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Public Health Service, Center for Disease Control
National Institute for Occupational Safety and Health
Rockville, Maryland 20851
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AN EVALUATION OF PERSONAL SAMPLING PUMPS IN SUB-ZERO TEMPERATURES

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AN EVALUATION OF PERSONAL SAMPLING PUMPS IN SUB-ZERO TEMPERATURES

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RTI Project No. 43U-1271

U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
Center for Disease Control
National Institute for Occupational Safety and Health
Division of Physical Sciences and Engineering

December 1977

DISCLAIMER

NIOSH Project Officer: Charles S. McCammon

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ABSTRACT

Personal sampling pumps suitable for industrial hygiene surveys were evaluated to discover their characteristics as a function of temperature for temperatures between 25° and -50°C. The pumps evaluated were significantly influenced by low temperatures. In general, most provided a sampling capability at -10° to -20°C, but were marginal at lower temperatures. None were useful at -50°C. Most of the pumps survived low temperature exposures to -50°C without significant damage.

The nickel-cadmium batteries which power these pumps are concluded to be the most suitable available. Although the energy available from these batteries is significantly reduced at low temperature, a large percentage of the nominal energy is available at -20°C and some energy at -40°C. These batteries are not useful at -50°C.

ACKNOWLEDGMENTS

The authors wish to express their gratitude to the following companies for their cooperation in the conduct of these investigations and for allowing us to use a complement of sampling pumps on a consignment basis.

Anatole J. Sipin Company
386 Park Avenue South
New York, New York 10066

E.I. Du Pont De Nemours and Company
Applied Technology Division
Brandywine Building
Wilmington, Delaware 19898

MDA Scientific, Inc.
(Lefco Engineering)
808 Busse Highway
Park Ridge, Illinois 60068

Mine Safety Appliances Company
400 Penn Center Boulevard
Pittsburgh, Pennsylvania 15235

Research Appliance Company
Route 8
Gibsonia, Pennsylvania 15044

Spectrex Company
3594 Haven Avenue
Redwood City, California 94063

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INTRODUCTION

The Research Triangle Institute (RTI) has conducted an experimental program to evaluate the characteristics of personal sampling pumps at temperatures as low as -50°C. These evaluations were completed under a National Institute for Occupational Safety and Health (NIOSH) contract, "An Evaluation of Personal Sampling Pumps In Sub-Zero Temperatures," Contract No. 210-76-0124. The results of these evaluations are reported herein.

BACKGROUND

The development of the large oil reserves along the northern slope of Alaska's Brooks Range and nearby Prudhoe Bay typifies the industrialization taking place in cold environs. These developments, precipitated by America's growing dependency on foreign oil with its inherent threat of crippling embargoes, is taking place in a severe environment which tests the endurance of both men and machines. The growth of industralization in these and other cold regions has generated a growing need for air sampling instrumentation and methodology suitable for industrial hygiene investigations in sub-zero temperatures. In response to these needs, NIOSH has sponsored the investigations described herein. Personal sampling pumps are significantly important industrial hygiene tools, and RTI has investigated their suitability for use in cold environs, i.e., to temperatures as low as -50°C. The Alaskan environment is also briefly defined since it is a cold region currently undergoing considerable industrialization and is perhaps reasonably typical of other cold environs.

SCOPE

The pumps evaluated during these investigations were tested at temperatures between ambient room temperature (25°C) and a low temperature of -50°C. While many environmental factors or stresses act in synergism with temperature, most are of significance only at high temperatures and were not incorporated into the experimental program described in this report. One environmental factor which does have an important synergistic relationship with temperature at low temperatures is humidity. In cold environs humidity is low. Consequently, air sampled during these tests was obtained from a dry air manifold.

The personal sampling pumps evaluated can be categorized into two different groups. One group is the Coal Mine Dust Personal Sampling Units (CMDPSU) for which a certification program has been defined and is in effect (Ref. 1). In order to be certified, the CMDPSU pumps must be capable of operating from their internal battery packs at a nominal flow of 2 liters per minute against a resistance of 4 inches of water for not less than 8 hours, presumably at room temperature. Thus, a performance requirement has been defined which is useful in establishing test conditions for the evaluation tests described herein.

The other class of pumps are used with a variety of sample collection devices under a variety of conditions. This suggests, and it is true, that these pumps, in the aggregate, provide industrial hygienists a wide range of sampling capability. A given pump, in contrast, may only function over a narrow region of the aggregate range. Thus, it is impractical to define a single set of test conditions which will be meaningful in terms of the capability of all of these pumps. The practice adopted for these evaluations was to test each pump under a set of conditions which was somewhat representative of each pump's capabilities as stated by the manufacturer. CONSEQUENTLY, THE DATA REPORTED HEREIN ARE NOT INTENDED TO BE USED TO COMPARE ONE PUMP AGAINST ANOTHER. Instead, these data are intended only to demonstrate how each pump's operation is affected by a low temperature environment.

TEST PROTOCOL

Those aspects of the evaluation program which required experimental tests at low temperatures were generally conducted over a range of temperatures between +25° and -50°C. In some instances, performances at intermediate temperatures were such that no tests were run at lower temperatures. However, all pumps were placed in an operational mode for at least one period of 8 hours at -50°C. In general, all tests were completed at temperatures of -20°C and above before tests at lower temperatures were conducted, so that any catastrophic failures at very low temperatures would not circumvent a completion of planned testing at intermediate temperatures, i.e., -20°C and above. Test apparatus and procedures for some of the more frequent tests are described in following paragraphs.

During the experimental program, pump batteries were used very carefully to enhance their capacity and cycle-life. With few exceptions, batteries were stored fully charged, used for a full cycle of operation, and recharged according to the manufacturers instructions using the charger supplied with the pump. It is doubtful that many pumps will be used as carefully in the field environment. Careful use was probably responsible for the reliable performance of batteries observed during those investigations.

Basically, the test apparatus consisted of a temperature test chamber which contained the pumps under test and a heat exchanger for each pump to equilibrate the air sample with the test chamber ambient. The test chamber was cooled with liquid nitrogen (LN_2). When the LN_2 is turned on, the chamber begins to modulate a valve that releases gas from the LN_2 source into the chamber. When the chamber reaches the set temperature, the modulation changes to control temperature at the set point. Our observation is that for a temperature change of 50°C, e.g., +20°C to -30°C, a thermocouple in the center of the chamber will indicate that 55 percent of the transition has occurred in 5 minutes, 75 percent in 10 minutes, and 90 percent in 25 minutes. The transition is essentially complete in about 50 minutes. A thermocouple located in a 2ℓ/min. effluent from the shortest ($\approx$7 ft.) heat exchanger essentially duplicates the chamber air temperature. The chamber pressure is slightly above ambient when gas from the LN_2 source is modulated into the chamber; thus, condensation does not occur on the pumps under tests. The actual pressure difference largely reflects the tightness of the seals at the access port through the chamber walls. Our observation is that this difference is less than 1/4" H_2O, and it was neglected as an experimental factor. Pressure in the dry air manifold was negligibly different from the room ambient. The sampled air was taken from a dry air manifold to more closely simulate use conditions in cold environs and circumvent condensation in the heat exchanger and pump. The instrumentation was external to the test chamber. Flow rates were measured with rotometers that were calibrated against bubble flow meters at the beginning of the test program. Pressure drops were measured with a U-tube water manometer and temperatures with either an alcohol-in-glass thermometer or a thermocouple. Figure 1 is a photograph of the basic test facility, and Figure 2 is a schematic diagram of the basic test apparatus configuration. Specific procedures and apparatus are described in subsequent paragraphs.

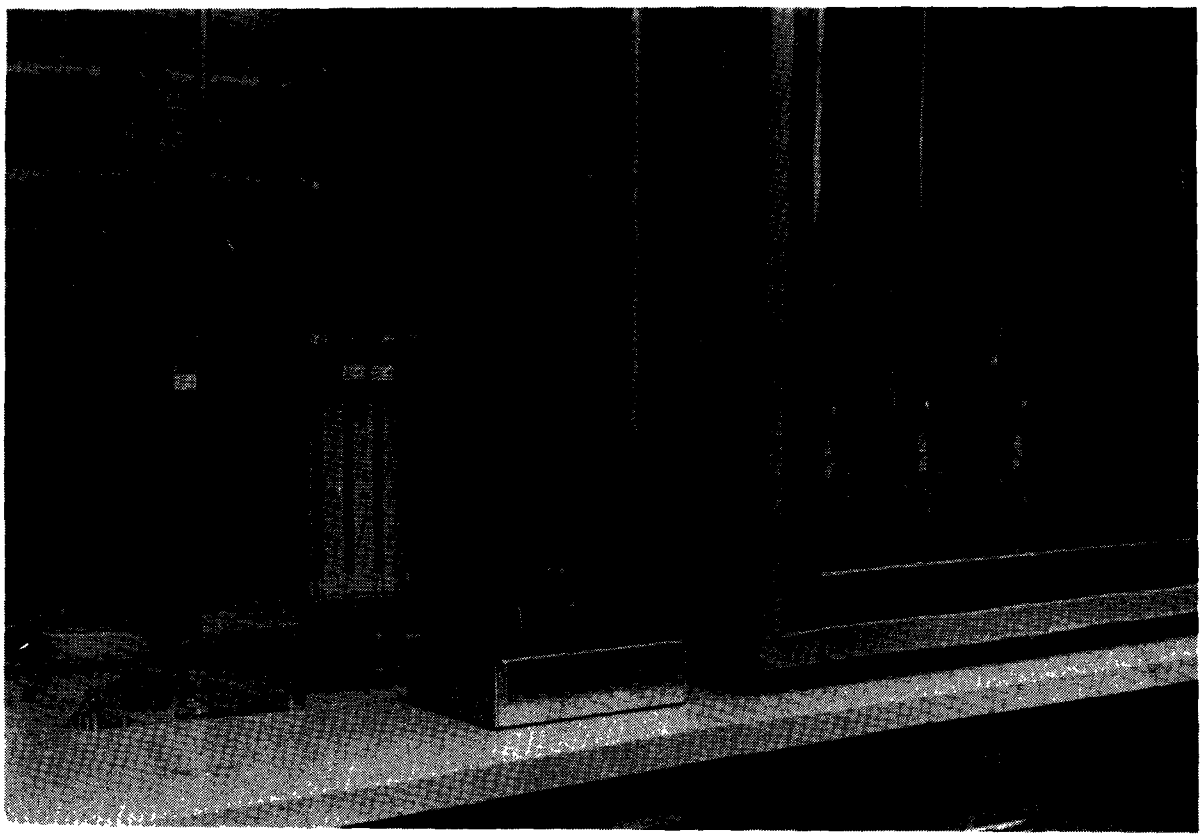

Figure 1 Photograph of the Basic Test Facility

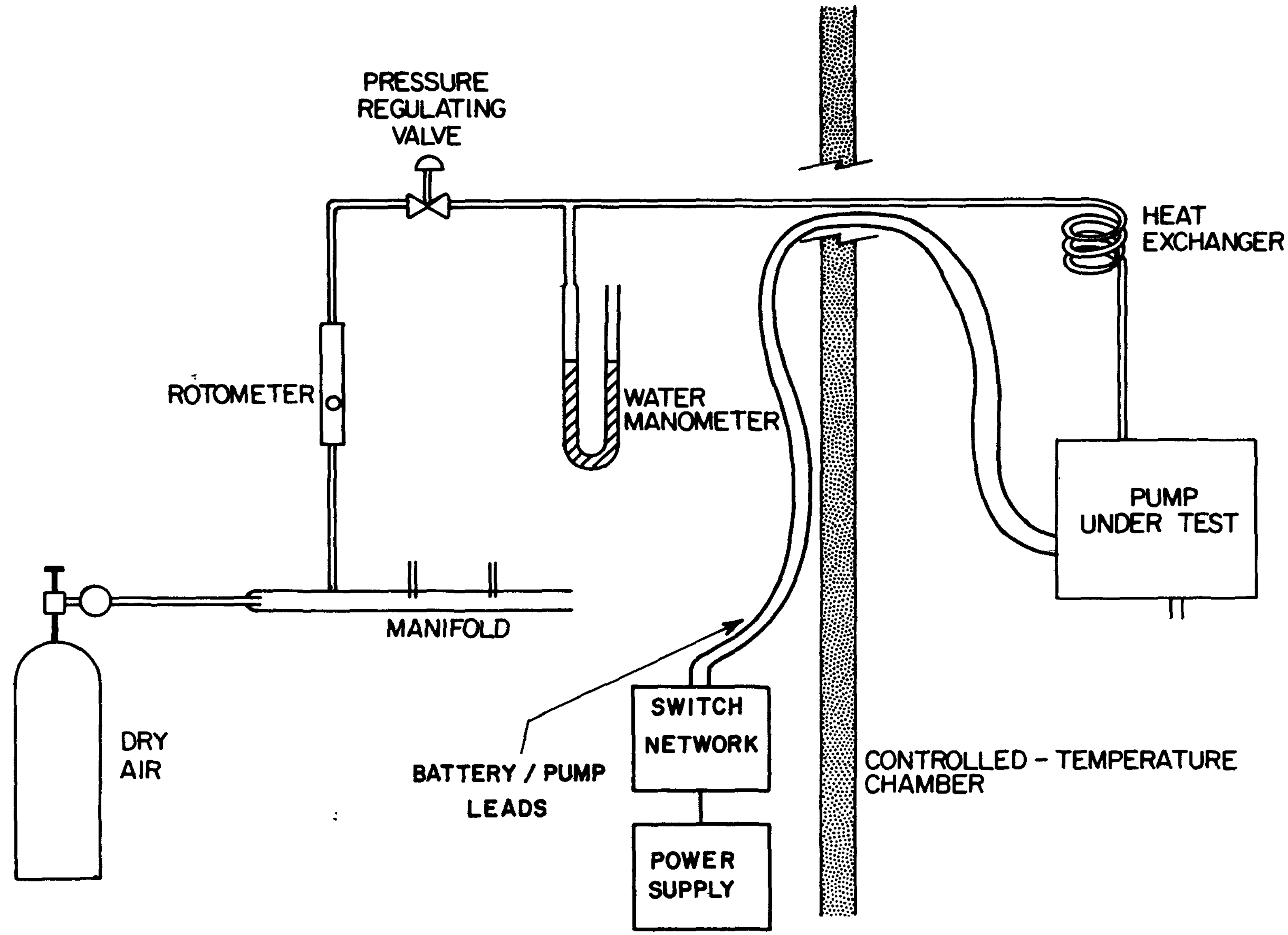

Figure 2 Schematic of the Basic Test Facility

In the basic test configuration of Figure 2, a pump under test pulls sample air from a room temperature, room pressure manifold, and the flow rate is measured at room temperature. The air sample passes into the test facility and through a heat exchanger before entering the pump and, therefore, is at the test chamber temperature when it enters the pump. Thus, the sample air is exhausted at the test temperature and at room pressure. According to the general gas law (PV=NRT) the volume of air which passes through the pump is less than the volume indicated by the room temperature rotometer. To elaborate, one can write that for the sampled air,

$$\frac{P_R V_R}{T_R} = \frac{P_c V_c}{T_c} ,$$

where P_R, V_R, and T_R are the pressure, volume and absolute temperature of a given sample at room conditions and P_c, V_c, T_c are similar quantities at the test chamber conditions. Since P_R and P_c are the same,

$$\frac{V_R}{T_R} = \frac{V_c}{T_c}$$

Thus a volume V_R at room condition will occupy a volume of

$$V_c = V_R \frac{T_c}{T_R}$$

when passing through the pump and exhausting into the test chanber at test chamber conditions. Since the volume is related to the volume flow rate by

$$Qt = V ,$$

where Q is volumetric flow rate and t is time, it is also true that

$$Q_c = Q_R \frac{T_c}{T_R} .$$

In subsequent presentations of data, references to corrected data mean that flow rates measured at room temperature have been multiplied by the T_c/T_R ratio to obtain a value corrected to the test chamber conditions.

It is also significant that the rotometer on the input of several of the pumps, e.g. the CMDPSUs, will also be influenced by the sample temperature and the fact that it is at a different pressure. Nelson [Ref 2] gives correction factors for rotometers for variations of pressure and temperature which differ from the initial rotometer calibration pressure and temperature. For a tube of linear range (which is characteristic of the tubes used in these evaluations and the tubes on most of the pumps), the correction is given by

$$Q_{T_2P_2} = Q_{T_1P_1} \left[\frac{P_2T_1}{P_1T_2}\right]^{\frac{1}{2}} ,$$

where $Q_{T_2P_2}$ = flow rate at test temperature and pressure,

$Q_{T_1P_1}$ = flow rate at calibration temperature and pressure,

T_2,P_2 = test temperature and pressure, and

T_1,P_1 = calibration temperature and pressure.

