

FINAL REPORT

***PERSONAL SAMPLER PUMP
FOR CHARCOAL TUBES***

CONTRACT HSM 099-71-31

PREPARED FOR

**HEALTH SERVICES AND
MENTAL HEALTH ADMINISTRATION**

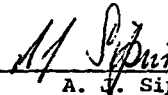
Rockville, Maryland

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FOREWORD

This is the final report of a program for the development of a Personal Sampler Pump for Charcoal Tubes. The report has been prepared for the Health Services and Mental Health Administration in partial fulfillment of Contract HSM-099-71-31.



A handwritten signature in cursive script, appearing to read "A. J. Sipin", is written above a horizontal line.

A. J. Sipin

Submitted: September 15, 1972

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1. INTRODUCTION

The personal sampler pump for use with charcoal tubes that has been developed under Contract HSM 099-71-31 has followed the design approach of the original proposal, submitted in response to RFP EPAR 71-Neg-197, in which a reciprocating diaphragm pump is driven through a crank by a miniature, battery-powered DC gear motor. In general, the specifications of the delivered prototype are very close to the preliminary specifications listed in the proposal. The volume of the prototype is 14% greater than that of the preliminary design; but the weight of the prototype is 25% less. The performance of the prototype exceeds the preliminary specifications and the contract requirements in that the flow range has been extended to 50-200 cc/min and the duration of operation exceeds 8 hours. Specifications for the prototype sampler pump and also for a battery charger are listed in Tables 1 and 2. Table 3 presents a comparison of the prototype personal sampler pump characteristics with contract requirements.

The final prototype consists of a case, which houses the pumping mechanism, the controls, and the batteries, and of a separate holder for the charcoal tube. The case is sufficiently small and light to be carried in a shirt pocket. The tube holder is clipped to the shirt collar, and the charcoal tube is connected to the pump through a length of plastic tubing. A typical application of the personal sampler pump is illustrated in the photograph of Figure 1. Figure 2 is a photograph of the pump connected to the charcoal tube holder.

A description of the personal sampler pump and discussion of the work accomplished and of the test results are presented in the following sections.

TABLE 1

Personal Sampler Pump

For Charcoal Tubes

Anatole J. Sipin Co. Model SP-1

Contract HSM 099-71-31

Specifications

Flow Rate: Adjustable over the range of 50 to 200 cc/min.

Pressure Drop: Maximum of 2.5 inches of water through the charcoal tube at a flow rate of 200 cc/min.

Power: Rechargeable batteries - 2.6 V.

Duration of Pump Operation: Eight hours at constant speed without recharging batteries.

Dimensions: 1½ inches x 2½ inches x 5 inches.

Weight: 12 ounces.

Total Flow Indication: Pump stroke indication from 0 to 99,999.

Flow Rate Indication: 0 to 200 cc/min.

Charcoal Tube: The charcoal tube is protected by separate holder clipped to the worker's collar or lapel.

Flow Adjustment: The flow adjustment is recessed and screw-driver operated.

On-Off Switch: The switch is inaccessible when carried.

Accuracy: Pump stroke indication is linearly related to total airflow within ±5%.

TABLE 2

Personal Sampler Pump

For Charcoal Tubes

Battery Charger

Specifications

Input Voltage: 115 V AC

Input Frequency: 60 Hz

Rated Load Current: 45 ma

Output Voltage (at rated current): 2.9 V DC

Ambient Temperature Range: 0^o - 40^o C

Dimensions: 2 inches x 2 inches x 1½ inches

PERSONAL SAMPLER PUMP FOR CHARCOAL TUBES

COMPARISON OF PERSONAL SAMPLER PUMP CHARACTERISTICS AND REQUIREMENTS

Contract Requirements

a. The pump shall be capable of producing a flow rate of 200 cc/min through a charcoal tube having a maximum resistance of 2.5 inches of water. The flow rate shall be adjustable over the range of about 100-200 cc/min.

b. The pump shall be battery operated and shall be capable of operating for at least four hours without recharging or replacing the batteries. Either primary or rechargeable batteries may be used.

c. The overall unit, including the pump, battery, flow counter and sample tube holder, shall be as small, light and compact as possible.

d. An indicating device, such as a stroke or revolution counter, which gives a number which can be converted to total volume of air sampled within $\pm 5\%$ shall be provided.

e. The unit shall be provided with either a built-in flow rate indicator or an external device for initial setting of the flow rate.

Pump Characteristics

a. The flow rate is adjustable over the range of 50-200 cc/min.

b. The pump is operated by rechargeable batteries. It is capable of operation in excess of eight hours without recharging.

c. The pump dimensions are $1\frac{1}{2}$ " x $2\frac{1}{2}$ " x 5". It weighs less than 12 ounces, and it can be carried in a shirt pocket.

d. A revolution counter is supplied to indicate total sampled air volume. Accuracy is within $\pm 5\%$.

e. The pump case includes a built-in flow rate indicator. Provision is also made for external measurement of flow rate.

PERSONAL SAMPLER PUMP FOR CHARCOAL TUBES

COMPARISON OF PERSONAL SAMPLER PUMP CHARACTERISTICS AND REQUIREMENTS

Contract Requirements

f. The case of the unit shall protect the glass charcoal tube from breakage and shall protect the inlet so that only airborne contaminants may enter.

g. The unit shall be equipped with a means of attaching to the worker in such a location that the sample will be collected from his breathing zone.

h. Loading, adjustment and attachment features shall be so designed as to limit opportunities for deliberate or accidental tampering with the sampler while it is in operation.

Pump Characteristics

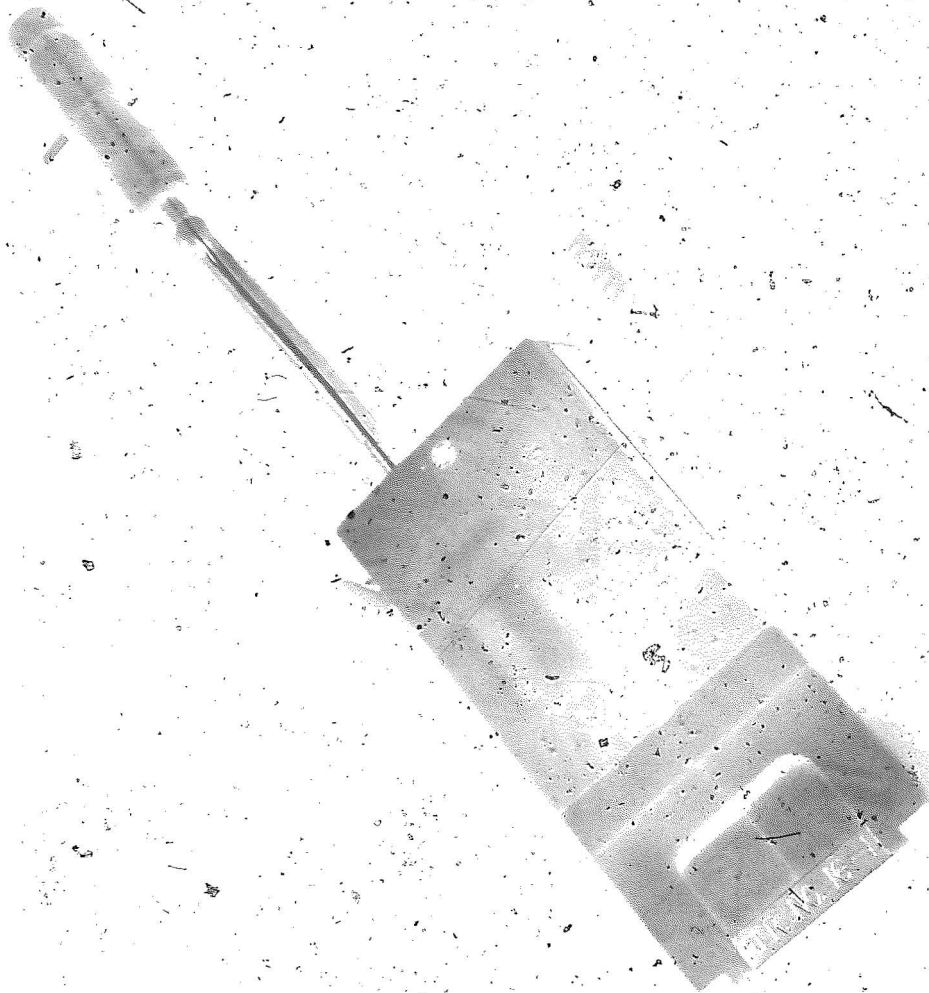
f. A separate holder is provided for the charcoal tube. The inlet is protected by a screen.

