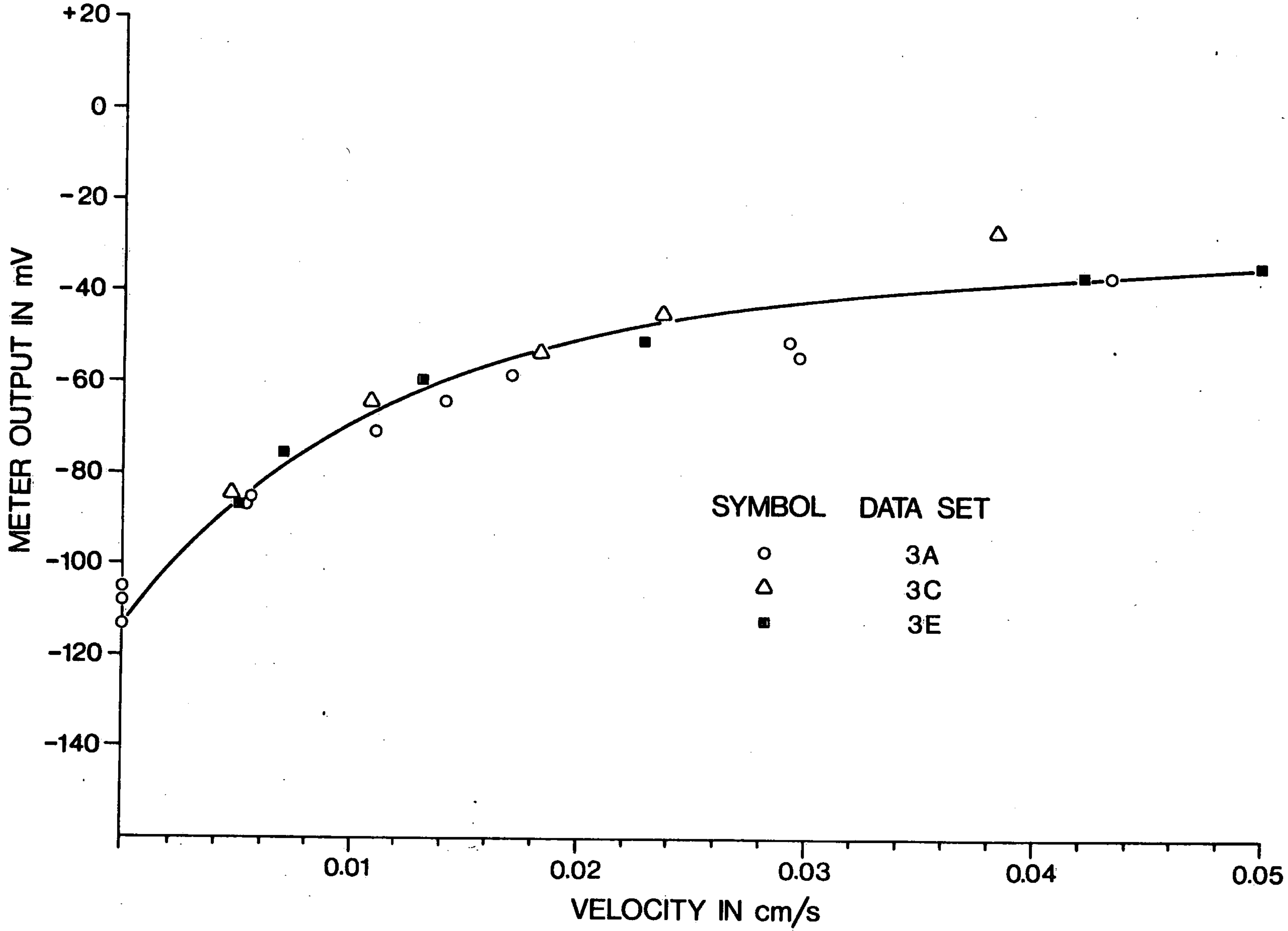



FIGURE 10c. CALIBRATION CURVE WITH PEAT PLUG No.3 (Curve no.3)