Rotometers on the pumps presumably were calibrated at or near room temperature and a pressure near 1 atmosphere. Most of these tests were conducted at 0.997 atmosphere (-4 inches of water gauge) or less. Thus, corrections due to pressure differences are small, i.e., less than 0.25 percent, and are not considered further. The correction for temperature, however, can be significant. According to Nelson [Ref.2], the flow rate indicated by a pump rotometer at test chamber conditions will differ from the flow rate indicated at calibration conditions (and also indicated by the room temperature rotometer in Figure 2) by a factor of

$$Q_R = Q_c \left[\frac{T_c}{T_R}\right]^{\frac{1}{2}} ,$$

where

Q_R = flow rate corresponding to calibration conditions (and which would be read on the room temperature rotometer),

Q_C = flow rate indicated on the pump rotometer at test chamber conditions,

T_C = test chamber temperature, and

T_R = room temperature (calibration temperature).

Thus, if a CMDPSU unit is pumping 2ℓ /min at room temperature (e.g. 21°C or 294°K), the pump rotometer and the room temperature rotometer should read 2ℓ /min. If the test chamber temperature is lowered to 0°C (273°K), for example, and the room temperature rotometer continues to read 2ℓ /min, the pump is actually pumping at a volumetric flow rate of

$$Q_c = 2\ell/\text{min} \quad \frac{273}{294}$$

$$= 1.86\ell/\text{min},$$

and the pump rotometer would indicate a flow of

$$Q_{CP} = 2\ell/\text{min} \quad \frac{273}{294}$$

$$= 1.93\ell/\text{min},$$

using the room temperature calibration curve.

The significant point is that although the mass flow is constant throughout the system, the room temperature rotometer shows a different volumetric flow rate than is actually pumped at low temperatures, i.e., the room temperature rotometer reads high. A pump rotometer at the same temperature as the pump will also read differently. If its reading is interpreted from a room temperature calibration, it will indicate a higher flow rate than is actually being pumped (by the square root of the temperature ratio), and a lower flow rate than the room temperature unit (again by the square root of the temperature ratio). In the preceding example, the actual volumetric flow rate through the pump is 7 percent less than is indicated by the room temperature rotometer and 3.5 percent less than indicated by the pump rotometer using the room temperature calibration. The two rotometers will differ by only 3.6 percent.

Under worst case conditions, i.e., assuming a room temperature of 25°C, a pump rotometer calibrated at 25°C, and a test temperature of -50°C, a 2ℓ/min flow on the room temperature rotometer would appear as a flow of 2 (223/298) = 1.73ℓ /min (a difference of 13.5 percent) on the pump rotometer, and would correspond to a volumetric flow rate of 2 (223/298) = 1.5ℓ /min (a difference of 25 percent) through the pump.

In the discussions of experimental data in subsequent paragraphs, references to corrected flow rates mean that flow rates measured on the room temperature rotometer have been multiplied by the ratio of the absolute test chamber temperature to the absolute room temperature. These corrected data may or may not be more useful. When an air sample volume is cooled, a particulate or gaseous contaminant concentration will also become more dense, i.e., the contaminant concentration expressed in mg/m^3, for example, will also increase. (The concentration in parts per million (ppm) will remain unchanged.)

Stability of The Flow Rate

Flow rate stability with time was measured at test temperatures as follows.

Pumps under test were placed in the test chamber and adjusted, at room temperature, to a specified flow rate at a specified inlet pressure. (Presumably, in a cold region environment, pumps would be stored, recharged, and obtained by the wearer/operator in a protected environment.) The pumps were turned on and the test chamber temperature was set to the desired temperature at time zero. Flow rates, pressure drops, and battery voltages were monitored and recorded at regular intervals over an 8 hour period. Pumps that provided the wearer/operator with a flow-readout device, e.g., the rotometers on the CMDPSU pumps, were re-adjusted during tests to a higher flow rate whenever the flow dropped to an unacceptable value. (It will be seen that an adjustment to maximum was usually required.) At low temperatures, when acceptable flows could not be maintained, the pumps were switched during the tests from their internal battery packs to a laboratory power supply.

Pumps that did not provide a flow readout or a convenient flow adjustment were not readjusted during tests. A wearer/operator in a field environment would not have any way of knowing that the flow rates were inadequate or how to adjust the flow rate to a known value. When the flow rate decreased to an excessively low value, however, a laboratory power supply was substituted for the internal batteries.

Pressure Drop Versus Flow Rate Capabilities

Pumps under test were instrumented to measure flow rate and pressure drop as illustrated in Figure 1. The test chamber temperature was established and the pump temperature allowed to equilibrate for one hour. The pump was not operated during the equilibration period so that the batteries would remain in an approximately fully charged state for all test temperatures. The pumps were operated at each test temperature. The pressure drop value was used to establish a test pressure and the flow rate determined. After completing a data set at a given temperature, a new test temperature was established, the pump temperature equilibrated for an hour with the pump not operating, and a new data set determined at the test temperature. For each data set, the pump was initially calibrated to a "standard" flow rate and pressure drop at room temperature.

Reliability of Calibration

These data are inherently available in the data descriptive of each pump's flow-rate stability with time. It was obtained from the flow rate stability data corresponding to the first-hour data point at each test temperature.

Continuously Sample Cold Air

It became evident during these evaluations that most of the pumps would function reasonably well at -20°C, and that few would function satisfactorily at -30°C. Consequently, tests to demonstrate an ability to continuously sample cold air were conducted at -20°C. These tests consisted of establishing a manifold inside the test chamber at approximately the desired pressure drop and operating a complement of pumps from the manifold at -20°C for 8-hour periods. The only data tabulated was to document each pump's operation at the end of the 8-hour period.

Other Performances

Other performances evaluated consisted of subjective evaluations of different pump features or characteristics over the period of the experimental program. These included such features as ease of recalibration, battery performance, diaphragm reliability, bearing design, lubricants, and case ruggedness.

THE EVALUATION PROGRAM

SOLICITATION

It was the intent of RTI to identify as many personal sampling pumps as possible to be included in this evaluation program. Various directories and guides were searched to identify manufacturers and distributors of personal sampling pumps. The directories searched were the Thomas Register, MacRae's Bluebook, U. S. Industrial Directory (Vol. III), and Guide to Scientific Instruments (published by the American Association for the Advancement of Science). Other sources of information were various trade publications and RTI and NIOSH personnel. Each distributor or manufacturer identified received a letter describing the planned evaluation program and requesting brochures, specifications, and other information descriptive of personal sampling pumps. From responses, personal sampling pumps were selected for evaluation and solicited on consignment from the manufacturer or distributor. The selection was reviewed and approved by the NIOSH Project Officer. Five of each model of pump was requested to enhance the validity of the experimental results. An Appendix includes a list of the organizations that received a request for descriptive literature, a copy of the request letter, and a copy of the pump solicitation letter without the company-specific details.

PUMPS EVALUATED

A total of 85 pumps were requested for evaluation, i.e., 5 each of 17 different pumps. Twenty-nine were eventually received. Some manufacturers chose not to participate in the program, and others were still somewhat in a development period and their pumps were not ready for an evaluation. The pumps requested and those actually received for the evaluation are identified in Table I. Figure 3 is a photograph showing one of each type pump evaluated.

CHARACTERISTICS OF THE ALASKAN ENVIRONMENT

Separating the interior of Alaska from its territory to the north is a 600-mile stretch of low, but rugged mountains known as the Brooks Range. This expanse of mountains forms a natural partition between the climatic divisions designated (by the U. S. Weather Bureau) as the Interior Basin to the south and the Arctic Area to the north. The harsh, subzero environs of the Arctic

TABLE 1
PUMPS SOLICITED AND RECEIVED FOR EVALUATION

Manufacturer/Address	Pumps Solicited (5 of each)	Pumps Received
ANATOLE J. SIPIN COMPANY 386 Park Avenue South New York, NY 10066	Model SPI	1 Model
BENDIX ENVIRONMENTAL SCIENCE DIVISION 1400 Taylor Avenue Baltimore, MD 21204	Micronair II Model C11	
CENTURY SYSTEMS CORPORATION P. O. Box 133 Arkansas City, KS 67005	Portable Air Sampling Pump	
E. I. DU PONT DE NEMOURS AND COMPANY Applied Technology Division Brandywine Building Wilmington, DE 19898	Model P200 Model P4000	5 Model P125
MDA SCIENTIFIC, INC. (Lefco Engineering) 808 Busse Highway Park Ridge, IL 60068	Model 808	5 Model 808
MICROCHEMICAL SPECIALTIES CO. 1825 Eastshore Highway Berkeley, CA 94710	Model 4000	
MINE SAFETY APPLIANCES CO. 400 Penn Center Boulevard Pittsburgh, PA 15235	Model C-200 Model G Model S	5 Model C-200 5 Model G 5 Model S
RESEARCH APPLIANCE CO. Route 8 Gibsonia, PA 15044	Cat. No. 2392-K	1 Cat. No. 2392-PS

TABLE 1
PUMPS SOLICITED AND RECEIVED FOR EVALUATION
(Continued)

Manufacturer/Address	Pumps Solicited (5 of each)	Pumps Received
SKC INC. P. O. Box 8538 Pittsburgh, PA 15220 Attn.: Mr. Lloyd Guild	Model No. 222-3P (50-200 ml/min- with changer)	-
SPECTREX COMPANY 3594 Haven Avenue Redwood City, CA 94063 Attn.: Mr. John M. Hoyte	Model No. PAS-2000 Model No. PAS-1000	2 Model No. PAS-1000
WILLSON PRODUCTS DIVISION P. O. Box 622 Reading, PA 19603	Model BC	-

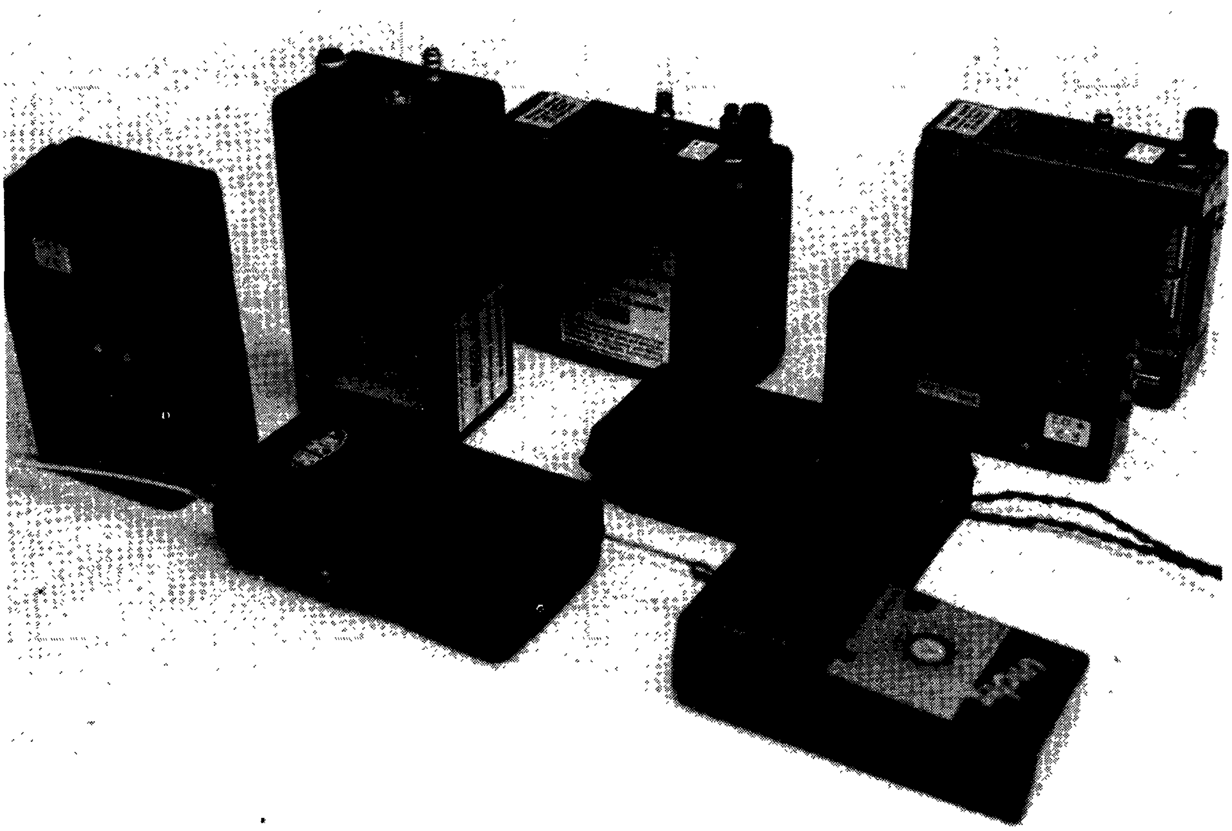

Figure 3 Photograph Showing One of Each Type Pump Evaluated

Area, particularly the Alaskan oil fields located along the north slope of the Brooks Range, are our primary concern here.

Although recognized as a definite topographical barrier, it is difficult to determine just how much the Brooks Range influences the climate of the Arctic Area. In similar topographies, around Ft. Yukon in the Interior, for example, there is a significant downslope drainage of cold air off the northern slopes of the surrounding range which drops temperatures in the area to notable lower levels. However, this does not seem to occur in the Arctic Area. In fact, temperatures within the Arctic Area generally fall within a much narrower limit than those of the Interior Basin and, on the average, tend to be higher. In the Arctic Area, temperatures in January average out at -24°C and in July, 8°C. The mean annual temperature logs in at -12°C.

Temperatures never reach extreme highs in the Arctic Area. As the Sun moves further above the horizon during the summer months, prolonged periods of continued daylight with a greater amount of possible sunshine occur and temperatures rise. However, even then, highs seldom go above 27°C. This is partially due to the fact that in summer the Sun's rays reach the earth at such relatively low angles as to cause little surface warming.

During the winter months extreme lows from the Weather Bureau's five reporting stations in the Arctic Area range between -43°C and -53°C, with the station at Umiat holding the record low. It is seldom that Arctic Area stations have recorded temperatures lower than -46°C. By comparison, 9 out of 10 reporting stations in the Interior Basin have recorded lows of less than -46°C.

The Arctic experiences much more wind during the winter months than any of the other climatic divisions of Alaska. As a result, prolonged periods of drifting and blowing snow occur, making winter life especially tenuous. This is particularly true along the coast from Cape Lisburne to Barter Island, which encompasses the oil fields at Prudhoe Bay. Winds along this area may occur frequently at 50 to 60 mph. At Barter Island it is not unusual to have winds of 70 mph during the months of February, March, and November, and the station there recorded a wind speed of 86 mph in February one year.

Because of these high winds and subsequent drifting snow, measurements of precipitation have been difficult to obtain. At any rate, precipitation is light. Maritime factors play some role here, but due to the prevalence of cold air and its low moisture carrying capacity, precipitation is much lighter than one would normally expect for maritime characteristics.

The mean yearly precipitation (all forms converted to rain equivalent) for the entire Arctic Area is recorded at 6 inches. Cape Lisburne records the highest annual precipitation at 16 inches. Other stations average from 4 to 10 inches. Kotzebue, which is sheltered from moisture-carrying southwestern winds, averages 8 inches yearly.

Snowfall makes up a large portion of the precipitation reading, and Cape Lisburne receives the greatest amount annually at 65 inches. Other areas along the Brooks Range average about 40 inches. Kotzebue receives a smaller proportion of snow to total precipitation than any other reporting station.

The same winter winds which whip the snow about tend to pack it down into firm, thick layers along the northern coastal sections. From Cape Lisburne eastward, these ice layers begin to appear along the shoreline around September or October and remain there until warming temperatures bring about their breakup around June or July. Once these layers have adhered and there is no open water surrounding the coastline, the climate demonstrates fewer maritime characteristics and more continental characteristics.

Throughout the year much of the Arctic Area remains in a continuous state of permafrost. Vegetation exists as tundra, a mat-like cover over the frozen ground composed of lichens, mosses, wild flowers and tiny willow trees. In spring when the surface begins to warm, the top layers of the permafrost will melt making the entire area soggy and creating numerous glacial lakes. Near the shore, the tundra is largely covered by standing water. (Refs. 3-10)

Arctic Area weather stations in the general area of the Brooks Range and Prudhoe Bay include Point Barrow, Barter Island, and Kotzebue. Point Barrow, centrally located to the north of the Brooks Range oil reserves, is the most northerly of the U. S. Weather Bureau's stations, and usually records one of the lowest mean air temperatures for Alaska during the winter months. (However, it does not hold the lowest temperature on record. Tanana, in the Interior Basin, dropped to -60°C in January 1886.) Temperatures here generally fall below freezing all year round. A daily maxima of 0°C or higher may be recorded for only 109 days out of the year, while a daily minima of less than 0°C may be recorded for 323 days. In addition, lows of 0°C or less are usually recorded every month of the year.