g. The charcoal tube holder is clipped to the worker's collar or lapel.

h. The charcoal tube is totally enclosed. The flow adjustment is recessed and screw-driver operated.



FIGURE 1



2. DESCRIPTION OF PERSONAL SAMPLER PUMP

An outline drawing of the personal sampler pump is shown in Figure 3. The device consists of a pump and battery package and a separate charcoal tube holder, which is connected to the pump through a length of plastic tube. The dimensions of the pump and battery package are 5.12 in. high, 2.50 in. wide, and 1.25 in. deep. As shown in Figure 1 the pump and battery package are sufficiently small to be carried in a shirt pocket, and the charcoal tube holder can be clipped to a collar to sample air from the breathing zone.

A digital counter is exposed through a window on the front surface of the pump housing to indicate total air flow. A recessed, screw driver operated, flow rate adjustment is also located on the front surface next to a rough air flow rate indicator. A jack is provided to permit a more precise external measurement of motor voltage (hence air flow rate). An on-off switch is located on the top of the pump and battery package, and a jack is provided on the side of the package to charge the battery when it is not in use.

The personal sampler pump with a transparent cover, providing an internal view, is shown in the photograph of Figure 4; and an assembly drawing corresponding to that photograph is shown in Figure 5. In both illustrations the working parts of the sampler pump are exposed, including the pump drive, the pump stroke counter, the drive piston, and the inlet and outlet valves. The batteries are located in a separate package below the pump housing. The battery pack is removable and can be separately charged if necessary.

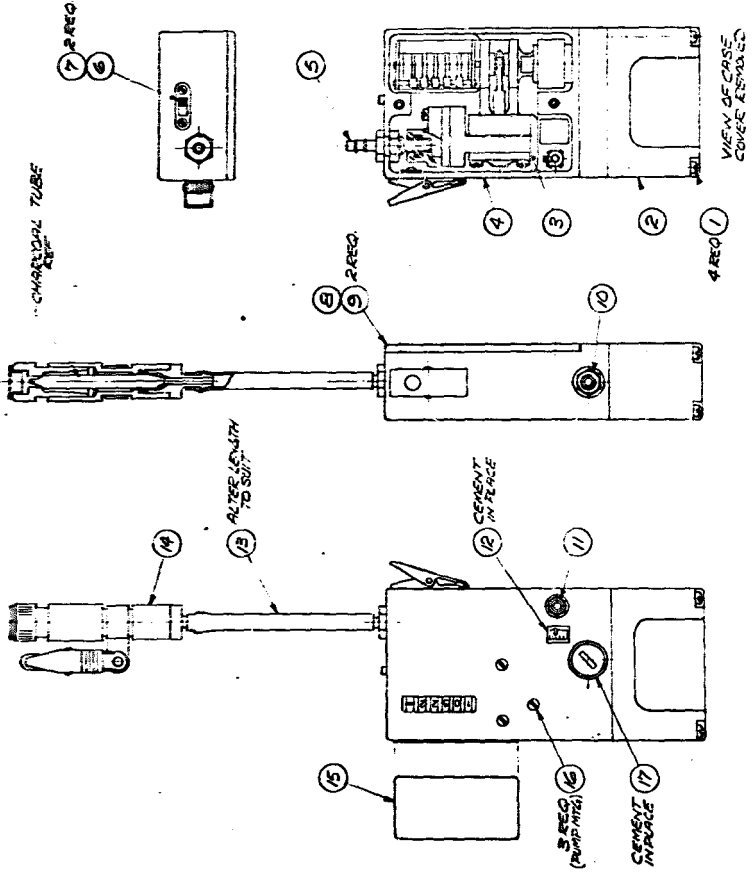
Figure 6 is a drawing of the pump and drive assembly, which is also shown in Figures 4 and 5. The inlet valve assembly, item 11, is shown in the partial section of the top view. The outlet valve assembly can be seen in section AA which also shows the piston and diaphragm assembly, item 5, and the drive shaft. The separate drive linkage and the motor and counter mounts are clearly shown in the partially sectioned side view.

Figure 7 is an electrical schematic diagram for the personal sampler pump. Plug 162044 and receptacle 162045 connect the reference battery 162046 and the power battery 162047 to the pump drive. The reference battery is a mercury cell which energizes a flow adjusting potentiometer 162043. The wiper arm of the potentiometer is connected to the input of an electronic regulator, which controls the voltage applied to the terminals of the drive motor 162042 to be that selected by the potentiometer. Since the motor speed is very closely related to the terminal voltage (back EMF) a very constant drive speed is maintained at the selected value.

Because of the linear relationship between flow rate and drive speed and between drive speed and motor voltage, an indication of the motor voltage provides a measure of air flow rate with satisfactory accuracy. The flow indicator included in the pump package is an ultraminiature iron vane indicator, whose function is to permit setting of the air flow rate at approximately the desired value. For more precise calibration jack 162049 can be connected to an external voltmeter. A resistor 162051 is provided for calibration of the built-in flow indicator. The on-off switch 162040 is connected so that both the reference battery and the power battery are connected to the circuit by a single contact.