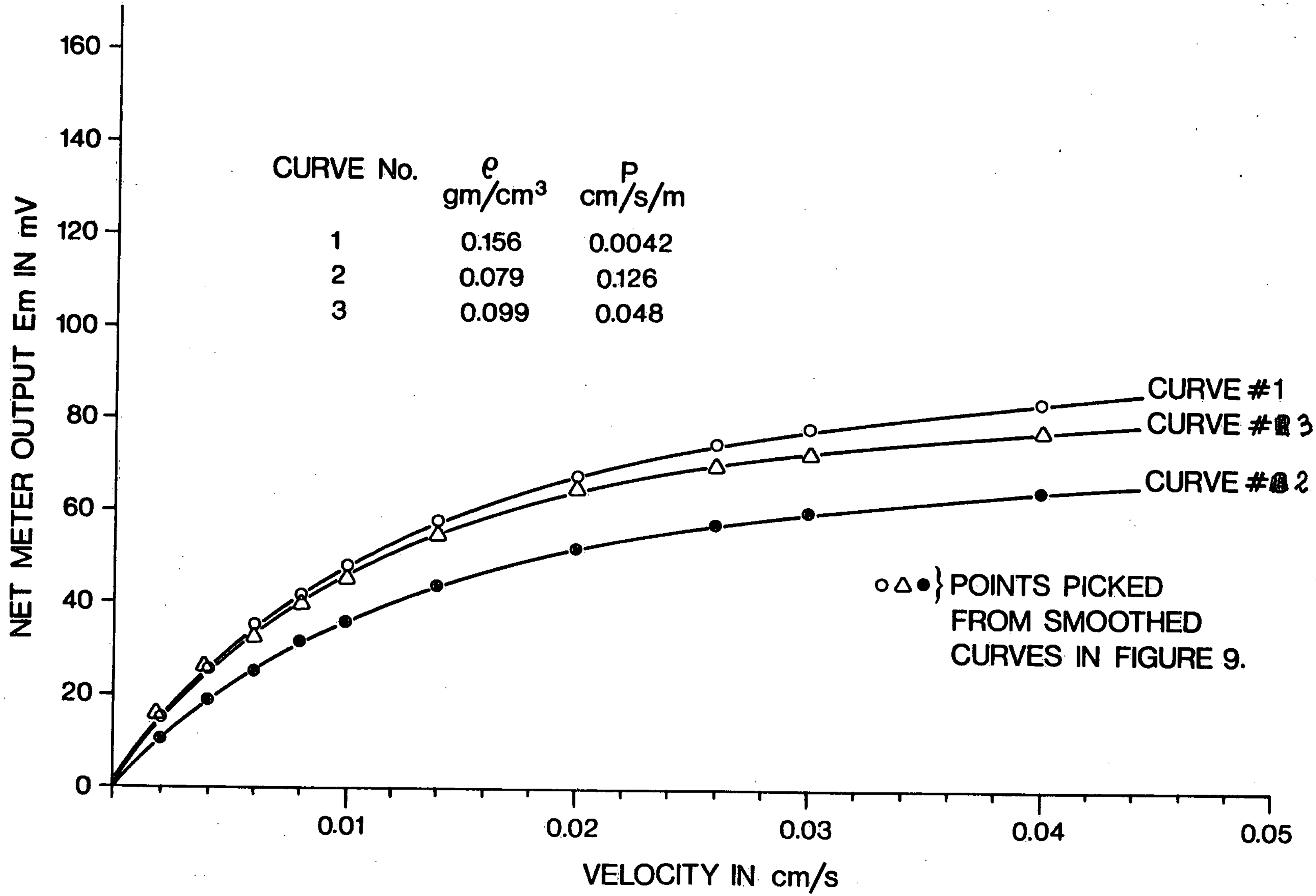



FIGURE 11. CALIBRATION CURVES FOR PEAT FLOW METER

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