February is the coldest month with a mean temperature of -28°C. March is only slightly warmer, and it is not until April that temperatures really begin an upward trend. May marks a definite swing from winter to summer, and temperatures become consistently warmer with July recording the highest mean temperature for the year at about 4°C. It is at this point, in late July or early August, that the surrounding Arctic Ocean becomes ice-free for the first time in summer. September usually marks the end of summer, and by November temperatures have dropped such that half the daily means for the month are zero or below.

Airline pilots find that March is the most favorable month at Point Barrow as far as average cloudiness, fog, precipitation and wind are concerned. In fact, March and December are both considered calm months with average hourly wind speeds of less than 11 mph. However, this does not mean high winds are not experienced during these months. Indeed, they are, and the highest winds for any month of the year are often recorded at 40 to 50+ mph. The highest monthly mean wind speed occurs in October at 13.7 mph.

At the end of March, when daylight increases from 9 to 14 hours, temperatures begin to rise. With this upward trend clouds appear, and by April there are clouds in the sky daily. By May, ceilings of 1,000 feet or less occur at least half the time, and snow and drizzle may fall frequently.

As the Sun moves higher and sunlight extends to 24 hours/day, cloud cover becomes so extensive that by June Point Barrow experiences 24 hours of continuous, moderate light daily. By July, the city is often under heavy fog. This cloudy, foggy weather continues into October and November, and it is not until colder, shorter days occur (in December and January) that the sky begins to clear.

Precipitation in Arctic Alaska is quite low and Point Barrow is no exception. The city records an average precipitation of only 4 inches of rain or so for the year. This includes 29 inches of snow converted to a rain equivalent. (One inch of rain is considered the equivalent of 10 inches of snow.) July records the greatest monthly average precipitation, and August the greatest average number of days with precipitation of .01 inches or more. October generally has the most snowfall of any month.

Barter Island, located off the northeast shore of the Alaskan mainland, and in the general vicinity of Prudhoe Bay, has no real topographic features of its own to affect temperature and precipitation. The island terrain and that of the nearby mainland is low, marshy, flat tundra with numerous lakes, and there are no elevations of consequence until the Brooks Range, 65 miles south. Consequently, its climate is largely determined by the surrounding open Arctic waters.

In fact, the Arctic Ocean (though often frozen) is one key element which prevents extremely low temperatures in the area during the long Arctic night period (November-January), and during summer months moderates the effects of a continuous period of possible sunshine from mid-May to late July.

Freezing temperatures are reached as a general rule during all months of the year. Daily temperatures reach a monthly maxima of -8°C in April and a minima of -13°C in June.

Snow, which falls practically every month, covers the ground about 8 months of the year. Accurate measurements of snowfall and precipitation, however, are difficult to obtain due to the very strong winds experienced from October to February. These winds contribute to generally unpleasant winter conditions.

Kotzebue is a long, thin peninsula located in northwestern Alaska, 26 miles inside the Arctic circle. Water bodies surrounding Kotzebue produce a maritime type of climate from mid-May to October. During this period cloudy skies and fog prevail and temperatures are fairly uniform.

The Kotzebue area generally experiences less severe low temperatures than the area north of the Brooks Range. In fact, temperatures here have never dropped as low as -46°C and there are long periods in the year (70-90 day stretches) when temperatures reach 0°C or higher. Maximum temperatures around 2°C occur even during the coldest months of the year and minimum readings remain at -18°C at least half of the days during the coldest winter months.

Annual precipitation is light at 8 inches. Over half that occurs during the months of July, August, and September. Snowfall averages about 41 inches a year and falls nearly every month in the year. Cyclonic storms, accompanied by high winds may occur during the winter months. (Refs. 11 - 13)

ENVIRONMENTAL EFFECTS ON MATERIALS

Metals

One of the most significant limitations to the use of metals at low temperatures is their increased tendency to brittle failure. While yield strength and tensile strength may actually increase as temperatures decrease, most metals concurrently develop a lowered resistance to impact or shock loading, and brittleness occurs. In some metals there is also a distinct decrease in ductility with lowered temperatures occurring over a relatively narrow temperature range. In addition, notch defects (scratches, nicks, holes, threads, machining marks, etc.) increase a metal's vulnerability to low temperature at which a metal will begin to behave in a brittle fashion. [Refs. 14-17]

Austenitic stainless steels are generally well recommended for low temperature environments because they retain their ductility and tensile strength, and are brittle-safe. Their most notable application is in cryogenics, where they are effective down to extremely low temperatures (-253°C). In addition, simple single phase structure of austenitic stainless steels allows them to maintain their low temperature properties, even after welding.

Metals themselves may not be suitable for subzero temperature applications, but metal alloys have proved to be more promising. Although aluminum alloys have lower densities than stainless steels, their yield strength-to-density ratios qualify some for low temperature use. Welding, however, reduces their effectiveness. Titanium alloys possess relatively high strength and low density, and are appealing in that they are lighter structures than steel or aluminum alloys, but with equal load-carrying capacity. Although relatively expensive to use at present, they are viewed as likely candidates for future applications. Nickel alloys possess high ductility at low temperatures in both solution-annealed and age hardened conditions. They are quite useful in wide temperature extremes. [Ref. 18]

Rubbers

Low temperatures often have adverse effects upon rubbers. Temperature decreases may create changes in brittleness, flexibility, and compression set characteristics, resulting in lost resilience, increased stiffness and increased hardness of the rubber. Further drops in temperature may eventually result in crystallization and vitrification, but the material usually becomes unserviceable well before this point. Adding selected plasticizers tends to improve flexibility at low temperatures, but often this is done at cost to tear, resistance to abrasion, and bondability.

There are suggested low temperature types of rubber available, such as silicone rubber. However, some of these have low chemical resistance, making them susceptible to material(s) passing through the rubber tends to extract those compounds giving the rubber its low temperature characteristics, thus reducing the rubber's efficiency. [Ref. 17]

Plastics

Although the strength of plastics increases with lowered temperatures, the durability of nearly all plastics subject to shock decreases as temperature decreases. Many plastics can be used successfully at temperatures as low as -40°C, provided that they are not subject to shock loading. Fluorocarbon plastics such as Teflon and Kel-F retain useful ductibility at temperatures even lower.

Organic plastics may undergo reversible or irreversible changes at low temperatures. Reversible effects include:

1. Dimensional changes due to thermal contraction and loss of moisture.
2. Increased yield and ultimate strength,
3. Decreased ductility,

and 4. Decreased resistance to impact.

Irreversible effects include:

1. Dimensional changes due to change of state,
2. Physical failure,

and 3. Crystallization.

Motors

Motors will start and operate satisfactorily at -50°C if specially developed low temperature lubricants are used. In general, as temperatures are lowered to this point, final operating speed is lowered and input power demand increases. [Ref. 17]

Lubricants

Many lubricants prove useless at low temperatures because of their tendency to freeze or harden. However, there are commercial engine and gear lubricants available which are useful down to -53.3°C, and some instrument greases useful at -73.3°C. Solid-film lubricants, used in cryogenics, are effective at even lower temperatures. [Ref. 17]

Batteries

Storage batteries lose a large percentage of their power capacity at low temperatures. For most applications in severe cold weather, the nickel-cadmium appears to be the most reliable. A more complete discussion of batteries at low temperatures follows in a subsequent section of this report.

Electronic Components

Component parts, such as resistors, capacitors and transistors, may develop problems at temperatures as low as -40°C. Their values may vary enough to necessitate readjustment when accurate situations are needed. However, in most cases, current products are manufactured which have been specifically designed for military usage, and are thus guaranteed for satisfactory operation at temperatures as low as -55°C. [Refs. 14, 20]

Resistors--
Wirewound resistors perform satisfactorily at low temperatures with very little change in resistance. Even as low as -65°C, resistance may vary less than 1 percent of its normal value. Copper-nickel wirewounds, for example, exhibit only a 0.5 percent change in resistance at -65°C. Temporary electrical discontinuity in variable wirewound resistors (due to ice formation or hardening of the lubricant on the resistance element) has been reported for operations at -55°C. [Refs. 17, 21]

Where carbon composition resistors are concerned, change of resistance with decreasing temperature is insignificant. A slight increase in resistance (.5 percent) may occur at -55°C. With other types of composition resistors, resistance may vary from 10-50 percent of normal value as temperature ranges from -55°C to -3.9°C. In addition, cracks in plastic insulating tubes may occur, shortening the resistor's life. Torque and electrical discontinuity problems may also occur for this type of resistor at low temperatures. [Refs. 17, 22]

Capacitors--
Capacitors are affected to varying extents by subzero temperatures. For most applications, temperature compensating capacitors are readily available from manufacturers. The capacitance of electrolytic capacitors drops off rapidly at low temperatures, although manufacturers can control this to some extent in determining the nature of the chemical makeup of the electrolyte. Aluminum electrolytes become ineffective at -40°C and lose all their capacitance at -55°C. (The electrolyte freezes, creating a high power factor and low capacitance.)

Tantalum capacitors may retain 80 percent of their normal value at -55°C, but only if used at low frequencies. If high frequencies are used, values drop off quickly. In general, tantalum capacitors are more acceptable for low temperatures than aluminum capacitors. [Refs. 17, 12, 24] Ceramic capacitors are designed to withstand and be operational at temperatures as low as -55°C, with little capacitance change (less than 0.5 percent of normal capacitance). [Ref. 25]

Paper and mica capacitors function at -55°C, although large changes (20 percent below normal variation) may occur with paper capacitors as the temperature drops to -50°C. Glass dielectrics operate at temperatures from -55°C to +125°C with only -1 percent change in normal capacitance in the lower levels.

Plastic-film capacitors appear promising as far as low temperatures are concerned. Polystyrene, polyparaxylene and TFE-fluorocarbon in this category generally rate at only 1 percent below normal capacitance at -50°C while even other plastic-film types rated no lower than 5 percent below normal at -50°C. [Refs. 26-29] Wax impregnated capacitors are subject to extensive cracking below -40°C, resulting in permanent changes in capacitance, insulation resistance and ac losses. [Ref. 17]

Transistors--
Transistors (and integrated circuits), like capacitors and resistors, can be designed to compensate for low temperature environments, and manufacturers usually produce a grade of components which fall into the military applications class (providing for guaranteed operation as low as -55°C). Detailed information on their performance at low temperatures is not readily available. However, temperature ranges and other information regarding performance at low temperatures is usually available from the manufacturer's catalog or specifications sheet. [Refs. 30-32]

Switches, Controls, Jacks and Plugs--
Difficulties with many of these components at subzero temperatures often occur because greases used with them freeze. In addition, differences in contraction of closely allied plastic and metal parts may cause cracking, which in turn may result in poor connections and short circuits. [Refs.17,20]

EXPERIMENTAL RESULTS

MSA Model G

Five MSA Model G CMDPSU units were evaluated. Figure 4 is a photograph of two of these units. (A thermocouple wire added for test purposes is evident on one of these pumps.)

Flow Rate Stability with Time--
The flow rate stability of the MSA Model G units was measured in the test apparatus of Figures 1 and 2. The pumps were calibrated at room temperature for 2.1 liters per minute at 4 inches of water. The pumps under test were turned on and the test chamber turned on to the desired temperature somewhat

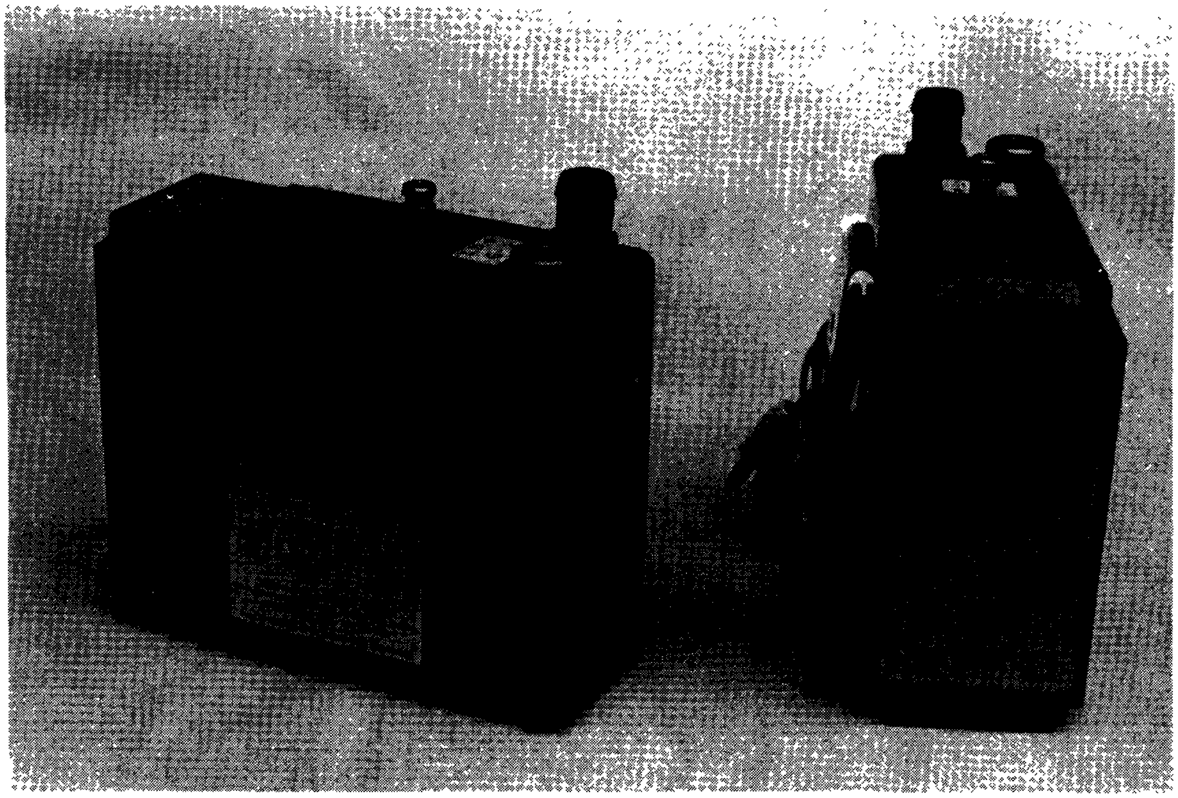

Figure 4 Photograph of the MSA Model G

concurrently, and the flow rate and pressure drop were measured over an 8-hour period. (As discussed previously, it can be assumed that the pump is approximately equilibrated at the test temperature after one-half hour and completely equilibrated in one hour.) Since the Model G has a rotometer to indicate flow, the flow rate was adjusted upward whenever it dropped to an unacceptable value. The pressure drop across each pump and each pump's rotometer reading were also monitored. These data are presented in this section.

Figure 5 is a plot of the Model G unit No. 1 flow rate stability with time. As shown, the room temperature performance of this unit was excellent. The -1° and -11°C data also show acceptable performance. In the -11°C data, for example, the pump's rotometer never dropped below the "yellow" band, which is indicative of satisfactory performance. At -22°C, the flow dropped below 1.6ℓ/min after 4 hours. A power supply was substituted for the battery pack and the test continued. The pump's performance was maintained above the 1.6ℓ/min flow rate, but a dramatic improvement was not achieved. This suggests that the degradation in performance was only partly due to battery degradation.

At -30°C, the flow rate dropped after one hour to 1.37ℓ/min. It was then adjusted for maximum flow which was 1.76ℓ/min. After 4 hours, it had dropped again to less than 1.6ℓ/min. A power supply was substituted for the battery pack and acceptable performance was maintained for the remainder of the 8-hour period.