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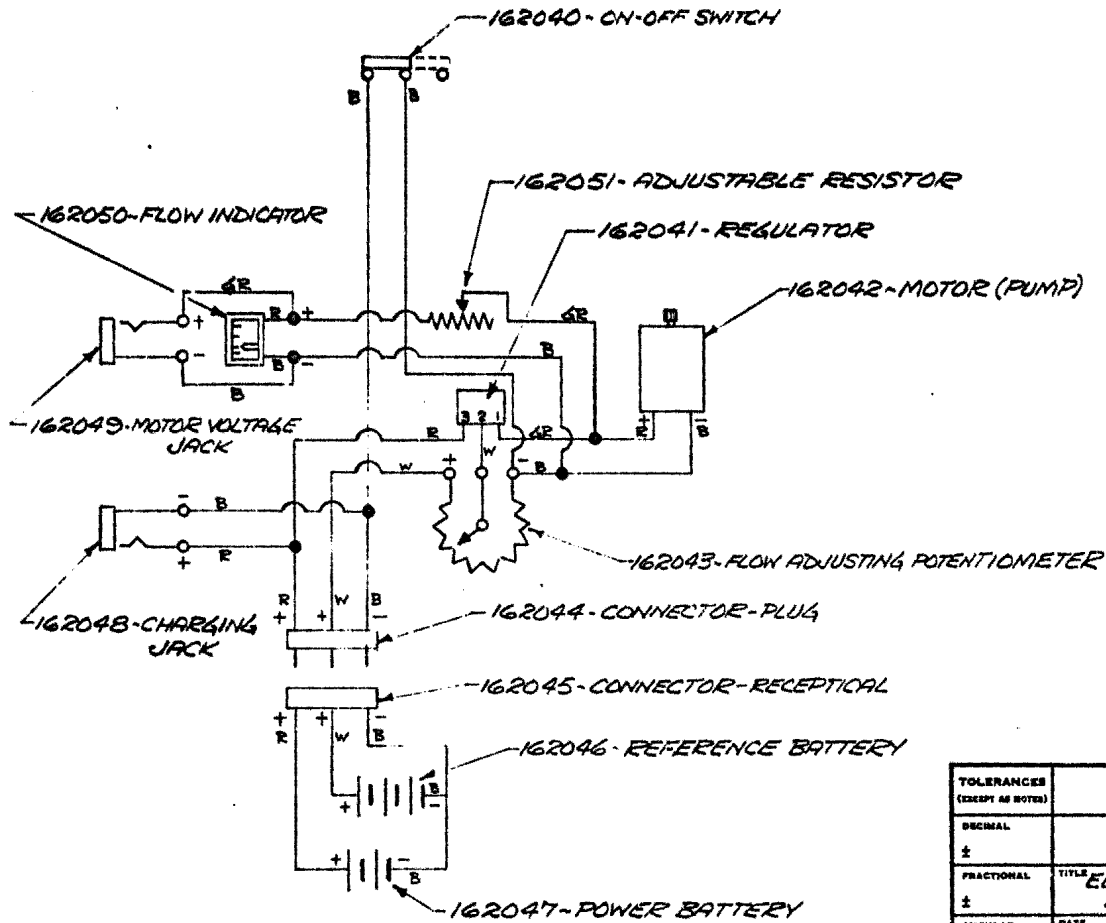


18	162000	CONNECTOR-PLUG
19	162001	REDUCER
17	162002	FLY WHEEL ADAPTER
16	162003	FLY WHEEL S.C.P. SPRINGLESS
15	162004	ARMATURE PLATE
14	162005	ARMATURE TUBE HOLDER
13	162006	FLY WHEEL INLET
12	162007	FLY WHEEL INLET
11	162008	WASHER W/INLET WASH
10	162009	CHARCING WASH
9	162010	CHARCING WASH
8	162011	CHARCING WASH
7	162012	CHARCING WASH
6	162013	CHARCING WASH
5	162014	CHARCING WASH
4	162015	CHARCING WASH
3	162016	CHARCING WASH
2	162017	CHARCING WASH
1	162018	CHARCING WASH

NOTE:
 1 REFER TO DENIS 16200 - ELECTRICAL SCHEMATIC
 FOR MEANS & LOCATION OF ITEMS NOT SHOWN

FIGURE 5

DATE	BY	REVISION RECORD	AUTH.



TOLERANCES (EXCEPT AS NOTED)	ANATOLE J. SIFIN NEW YORK, N. Y.		
DECIMAL ±	SCALE	DRAWN BY <i>J. Marley</i> APPROVED BY	
FRACTIONAL ±	TITLE ELECTRICAL SCHEMATIC DIAGRAM PERSONAL SAMPLER PUMP		
ANGULAR ±	DATE 6-19-72	DRAWING NUMBER 162010	

2-6

FIGURE 7

3. WORK ACCOMPLISHED

Work performed in development of the personal sampler pump consisted of design, component evaluation, fabrication and evaluation of test models, and fabrication and test of the final prototype.

The principal problems involved in development were:

- 1) Providing a high volumetric efficiency.
- 2) Achieving the linear calibration of flow rate to drive speed.
- 3) Designing the pump drive and selecting components for minimum battery power drain.
- 4) Achieving stable operation at constant low drive speeds.

An additional initial problem was in attaining a 1:1 correspondence between the flow rate and the reciprocating speed of the piston. Although this correspondence is attainable, it was ultimately abandoned because of the very low drive speeds that would be required at low flow rates of interest to obtain a correspondence between the digital output and total flow in discrete units (e.g. cc/revolution).

Consideration of the pumping dynamics indicated that the volumetric efficiency is a function of the resistance in the inlet and outlet flow lines. If the resistance is too high, the mass flow will be decreased. An effort was made, therefore, to attain valves of low resistance and high efficiency and to design the porting to maintain pressure drop at a minimum. Consideration was given to the introduction of arbitrary resistance in the line so as to reduce the effects of fluctuations in the resistance of charcoal tubes. A number of charcoal tubes of different sources were tested to determine the average resistance and the spread of resistance values. The large majority of the tubes had resistances well below the specified maximum. Tests of the prototype with a simulated resistance of 2.5 in. H₂O @ 200 cc/min showed that the pump calibration was within specifications, and there was no need, therefore, to introduce a linearizing resistance.

Various types of valves and valve designs were investigated. Of those tested a rubber valve with an umbrella shape provided the best combination of low forward resistance and low reverse leakage. These valves are used in the prototype. The valves and test results have been discussed in the semi-annual report.

Initial piston drives that were tested had no other bearings besides those of the motor and counter. Although this configuration is simple and workable, low speed operation was affected and there was an excessive battery drain due to high friction. Separate bearings, therefore, were installed for the drive linkage. Several motors with varying characteristics and several transmissions with different ratios were tested. The developmental drives also have been described in the semi-annual report.

Following the component tests, a test pump capable of assembly into the desired prototype package was built. Variations in linkages, drive components, diaphragms, and valves were all evaluated with the test pump assembly. After achievement of satisfactory operation of the test pump assembly, two prototypes were constructed. The first prototype met contract requirements; but since it is desirable to operate the pump at a much lower flow (50 cc/min) than that specified (100 cc/min minimum), additional development was performed to assure low flow operation.

To improve low speed operation and to provide constant speed over the period of operation of the pump, an electronic regulator was added. The regulator maintains pump voltage and pump speed at the selected value. The design was revised to include this regulator, and a new prototype with an improved envelope was built.

The final prototype was tested and showed performance exceeding contract specifications.