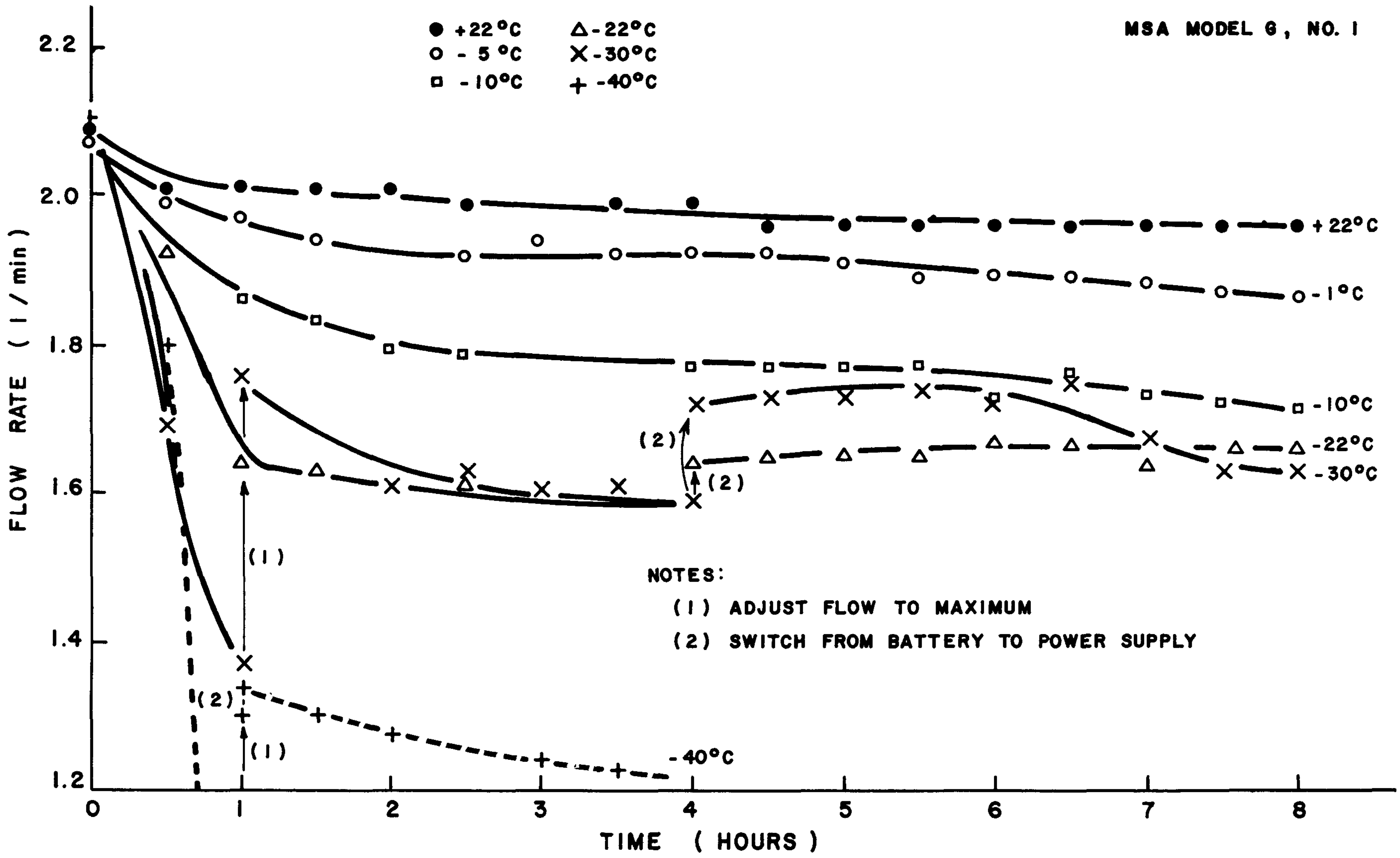

Figure 5 Flow Rate Stability with Time, Model G, No. 1

It is very significant that the battery terminal voltage at the time of substitution was 1.1V/cell (i.e., 5.56V for 5 cells). However, the pump current had increased from 201 mA at +22°C to 282 mA. When switched to a power supply at 6.2 volts, the pump current was 289 mA and eventually increased to 291 mA. This is evidence that degradation in performance is due to an increased power demand from the pump rather than a degradation in the battery pack.

At -42°C, the flow rate was adjusted to a maximum after one hour. This did not restore acceptable performance and a power supply was immediately substituted for the battery pack. The battery pack voltage at that point was 1.14V/cell. However, the pump current had increased from a +23.5°C value of 196 mA to 323 mA. It eventually reached 340 mA after 7 hours.

At -50°C, pump performance immediately degraded and a flow adjustment to maximum and a power supply substitution did not restore acceptable performance. The battery voltage at the substitution point (i.e., at 30 minutes) was 1.15V/cell, and the pump current was 330 mA. It eventually reached 425 mA. The pump flow remained very low (300ml/min) and tended to pulsate such that accurate readings could not be made.

In Figure 6, the flow rate stability data from Figure 5 are repeated except that the flow rates are corrected for each test temperature. This type of format tends to spread the data out somewhat; however, it is generally a more useful presentation.

Figure 7 is a plot of corrected flow rate stability data for the MSA Model G, No. 2. Some significant features of these data are that at -1°C the flow rate remained higher than at +24°C, and the -22°C flow rate remained at a satisfactory level. (The higher flow rate at -1°C is also evident in other data.) The -22°C performances were excellent. The pump's rotometer remained in the "yellow" range throughout the tests, and the room temperature flow was 1.8ℓ/min after 8 hours. It is significant that the battery voltage was 1.1V/cell at the end of the 8-hour test.

The -30°C results were marginal. With a maximum flow rate adjustment, the pump supplied 1.96ℓ/min at 3.85 in. of H_2O for more than 6 hours. The battery pack voltage was 1.1V/cell after 6 hours, and it was delivering 224 mA. At room temperature, the pump required 184 mA at 6.6V or 1.32V/cell. These results suggest that battery pack capacity and not degradation is a significant factor in a pump's performance at low temperature. The Model G requires significantly more current to operate at low temperatures.

The -40° and -50°C data are similar to the -30°C data. Satisfactory performance could not be maintained even with a power supply. The pump required excessive current and, after one hour at -50°C, failed to pump at all.

Figures 8, 9, and 10 are plots of temperature corrected flow rates for the MSA Model G, Nos. 3,4, and 5, respectively. These results are very similar to the

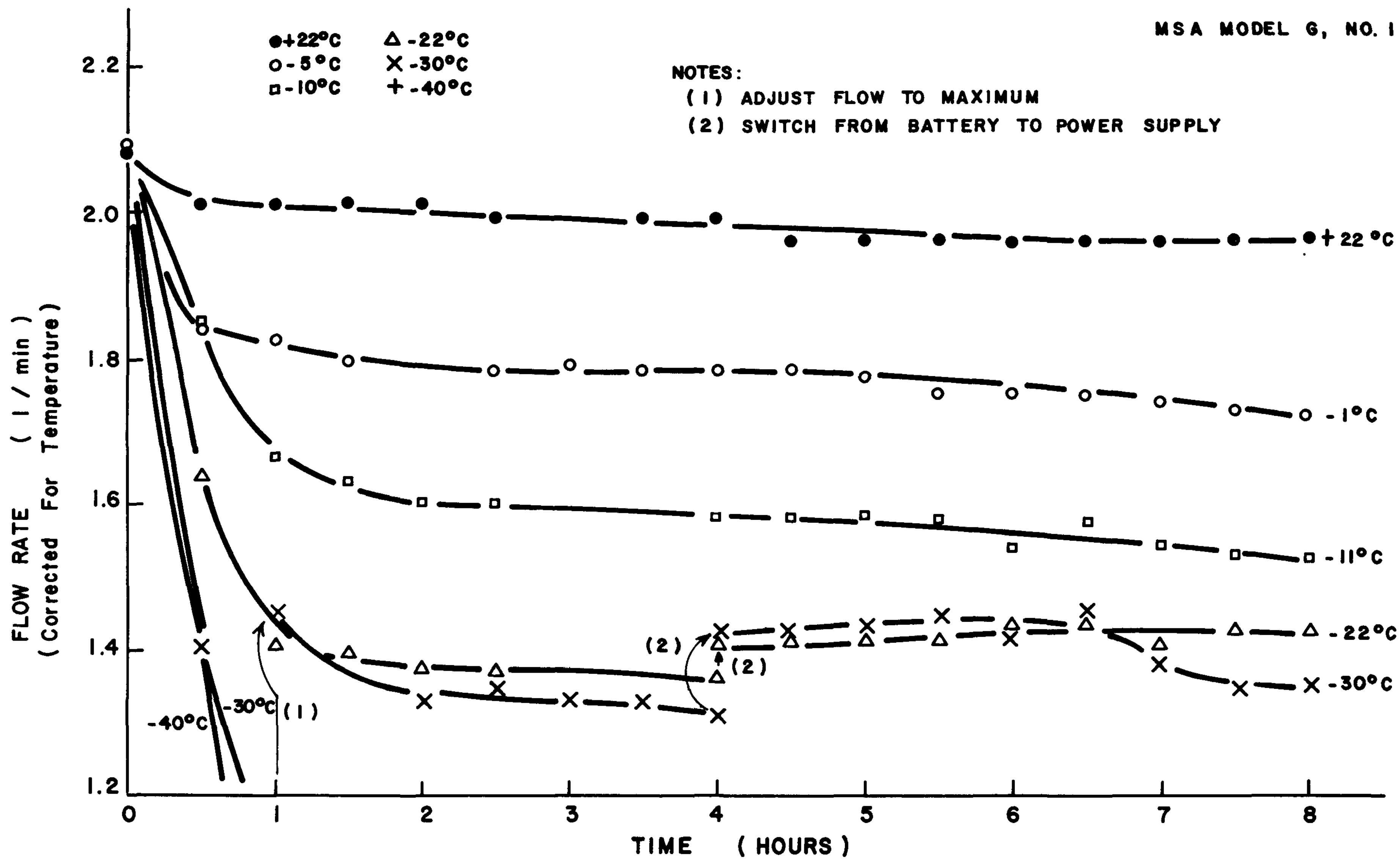

Figure 6 Flow Rate Stability, Corrected for Temperature, Model G, No. 1

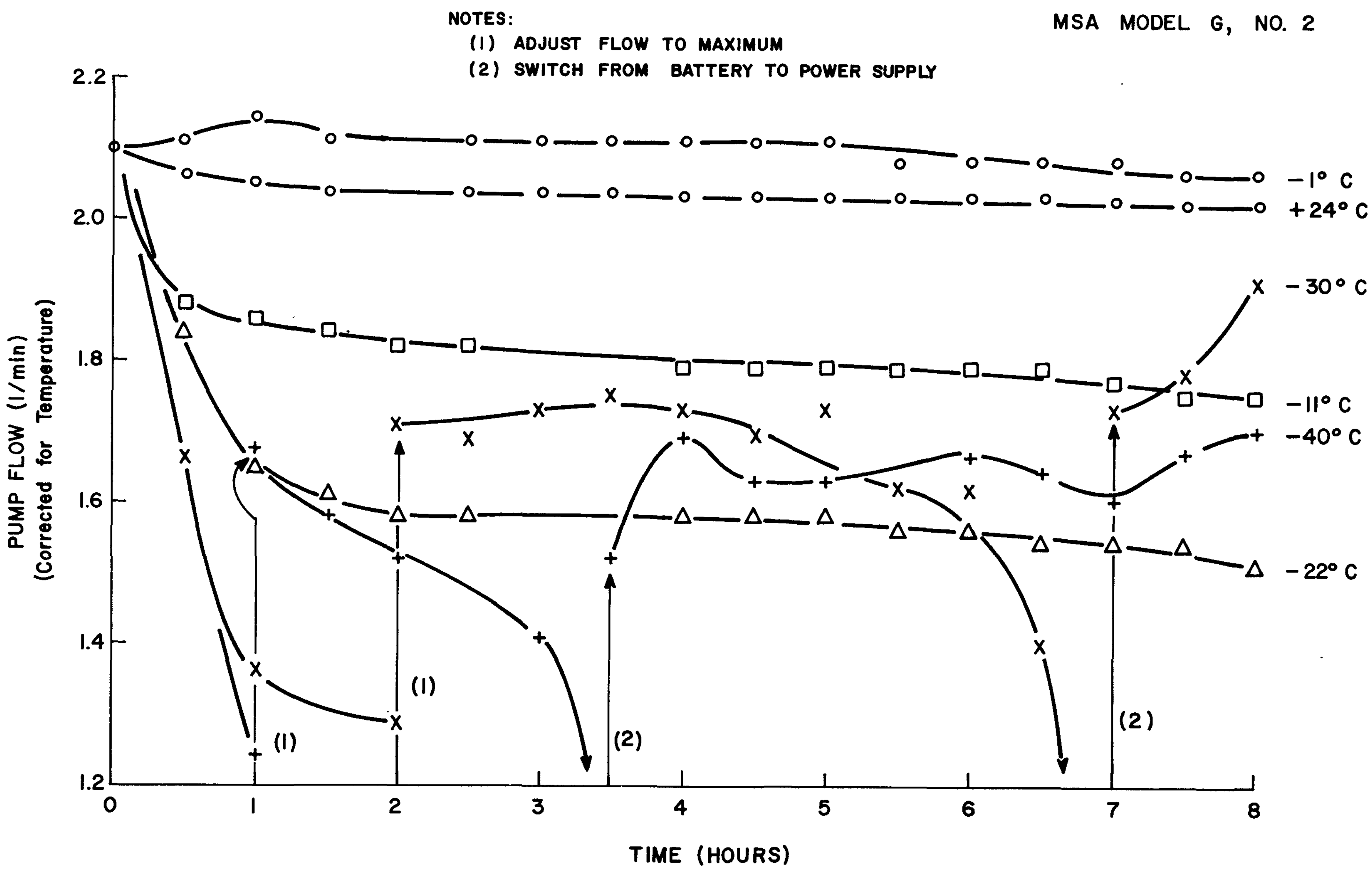

Figure 7 Flow Rate Stability, Corrected for Temperature, Model G, No. 2

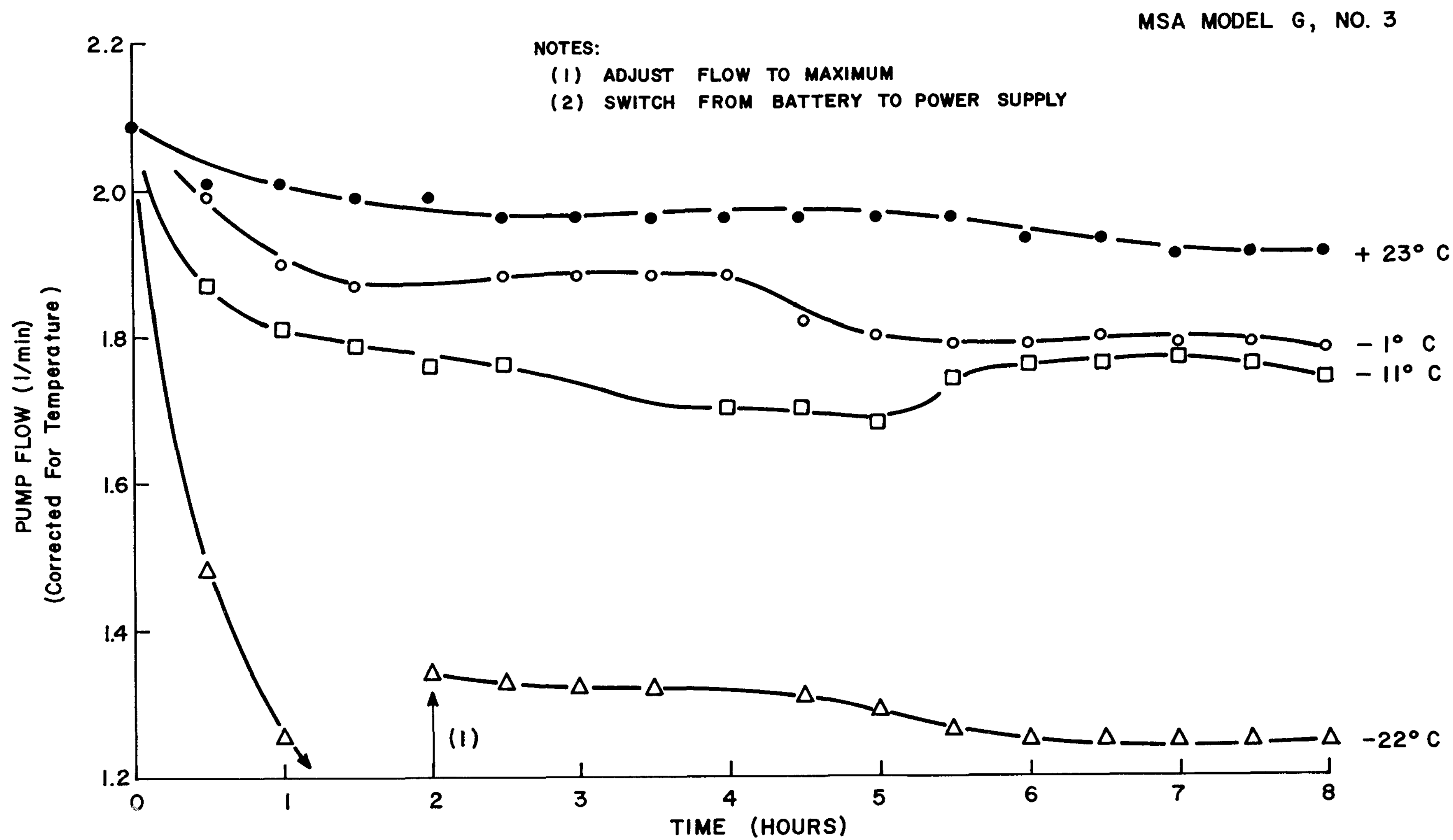

Figure 8 Flow Rate Stability, Corrected for Temperature, Model G, No. 3

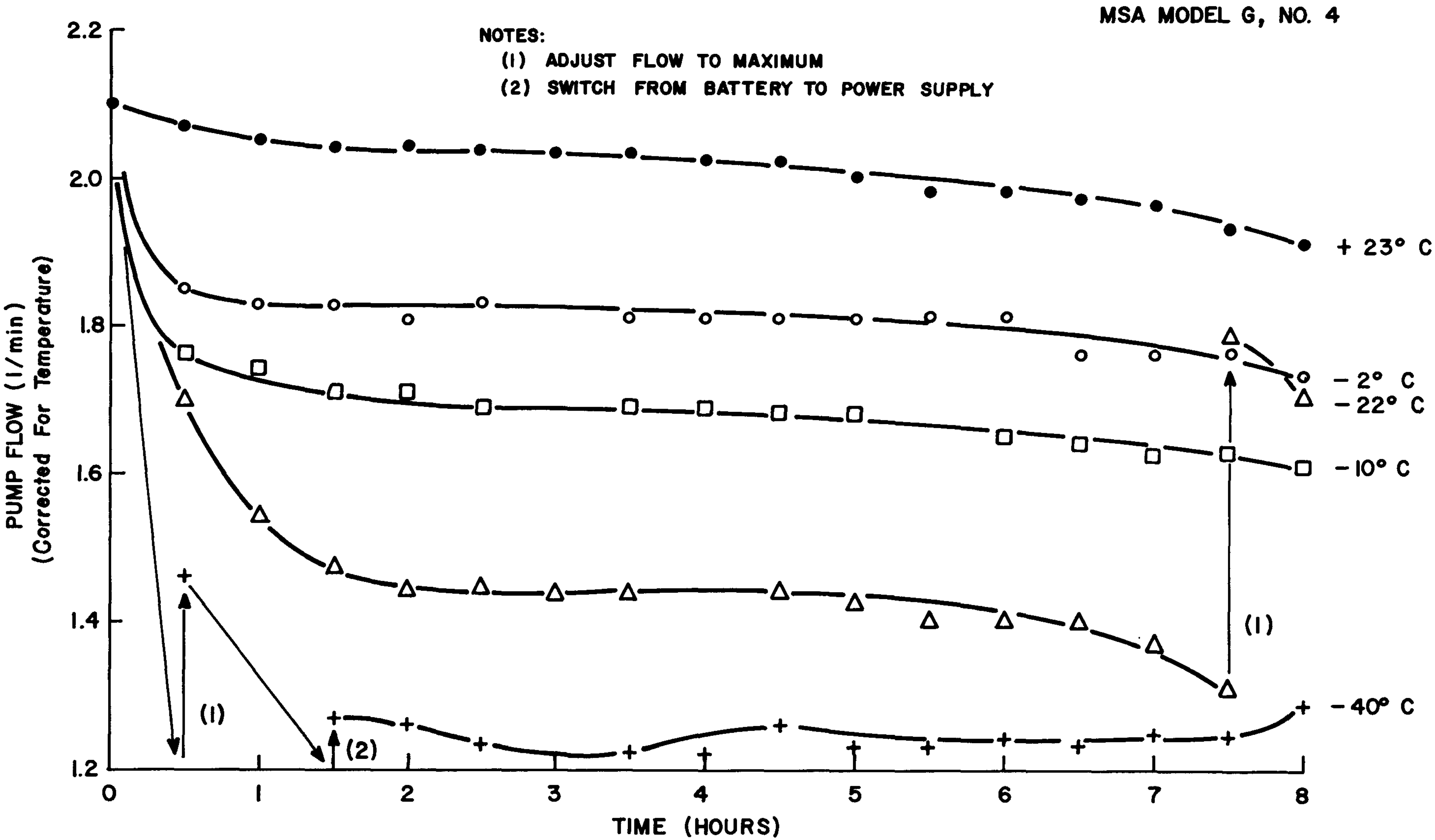

Figure 9 Flow Rate Stability, Corrected for Temperature, Model G, No. 4

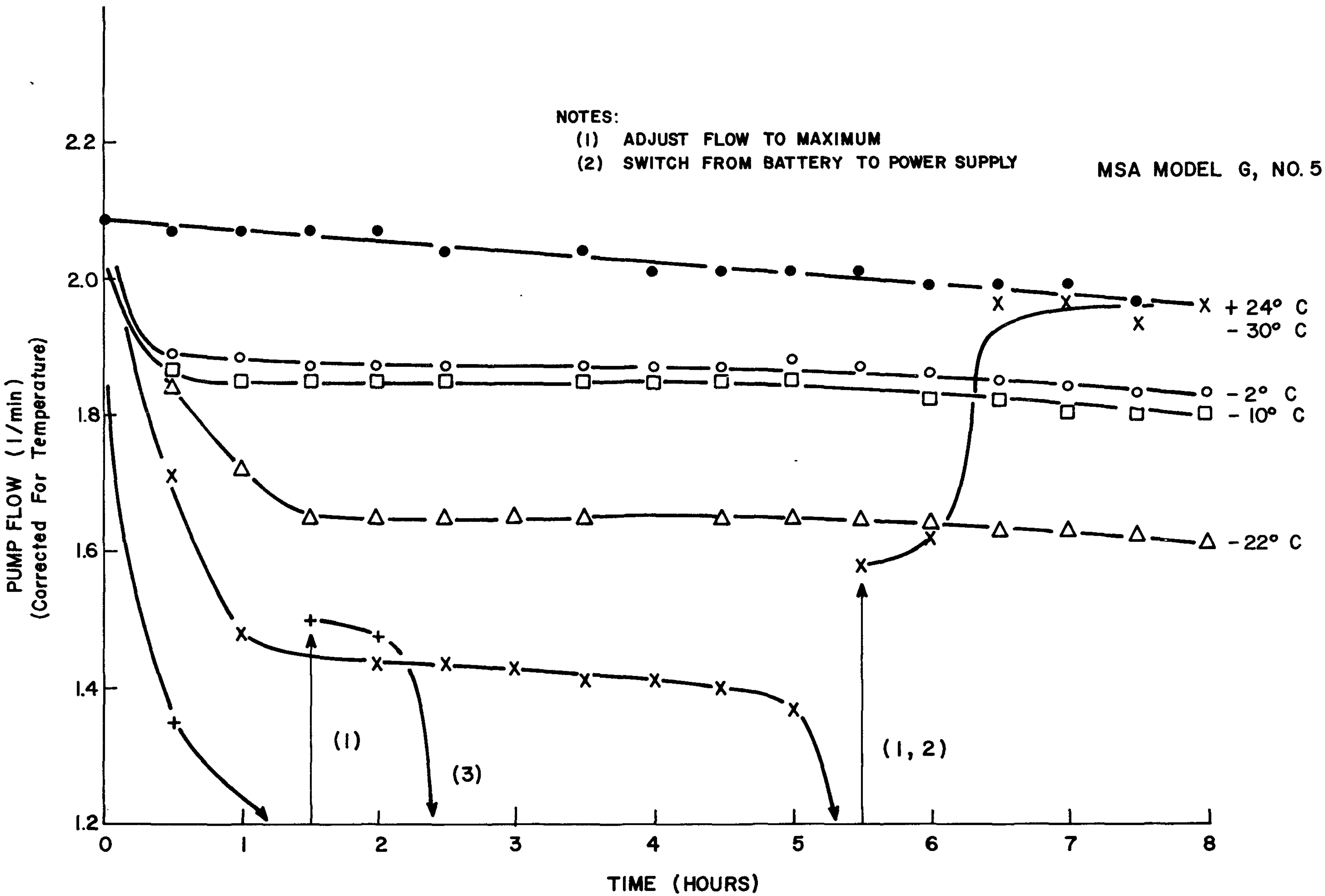

Figure 10 Flow Rate Stability Corrected for Temperature, Model G, No. 5

results from No. 1 and No. 2. The performances are excellent to about -10°, and good to marginal at -22°C. At temperatures below -22°C, performances tend to be marginal.

As temperature is lowered, these pumps require an increased current from the power source. At 250 mA, the battery pack rated capacity is adequate for an 8-hour operation. At the higher currents required at lower temperatures, e.g., 280 mA at -30°C, the rated capacity is exhausted in about 7 hours. Thus, the degraded performance at low temperature is largely due to pump characteristics. The increased current demand at low temperatures is such that the battery pack's ampere-hour capacity is exceeded, compounding the problem.

Flow Rate/Pressure Drop Characteristics--
The flow rate of each Model G was measured as a function of the pressure drop across the pump and temperature in the basic test apparatus of Figure 2. Each pump was adjusted for a flow rate of 2ℓ/min at a pressure differential of 4 in. of H_2O at 24°C, and this setting was not changed throughout these tests. For each test, the pump was equilibrated at the test temperature for a 1.5 hour period, nonoperating. After equilibration, the pump under test was turned on and the flow rate measured as a function of pressure differential across the pump. The pumps under test were not operated during the equilibration periods so that each test would be run with essentially a fully charged battery pack.

The results of these tests are shown in the data plotted in Figures 11, 12, 13, 14, and 15 for pump Nos. 1, 2, 3, 4, and 5, respectively. In each case, flow rates and corrected flow rates are shown for temperatures of +24°, 0° and -20°C. (The 0° and -20°C data are corrected for temperature.) At -30°C, none of the 5 pumps would operate after equilibrating for 1.5 hours. The pump motors did operate in most instances, but the rotometers only pulsated and the pump differential pressure was negligible.

These data show that the Model G pumps can perform a useful function at temperatures as low as -20°C, and that their performance is at best marginal at -30°C. It also shows a significant variance among the 5 pumps. Pump No. 3 and Pump No. 5 yielded the poorest and best performances, respectively. These differences are evident in other data, but perhaps are most obvious here.

Reliability of Calibration over Temperature--
The plots in Figure 16 were derived from the flow rate stability data presented earlier. Thus, for a given pump, each data point was acquired on a separate day. The pumps were initially calibrated at 2.1ℓ/min at 4.0 in. of H_2O at 22°C, and the data plotted in Figure 16 are either the 1 or 1.5 hour data point for each test temperature. (The 1.5 hour data point was preferred; the 1 hour point is plotted for those low temperature instances in