4. TEST RESULTS

Figures 8, 9, and 10 are plots of the final test data for the prototype personal sampler pump (No. 2) which has been delivered to the National Institute for Occupational Safety and Health. Figure 8 is the basic flow-speed calibration which relates the air flow rate (cc/min) to the speed of the drive shaft (i.e. piston strokes per minute). The calibration also can be expressed in cc/stroke (or revolution), since the counter which indicates total air flow is coupled directly to the drive shaft. Three different conditions are plotted in Figure 8: one with a charcoal tube having an average flow resistance of 1.5 in. H₂O at 200 cc/min; the second in which a low resistance tube is used; and the third in which a simulated maximum flow resistance of 2.6 in. H₂O at 200 cc/min is applied to the inlet. It is seen that the test points for all three conditions fall within an envelope of ±5% of maximum flow rate (200 cc/min), thus meeting specified accuracy. In the range of 50-200 cc/min, the points also fall within a tighter band of ±5% of reading. As described in Section 3, the flow rate is reduced as the resistance of the charcoal tube increases. However, this is only significant for a single plotted point, under a condition of high resistance and at a flow rate of 230 cc/min, which is outside of the specified flow range; and even this point is almost within limits. It is concluded, therefore, that the pump maintains a linear calibration with the specified accuracy of ±5% when used with a normal charcoal tube.

Figure 9 is a plot of air flow rate versus motor terminal voltage. The linearity of the calibration for all resistances over the required flow range is evident. This is due to the linearity of the speed-voltage characteristic of the drive motor, which is almost entirely determined by the back EMF of the motor, the IR drop being very small. The speed-voltage calibration is shown in Figure 10.

Figures 11, 12 and 13 are similar plots of the first prototype pump model, when operated with a motor voltage regulator and a representative charcoal tube. All of the characteristics are seen to be very linear when a charcoal tube of normal resistance is used. Stable flow rates have been achieved to as low as 25 cc/min, but because of the very low drive speeds, operation is not recommended below 50 cc/min. The differences between the first and second prototypes are very minor, and they do not affect performance characteristics. The test results show that the prototype personal sampler pump when operated with normal charcoal tubes exceeds contract requirements by providing an accurate flow indication over an extended range of 50-200 cc/min.

Figures 14, 15, and 16 show plots of flow rate vs drive speed, flow rate vs motor voltage, and motor voltage vs drive speed for the test pump described in Section 3. The design values used provided a ratio of flow rate to drive speed of approximately .87, so that every unit indicated on the counter was equivalent to a total air flow of .87 cc. No motor voltage regulator was used; and at low speeds the rotation was uneven, and occasional difficulty in starting was experienced. The lowest stable flow rate was approximately 80 cc/min. No flow resistance was connected to the inlet so that the flow characteristic of the basic pump could be determined. Flow rates of over 400 cc/min were achieved. The linearity of the flow characteristic is very marked.