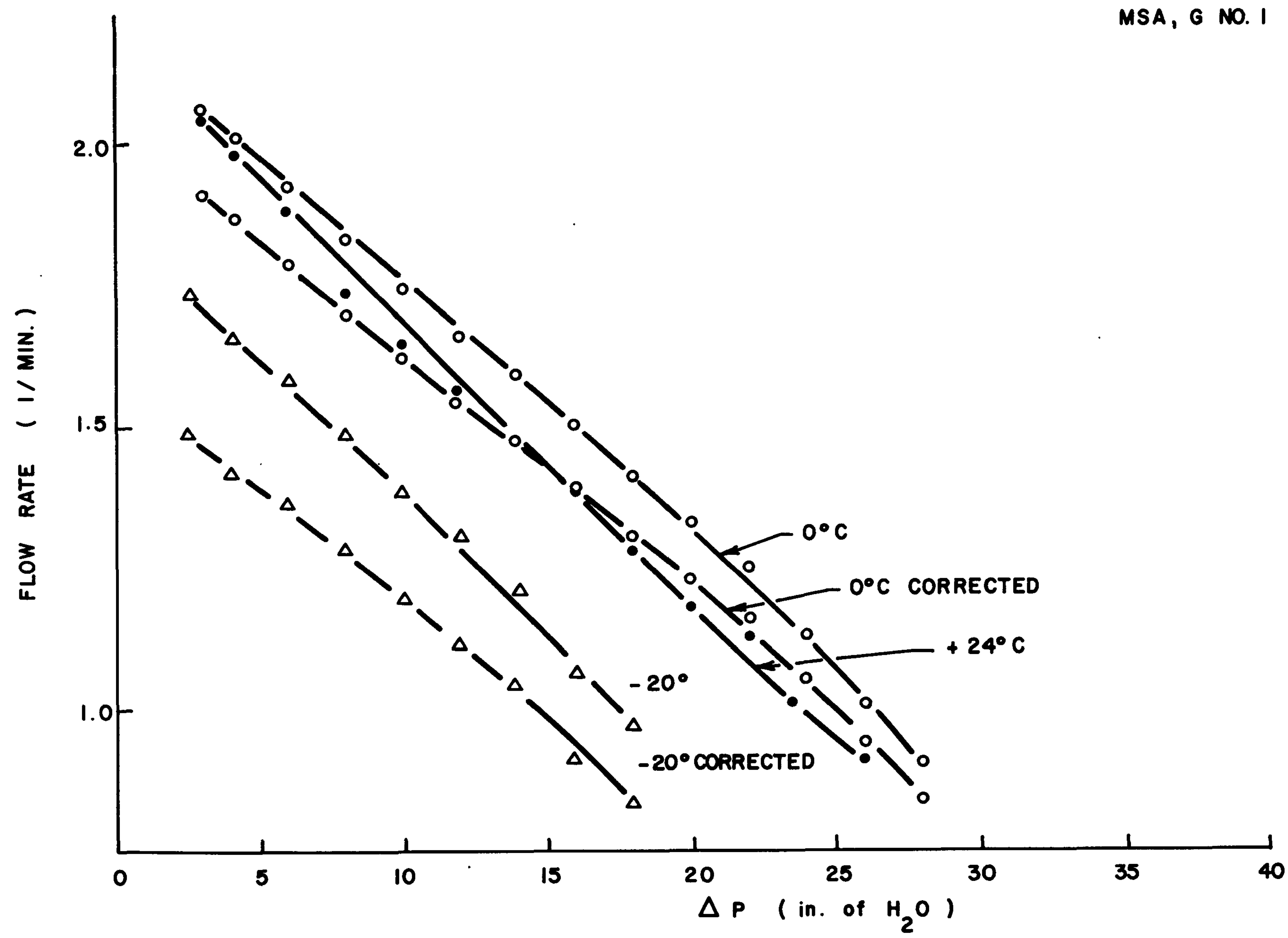

Figure 11 Flow Rate Versus Pressure Differential, Model G, No. 1

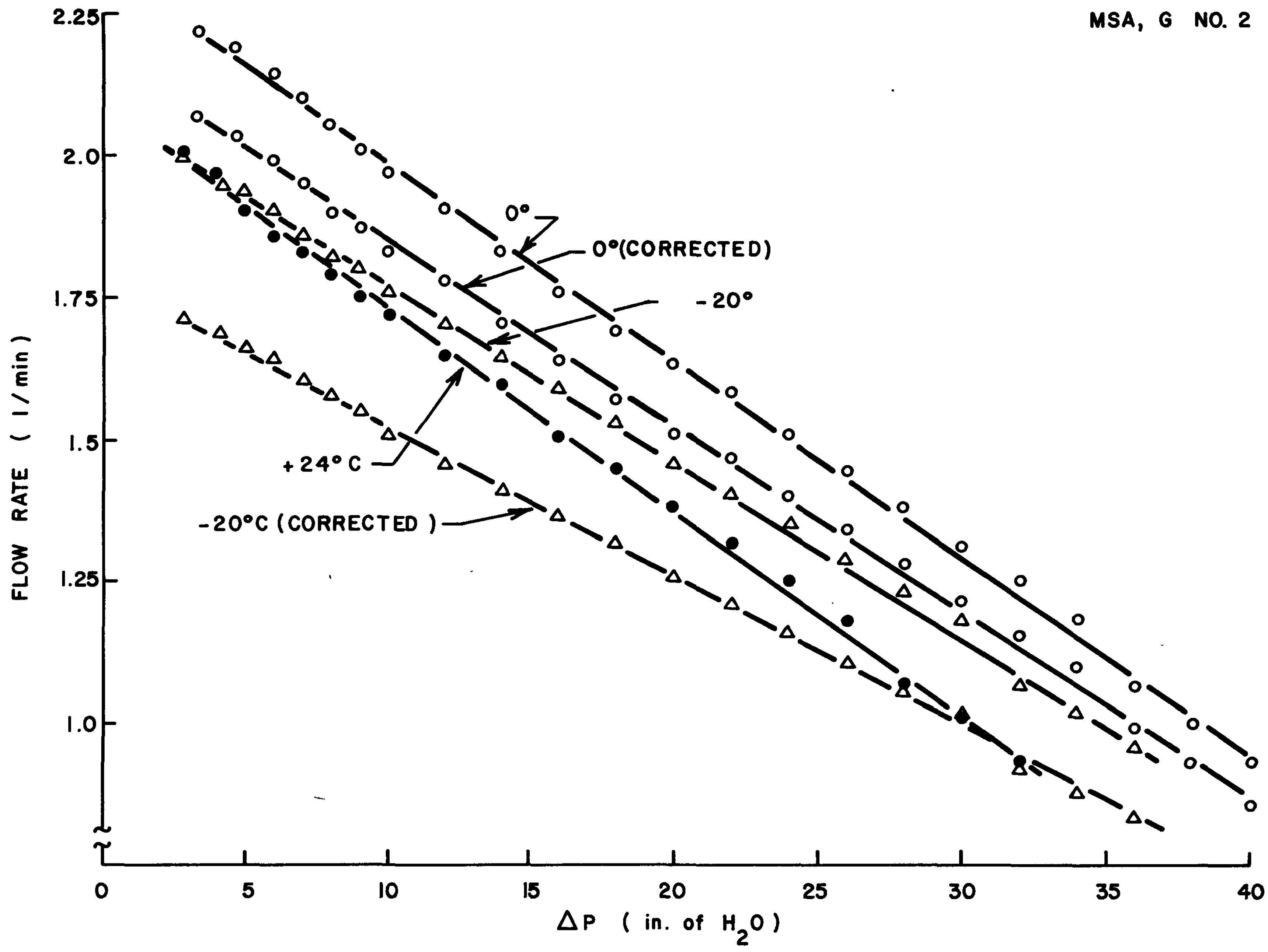

Figure 12 Flow Rate Versus Pressure Differential, Model G, No. 2

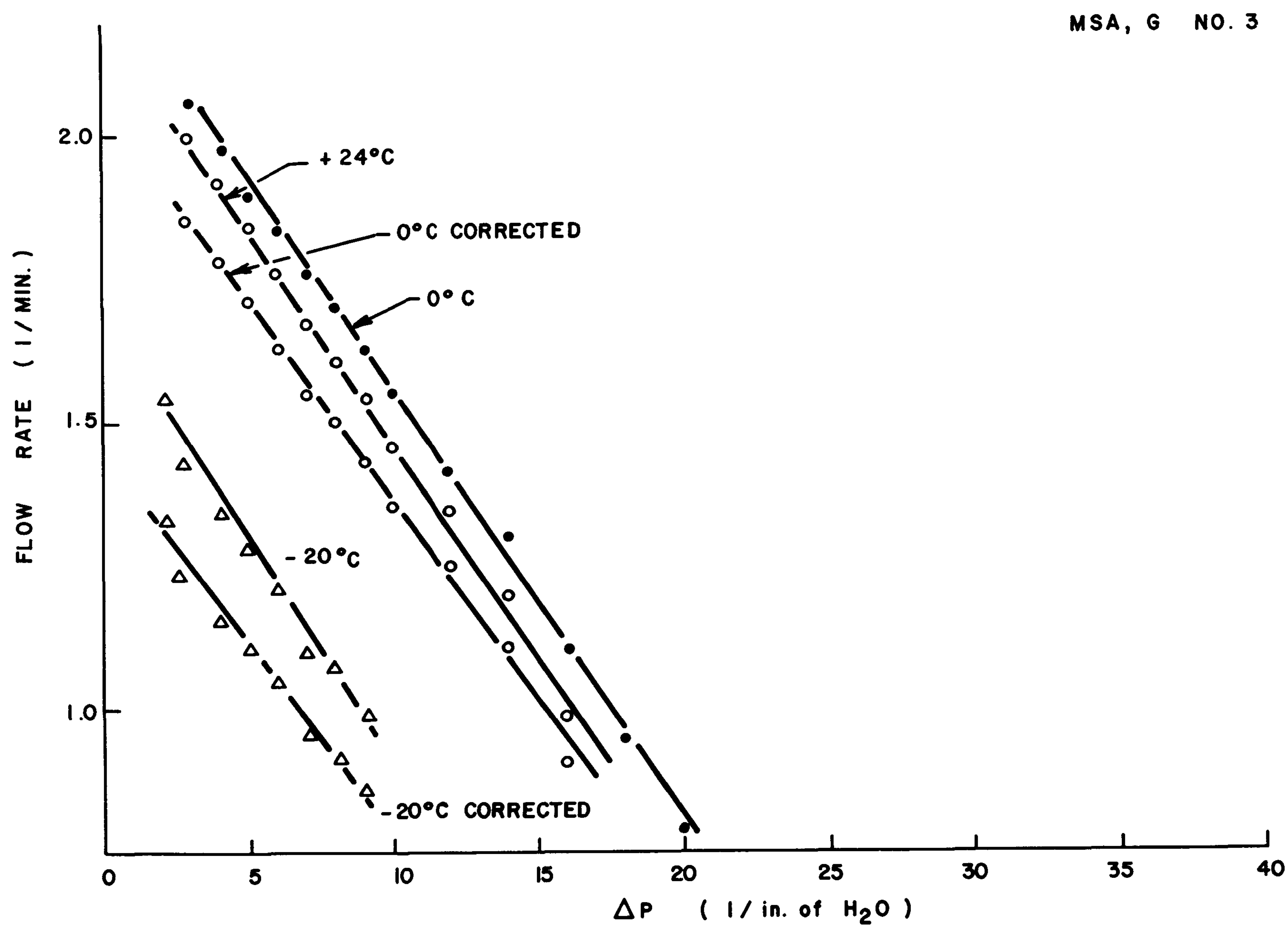

Figure 13 Flow Rate Versus Pressure Differential, Model G, No. 3

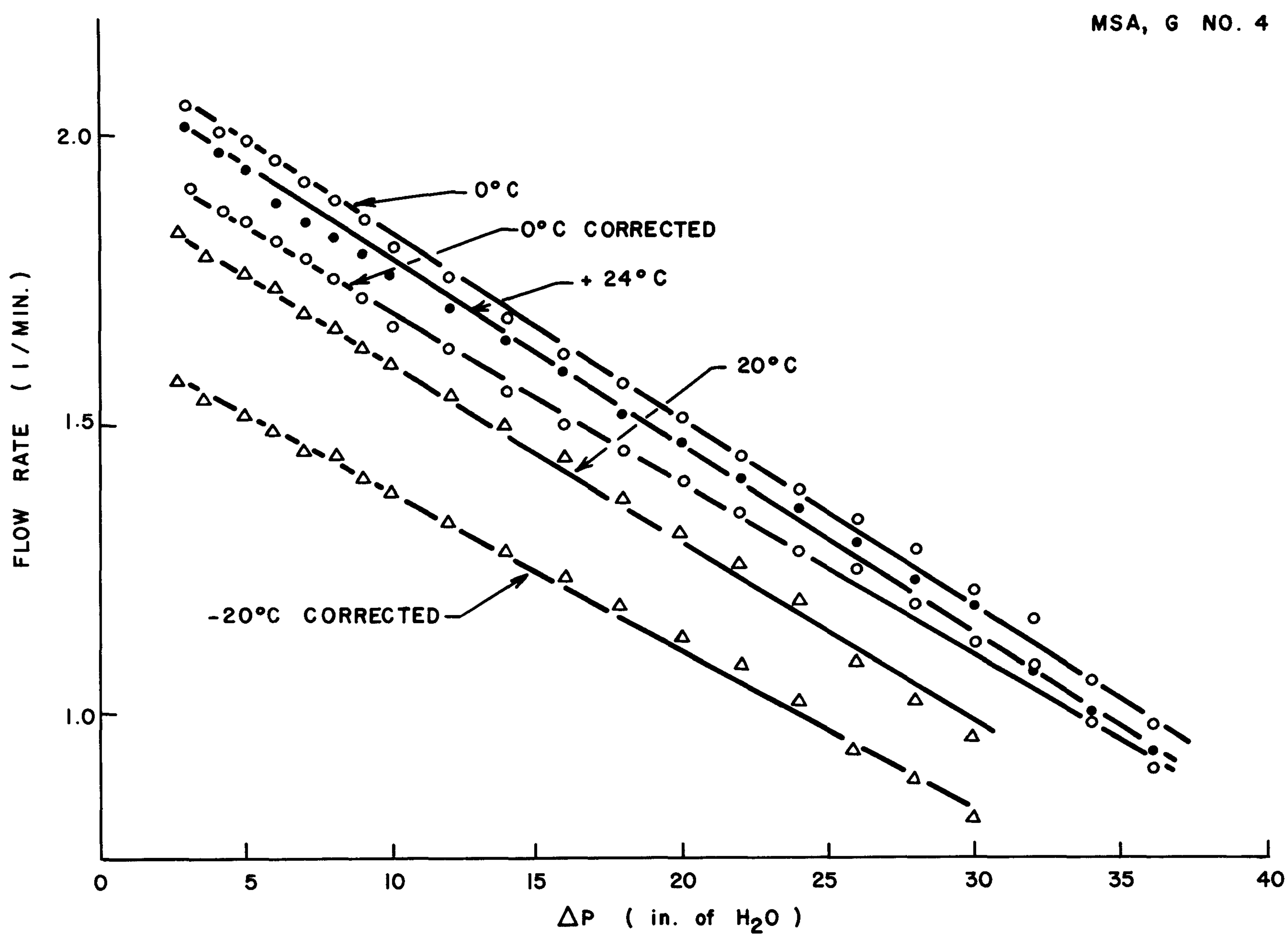

Figure 14 Flow Rate Versus Pressure Differential, Model G, No. 4

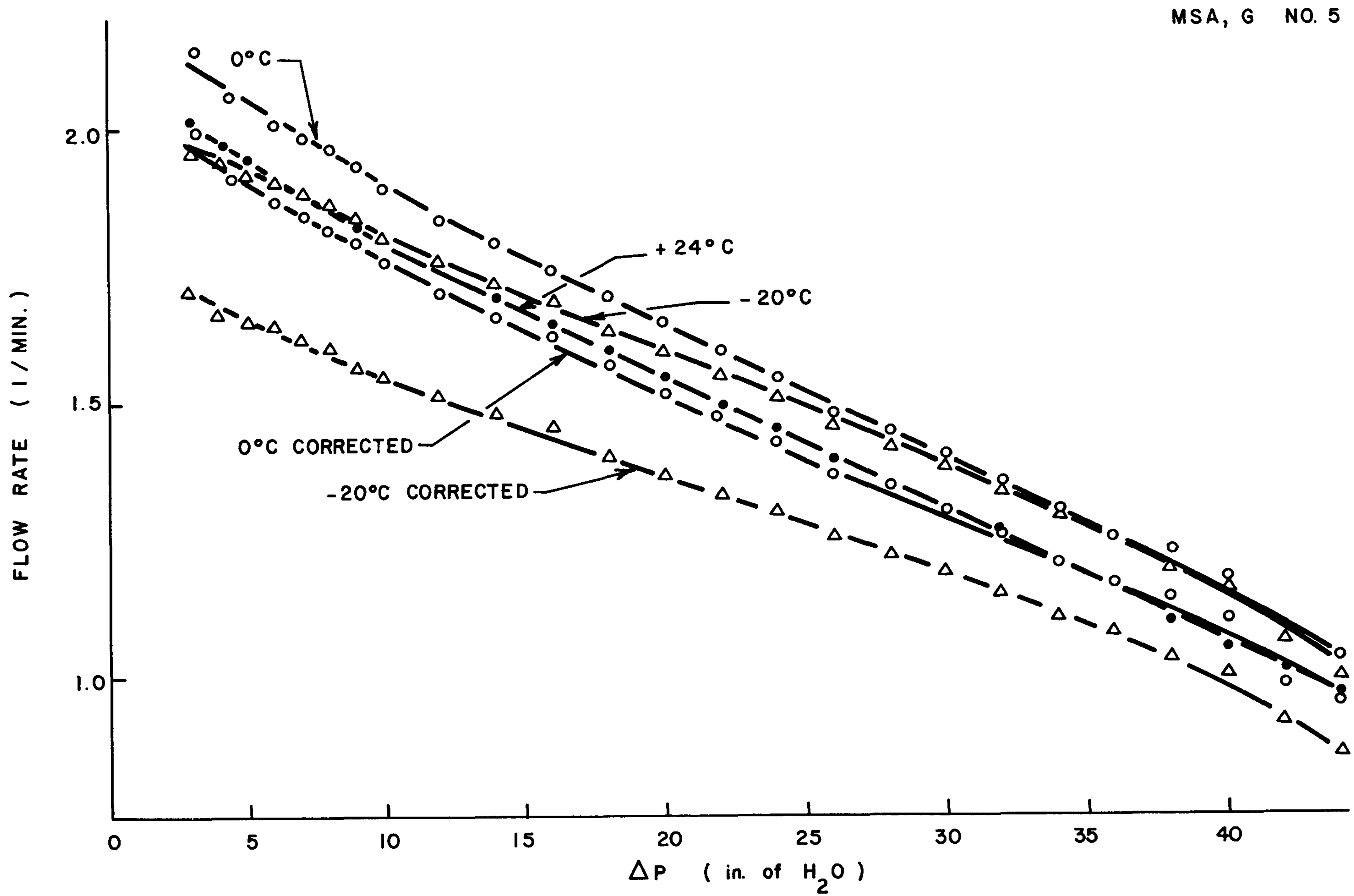

Figure 15 Flow Rate Versus Pressure Differential, Model G, No. 5

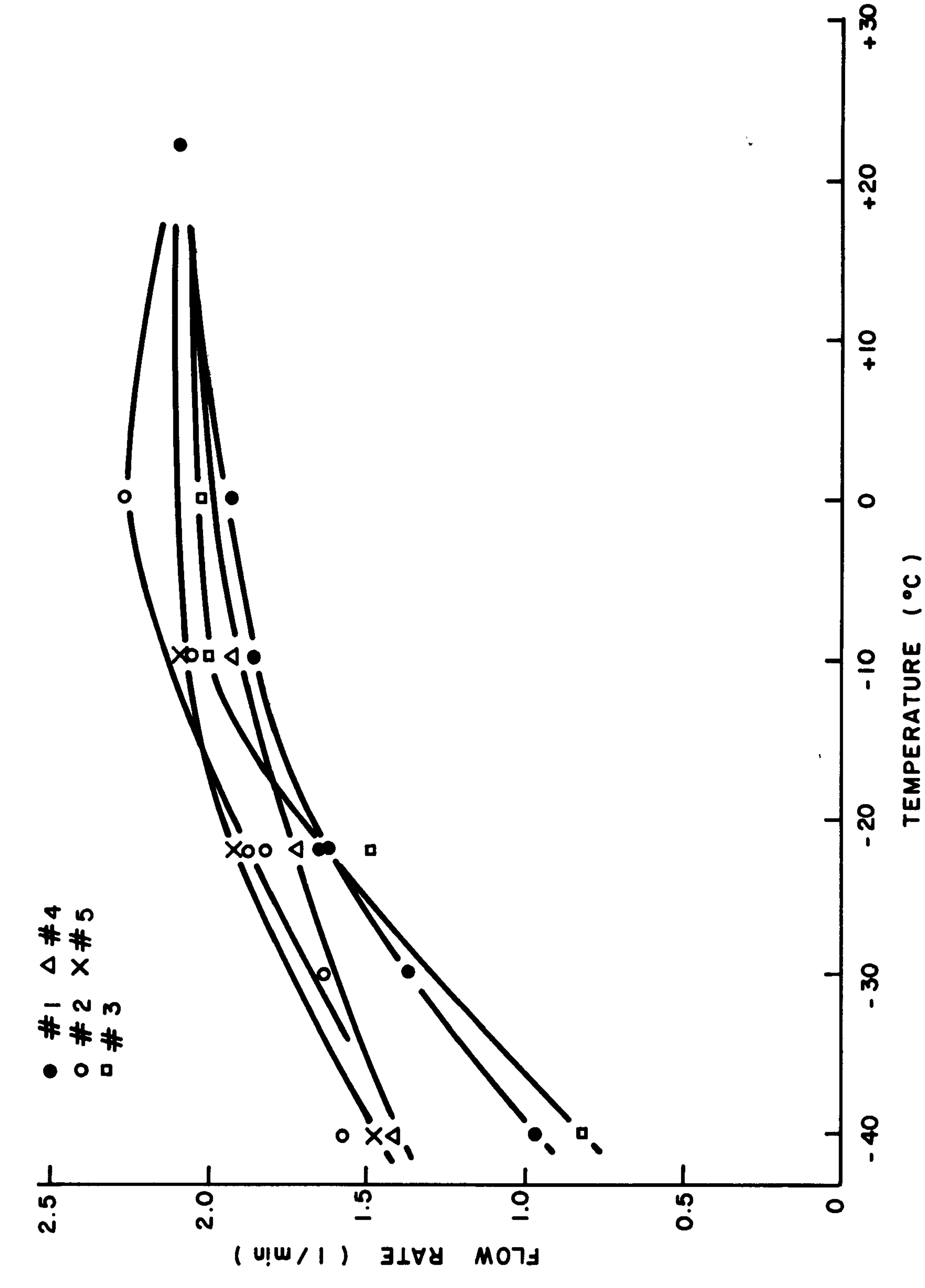

Figure 16 Flow Rate as a Function of Temperature, Model G

which a flow rate adjustment was required at the 1 hour point.) Thus, these data reflect between-days variances as well as variances due to temperature changes. In view of our experience with the flow rate/pressure drop data (inoperative pumps at low temperatures), we elected to accept these between-days variances as an alternative to variances due to battery degradation which would occur if the pumps were operated at low temperature so as to acquire these data on a single day.

Figure 16 also shows a considerable variance between pumps. At -22°C, for example, the measured changes in flow rate vary from 8 to 30 percent. At -40°C these changes vary from 25 to 60 percent. At -10°C the observed maximum changes are comparable to the changes permitted by 30 CFR 74.

Continuously Sample Cold Air--

The experimental evidence presented in preceding sections of this report suggest that the Model G can perform satisfactorily at -20°C, but is marginal in performance at lower temperatures. Thus, -20°C was selected as a temperature to test its ability to pump cold air continuously. After all other testing was completed, all five units were coupled to a manifold at 4 in. of H_2O and adjusted to pump 2ℓ/min. The test chamber was set to -20°C and the pumps operated for 8 hours. This procedure was repeated on 16 separate days after the completion of all other testing. There were no pump failures during these tests and flow rates remained satisfactory, i.e., characteristic of performances observed at about -20°C during all testing.

Ease of Recalibration--

The flow rate of the Model G was readily adjustable at temperatures as low as -30°C. The adjustment mechanism permitted precise flow adjustments that were commensurate with the resolution of the pump's rotometer, e.g., approximately 0.1ℓ/min. At -40° and -50°C, the flow tends to pulsate; thus, precise settings are not possible.

Battery Performance--

All of the personal sampling pumps evaluated were powered by secondary (i.e., rechargeable) sealed, sintered plate nickel cadmium (Ni-Cd) batteries. These batteries have very low internal resistance and can deliver high currents with little loss of voltage. A very significant feature is that when delivering moderate currents they will perform satisfactorily at very low temperatures. These cells can supply useful but reduced energy at temperatures as low as -40°C. [Ref.33] In this as well as in other respects, Ni-Cd batteries are superior to other battery systems.

In contrast to the low temperature performance of Ni-Cd cells (e.g., large currents with good regulation at -40°C) other systems do not perform as well. The capacity of carbon zinc batteries drops off sharply at low temperatures due to the increased resistivity and viscosity of the electrolyte, the decreased rate at which chemical reactions occur, and freezing. The net result is that carbon zinc systems provide very little service at sub-zero temperatures. Mercury cells are not nearly as effective at low temperatures as at room temperature. The zinc anode structure, for example, provides performance at -40°C equivalent to 20 percent of its room temperature capacity. Alkaline and silver oxide zinc batteries can supply only about 5 to 10 percent of their room temperature capacity at -40°C.

The capacity of a Ni-Cd battery depends largely upon the manner of operating the battery. Cells are usually characterized at 25°C and at a stated discharge rate, e.g., C/5 or C/10, where C is the rated ampere-hour capacity. The actual capacity is the function of the discharge rate and tends to decrease significantly with an increase in the discharge rate. A cell characterized at a C/5 rate will yield about 80 percent of rated capacity at a C/1 (1 hour) rate and about 108 percent of rated capacity at the C/10 rate. The cell capacity is also influenced by temperature. At 0°C, for example, a Ni-Cd cell will deliver approximately 90 percent of its room temperature capacity. [Ref.33]

There is very little data available descriptive of the reliability i.e., cycle-life of Ni-Cd cells at low temperatures. Data that are available show a seriously reduced cycle-life at -18° and -34°C; however, these results are attributable to the establishment of unsatisfactory operational conditions rather than any failure to the cell itself. [Ref.34] The reader should be mindful that many factors other than temperature influence the cycle-life and performance of Ni-Cd batteries. These include use factors such as routine depth of discharge, recharge practices, and discharge rates.

The results of these evaluations suggest that the Ni-Cd batteries used in personal sampling pumps yield good performances. While they are inadequate for the desired performances at low temperature, the problem is largely due to pump characteristics. Indeed, battery capacity is reduced at low temperature; however, the pumps demand more current. Thus the batteries must discharge at the higher rate which further reduces their capacities. These problems are compounded by the increased current demand of the pumps.

Figure 17 illustrates the increased current demand for the Model G pumps as temperature is lowered. In supplying a higher current, the 2,000 mA-hr. battery pack tends to be exhausted in less time and, additionally, the capacity is decreased at the lower temperature. If, as stated in a preceding paragraph, the capacity is only 90 percent of its room temperature value at 0°C the Model G battery pack should supply the required current for approximately (0.9) (2,000)/200 = 9 hrs. At -30°C, it is estimated to last somewhat less than (0.9) (2,000)/270 = 7.6 hrs. (We have used 0.9 again because an estimated reduction in capacity is not available for -30°C.) At -40°C, the estimated time would be significantly less than 5.4 hours.

It is significant that the battery pack voltage was never less than 1.1 V/cell when replaced by a power supply. This is indicative of the cell's low internal impedance at low temperatures. Typically, the battery packs were furnishing currents of, for example, 300 mA at -40°C when replaced by a power supply. (Since the replacement time was about 1 hour, one can infer that the capacity degradation at -40°C is about 85 percent.)

It is concluded that the battery packs are inadquate to operate the Model G pumps at -30°C and below. This is due to battery capacity degradation and the

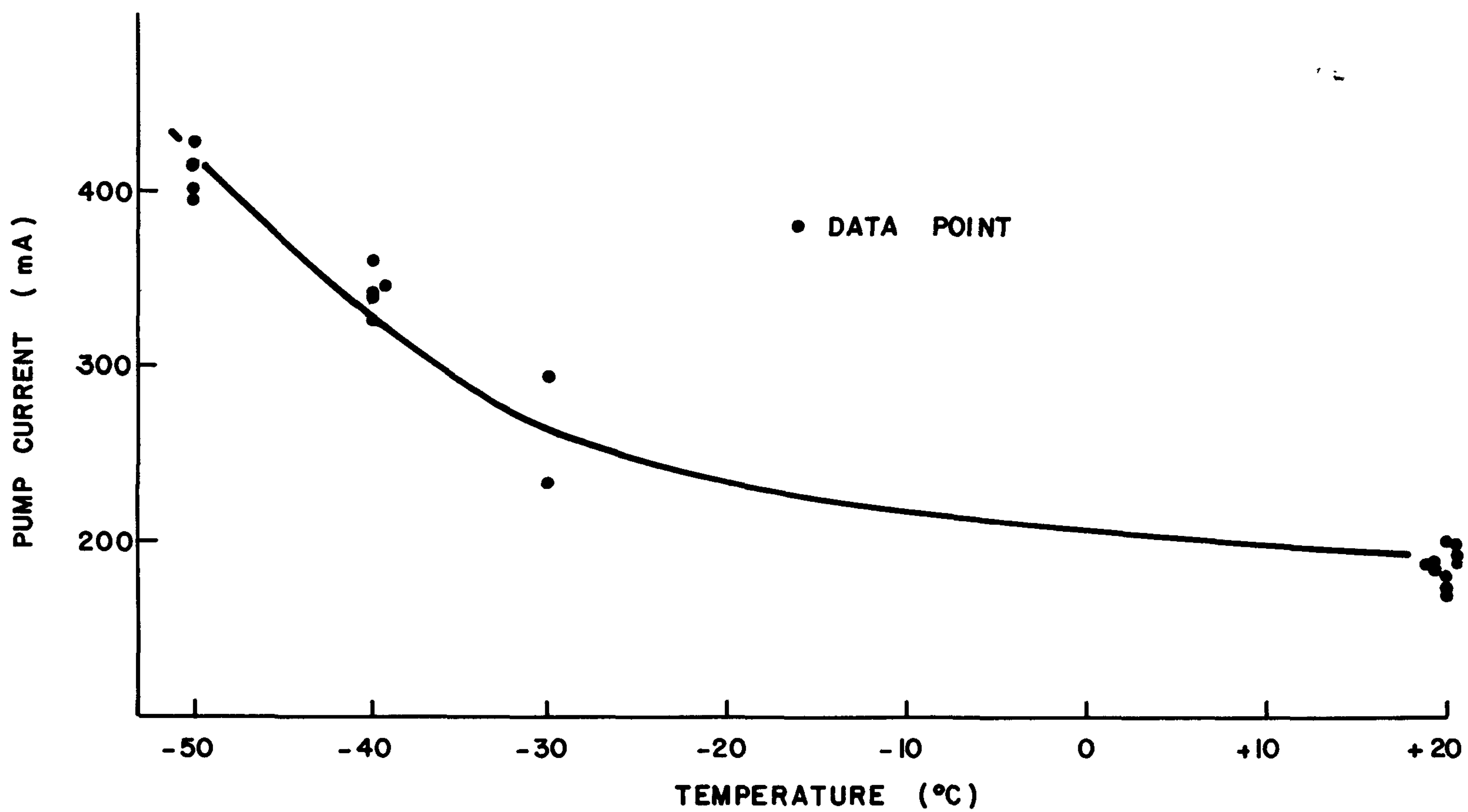

Figure 17 Pump Current as a Function of Temperature, Model G

increased current demand with decreasing temperature. However, the pump's performance was also unsatisfactory to marginal when supplied from a laboratory power supply. Thus, a larger battery pack will not insure a significant improvement in performance and is not warranted.

Diaphragm Reliability and Bearing Design--
It is noted that all of the Model G pumps survived the low temperature testing without significant damage. There appears to be some crazing of the plastic pump housing on one of the five units that may have occurred at -50°C, but the pumps' performances are not affected. Although the diaphragm reliability has not been measured, it is observed to be reliable in that there is no evidence of unreliability after significant testing at low temperatures. Similarly, there is no evidence of failure or performance degradation due to bearing design.

Lubricants--
The characteristics of the lubricants have not been explicitly evaluated. It is considered likely that the lubricant is partially the reason for the pumps' increased current demand at low temperatures.

Case Ruggedness--
There were no instances of case damage or degradation due to exposure and operation at the low temperatures. There was some crazing of the pump housing in one unit (No. 2) , but it had no effect on the pump's operation. Subsequent operation at -20°C suggests that the pump remains a reliable, viable structure. Other instances of crazing are very slight and are considered insignificant.

MSA Model S

Five MSA Model S CMDPSU units were included in these evaluations. Figure 18 is a photograph of two of these units. The Model S is essentially identical to the Model G except that the Model S incorporates a by-pass valve designed to compensate for sample flow restrictions so that the pump can operate more efficiently. This valve configuration is illustrated in Figure 19. The by-pass valve allows atmospheric air to flow to the pump; thus, the differential pressure across the pump is reduced. The valves are mechanically coupled such that if the by-pass valve is held fixed relative to the case while the sample valve is turned, opening the sample valve will tend to close the by-pass valve. The pump's rotometer indicates only the sample flow. The Model G does not include such a by-pass arrangement. These pumps are essentially the same if the Model S by-pass valve is completely closed. Except for this difference the MSA Models G and S appear to be identical with interchangeable cases, pumps, motors, and battery packs. The Model S pumps were subjected to identical testing as the Model G. The results of these tests are discussed in the following paragraphs.

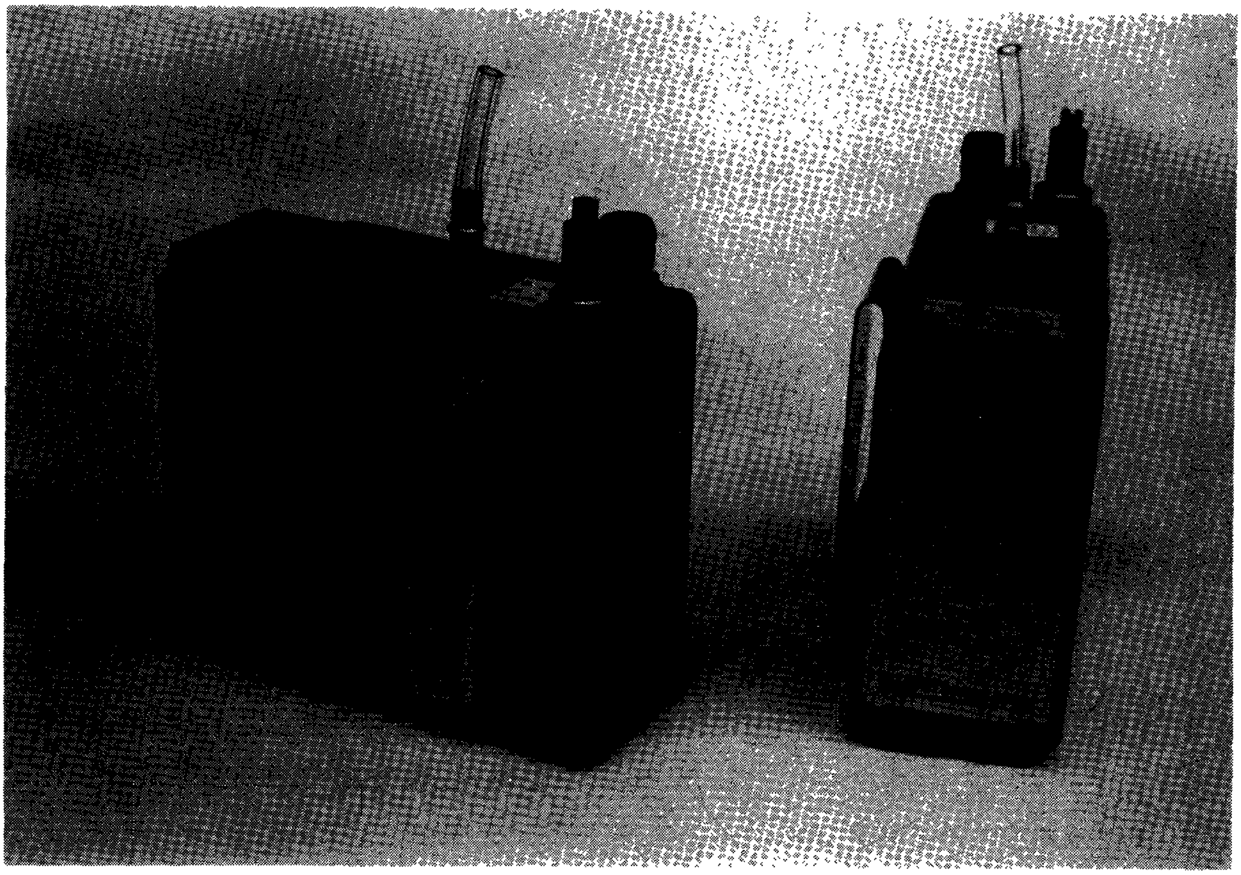

Figure 18 Photograph of the MSA Model S

Flow Rate Stability with Time--
The flow rates of the MSA Model S units were measured in the basic test apparatus, illustrated in Figures 1 and 2, following the procedures described previously. These results are shown in Figures 20 through 24 for the MSA Model S units 1 through 5, respectively. As discussed previously, the flow rates were measured at room temperature and have been corrected to reflect the lower volume of more dense air that actually moves through the pumps. These data plots show stable performances at +24°, -2°, and -10°C. At -22°C the performances tend to be erratic. Satisfactory flow rates could not be maintained for an 8 hour period in most instances at -22°C. Power supply substitutions were required in units 1 and 2, and maximum flows in units 3, 4, and 5, operating from their battery packs, were down to about 1.4 /min after 7.5 to 8 hours. (This is the equivalent of (1.4) (297/251) = 1.66 /min at +24°C.) In no instance could satisfactory performance be maintained at -30°C without a power supply substitution.