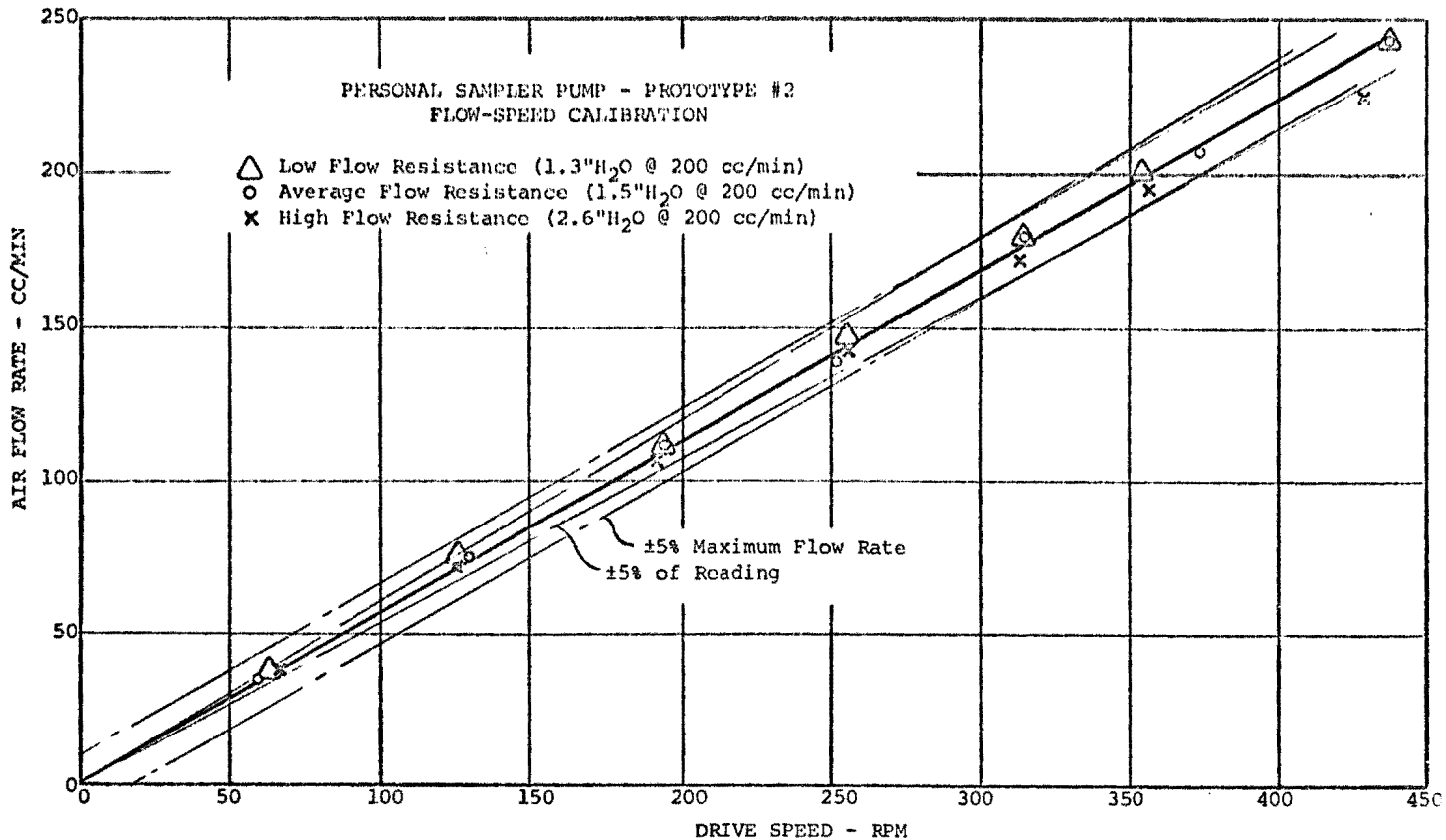


FIGURE 8

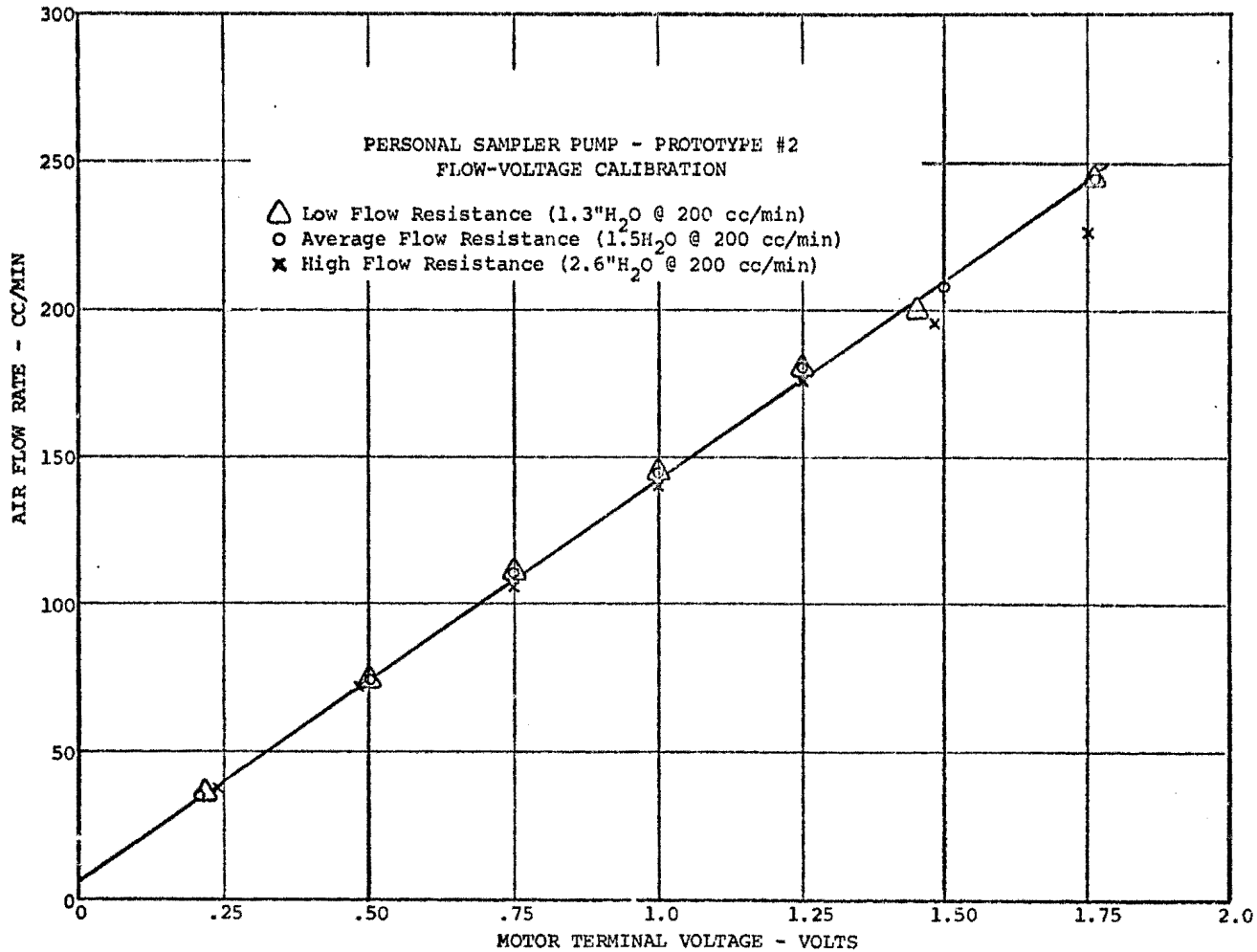


FIGURE 9

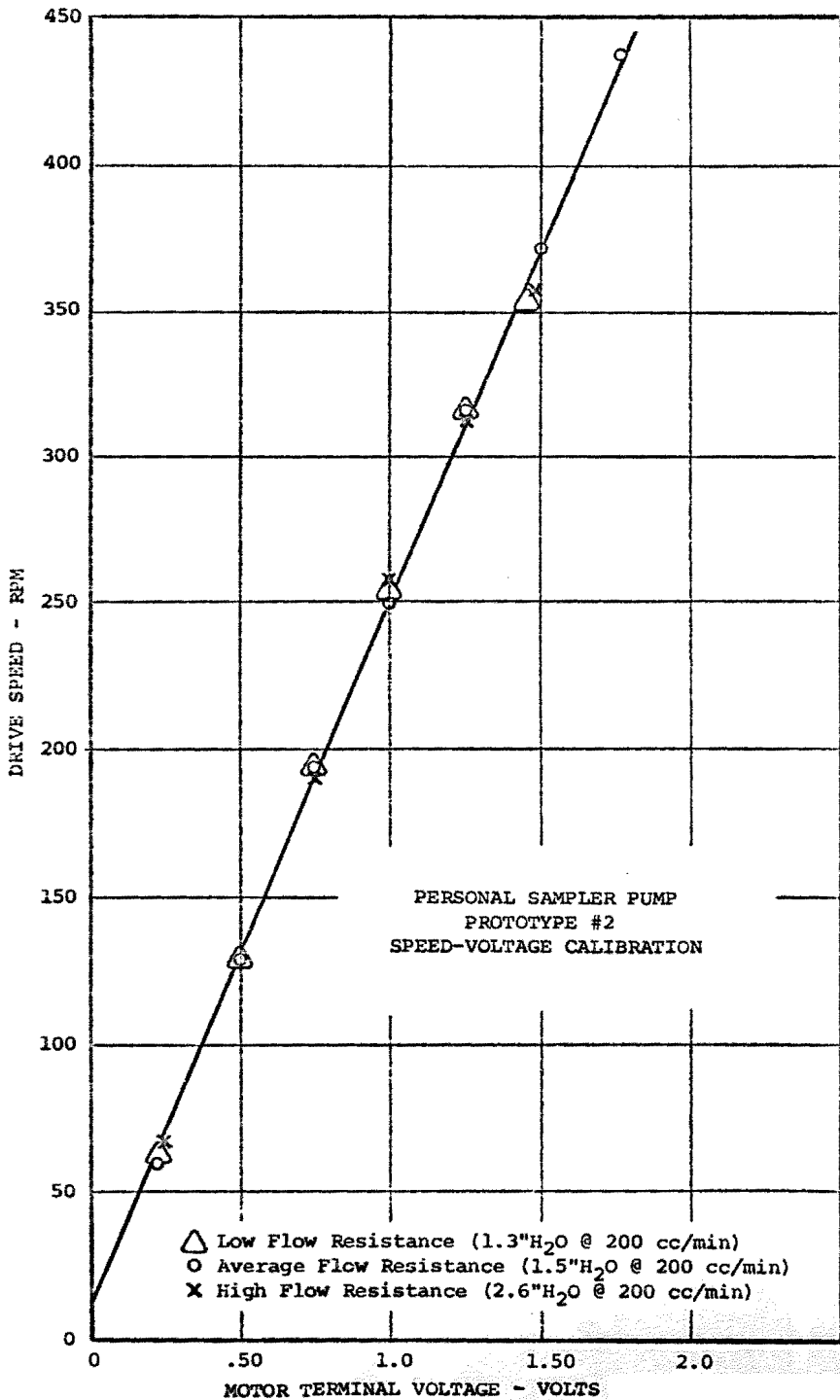


FIGURE 10

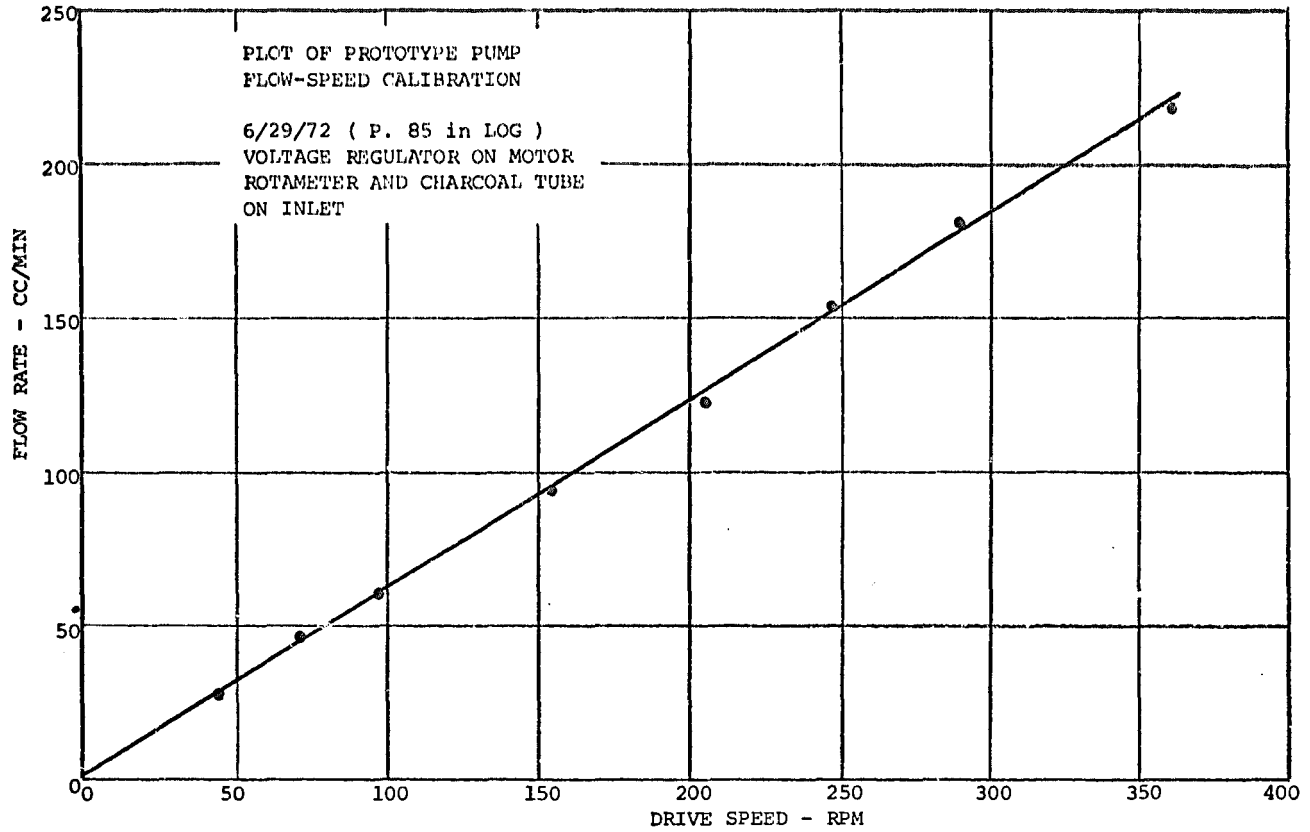


FIGURE 11

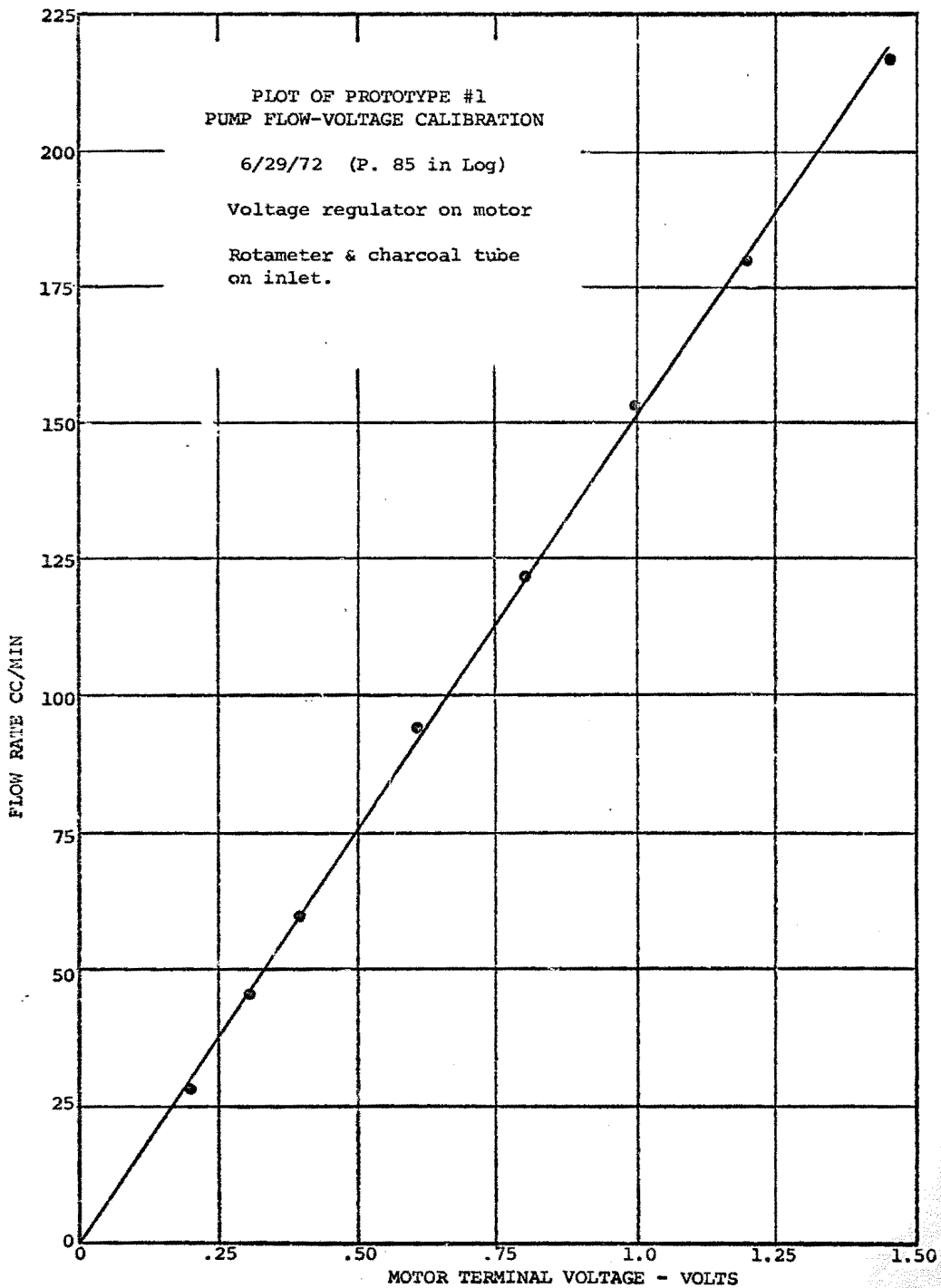


FIGURE 12

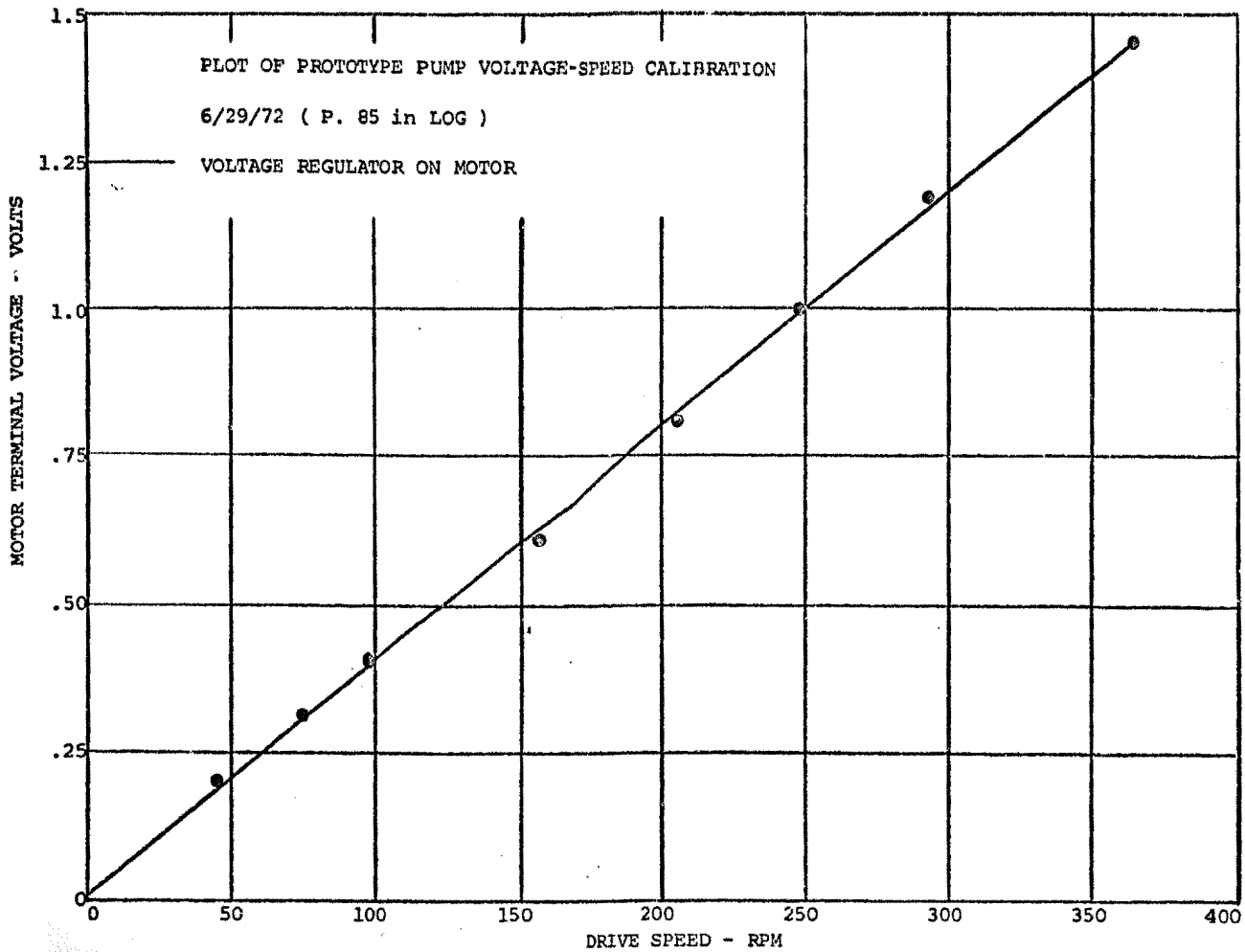


FIGURE 13

4-7

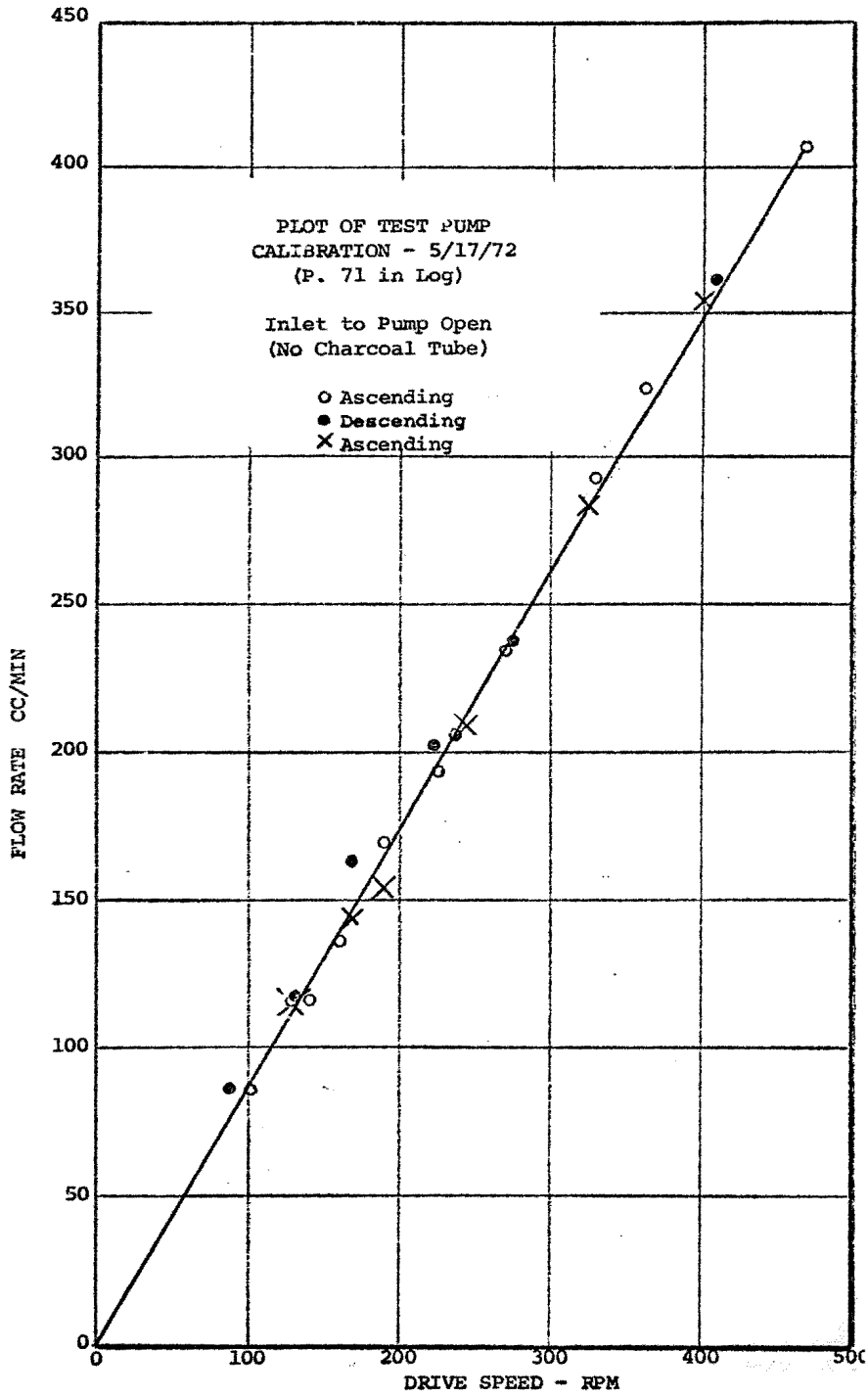


FIGURE 14

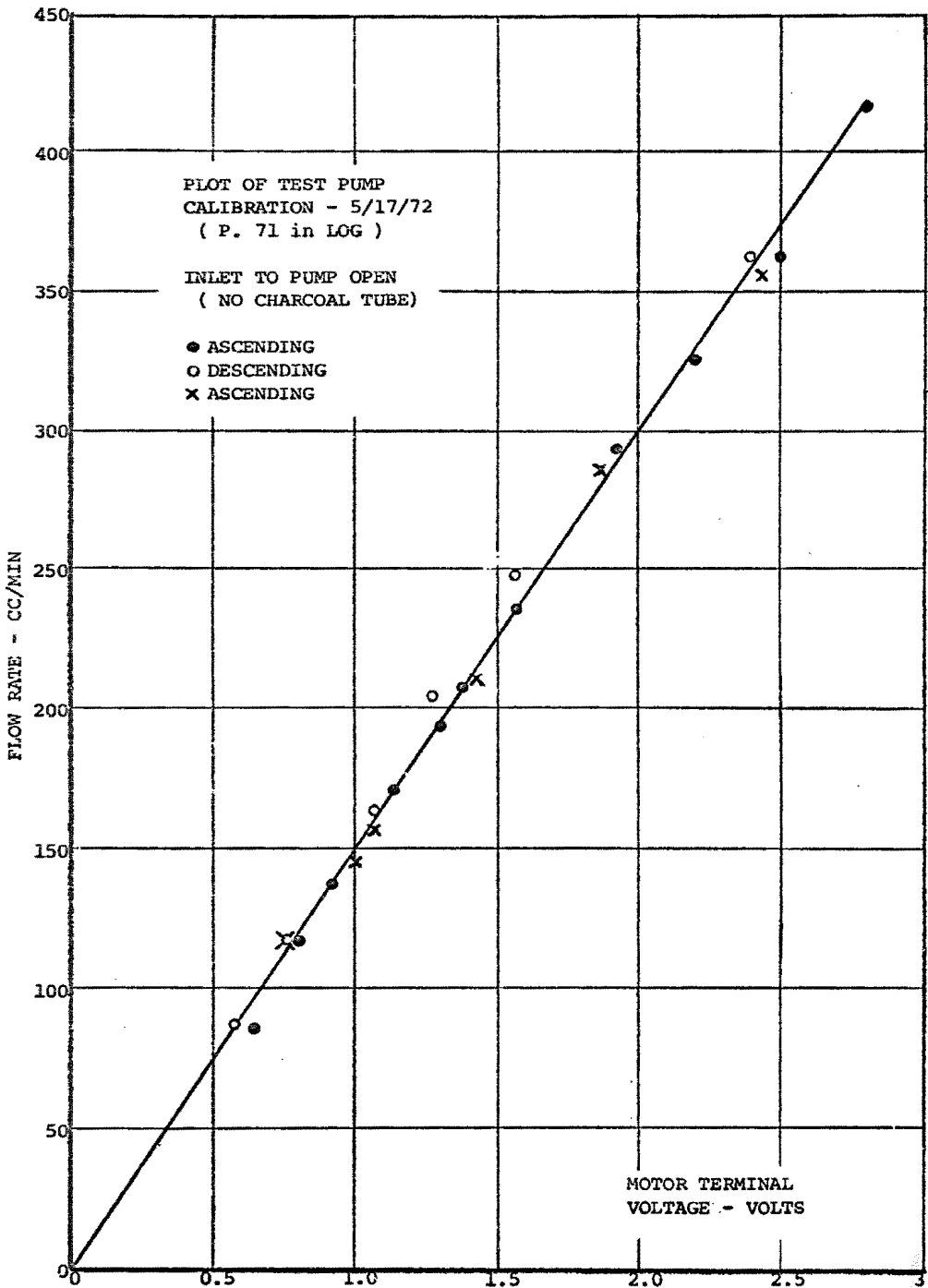


FIGURE 15

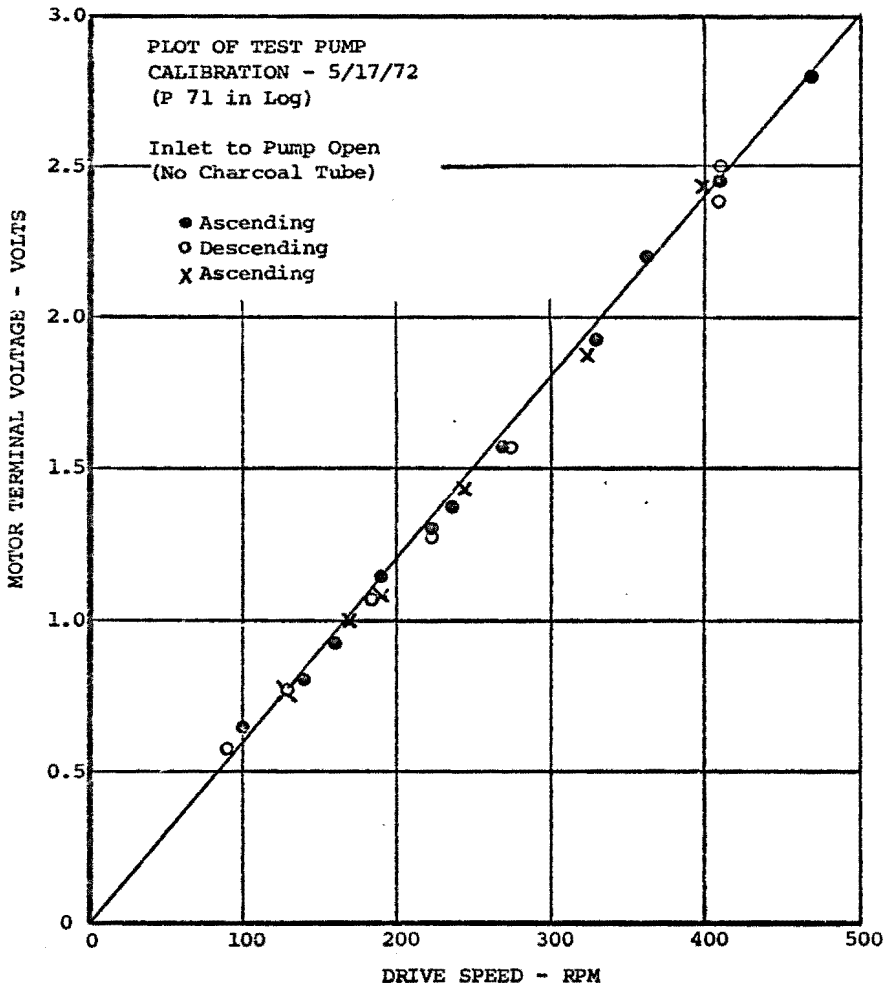


FIGURE 16