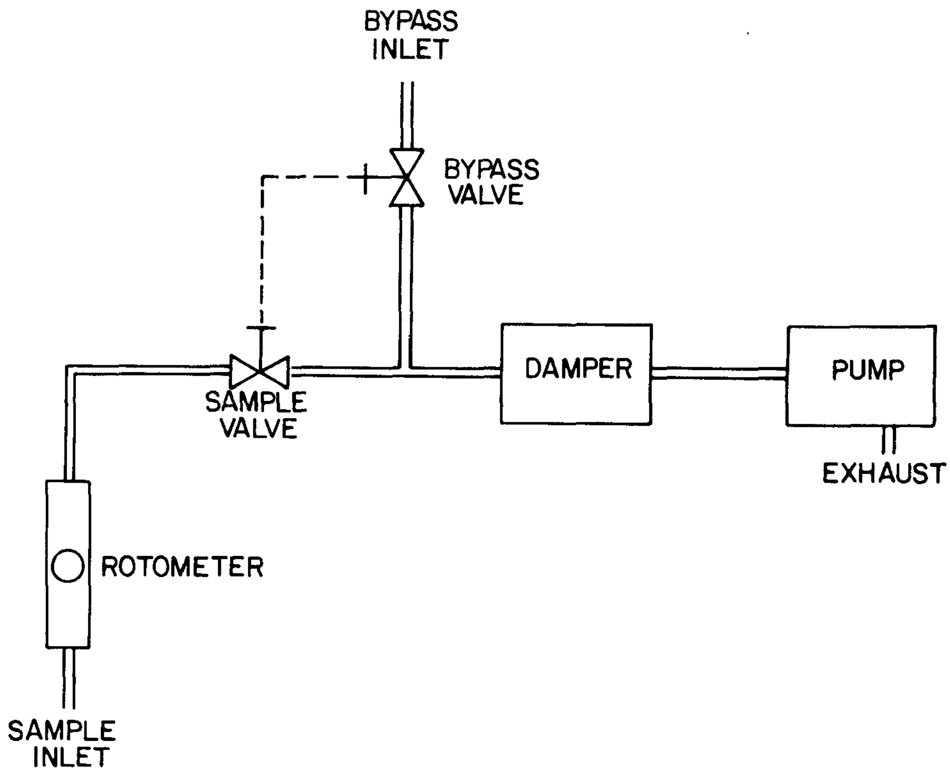

Figure 19 Illustration of the Model S Bypass Valve Arrangement

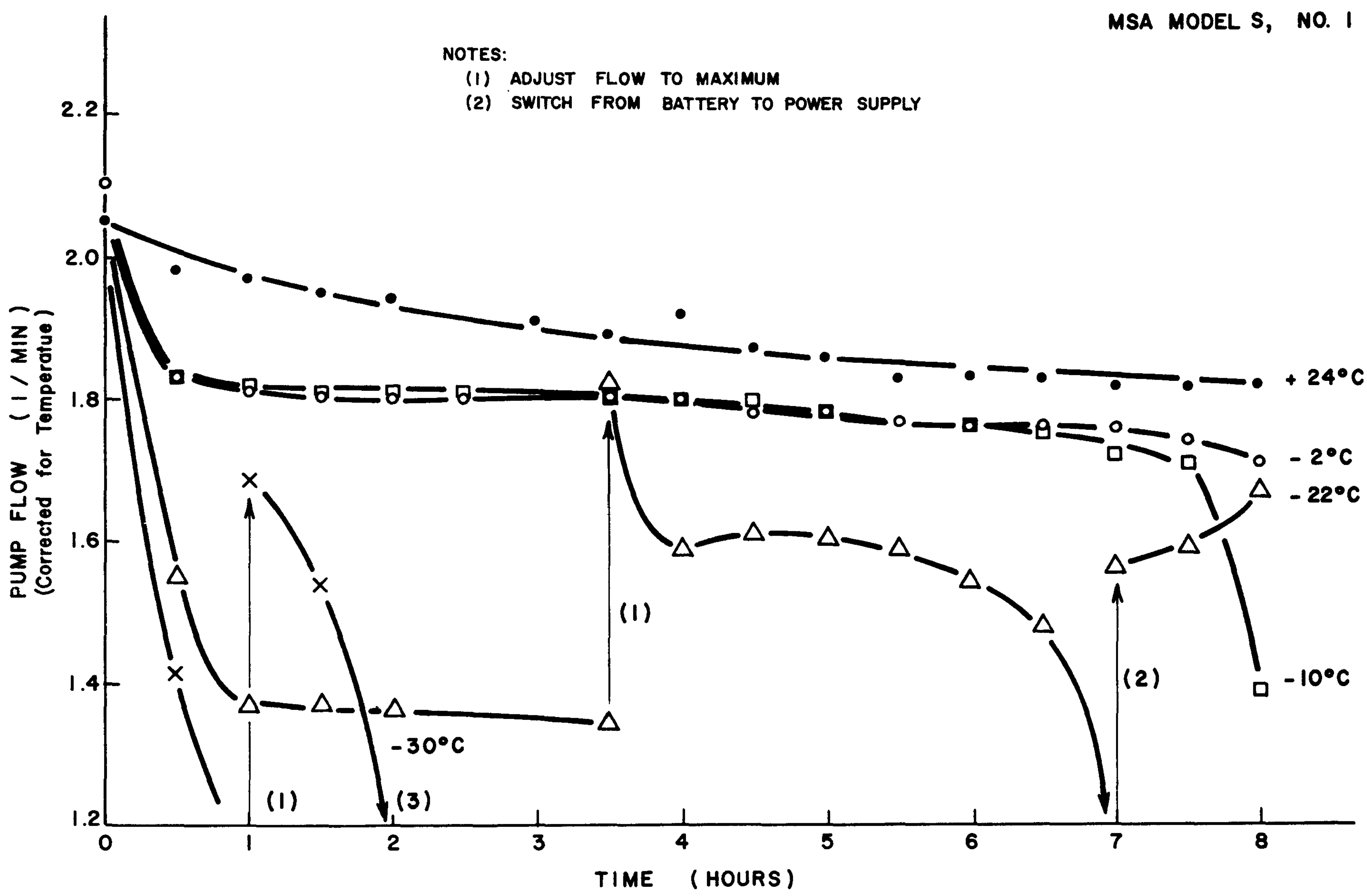

Figure 20 Flow Rate Stability, Corrected for Temperature, Model S, No. 1

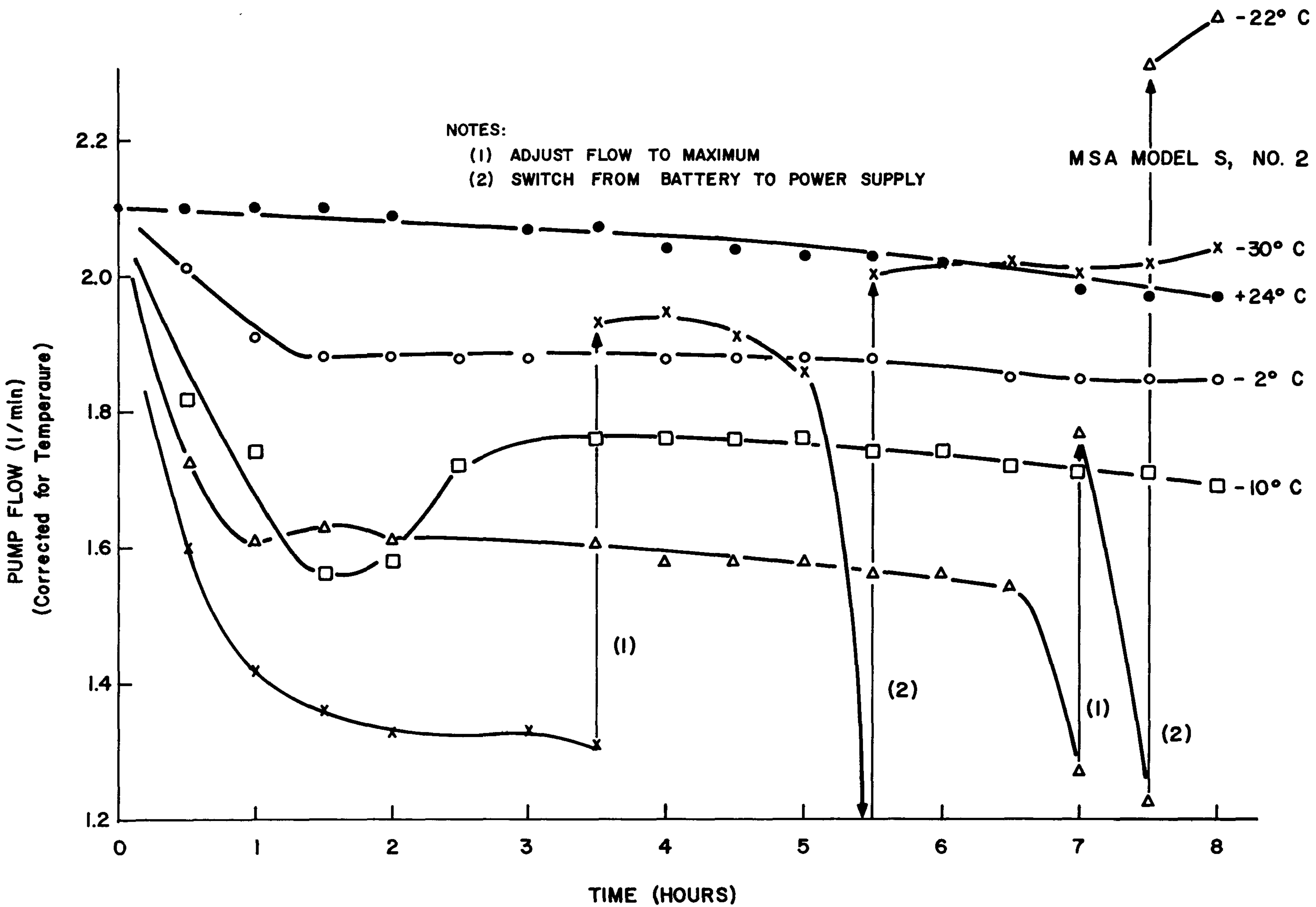

Figure 21 Flow Rate Stability, Corrected for Temperature, Model S, No. 2

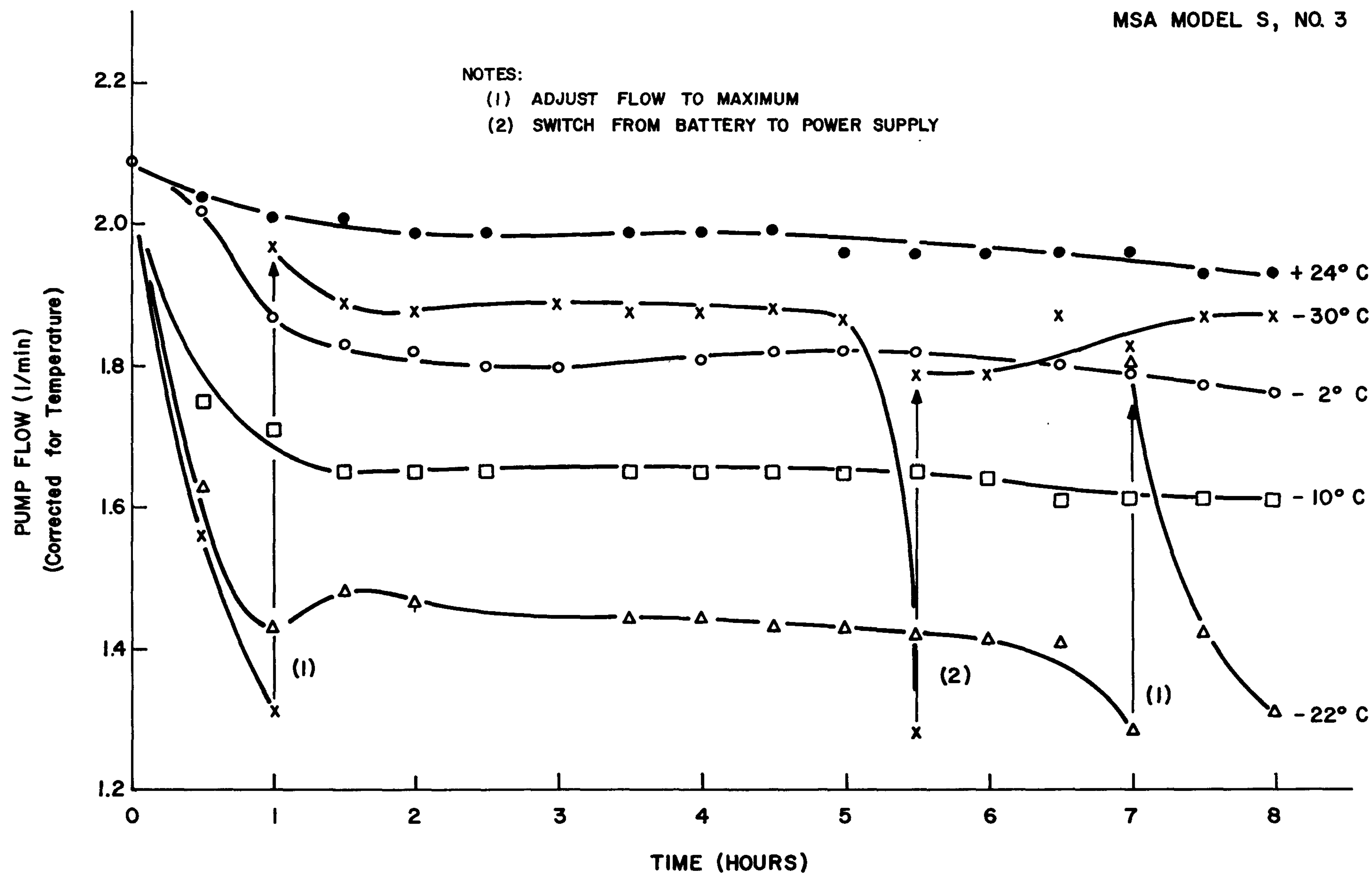

Figure 22 Flow Rate Stability, Corrected for Temperature, Model S, No. 3

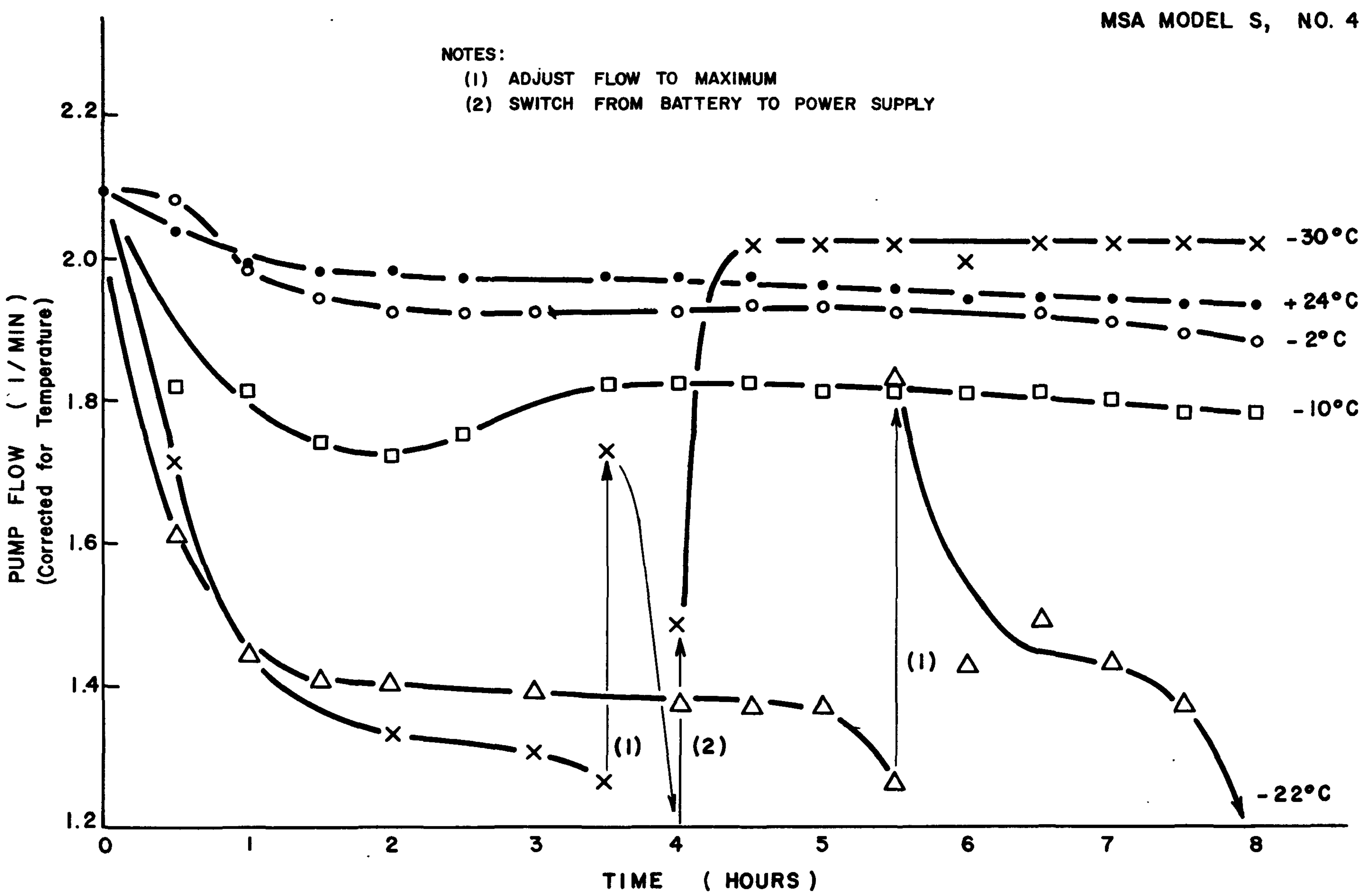

Figure 23 Flow Rate Stability, Corrected for Temperature, Model S, No. 4

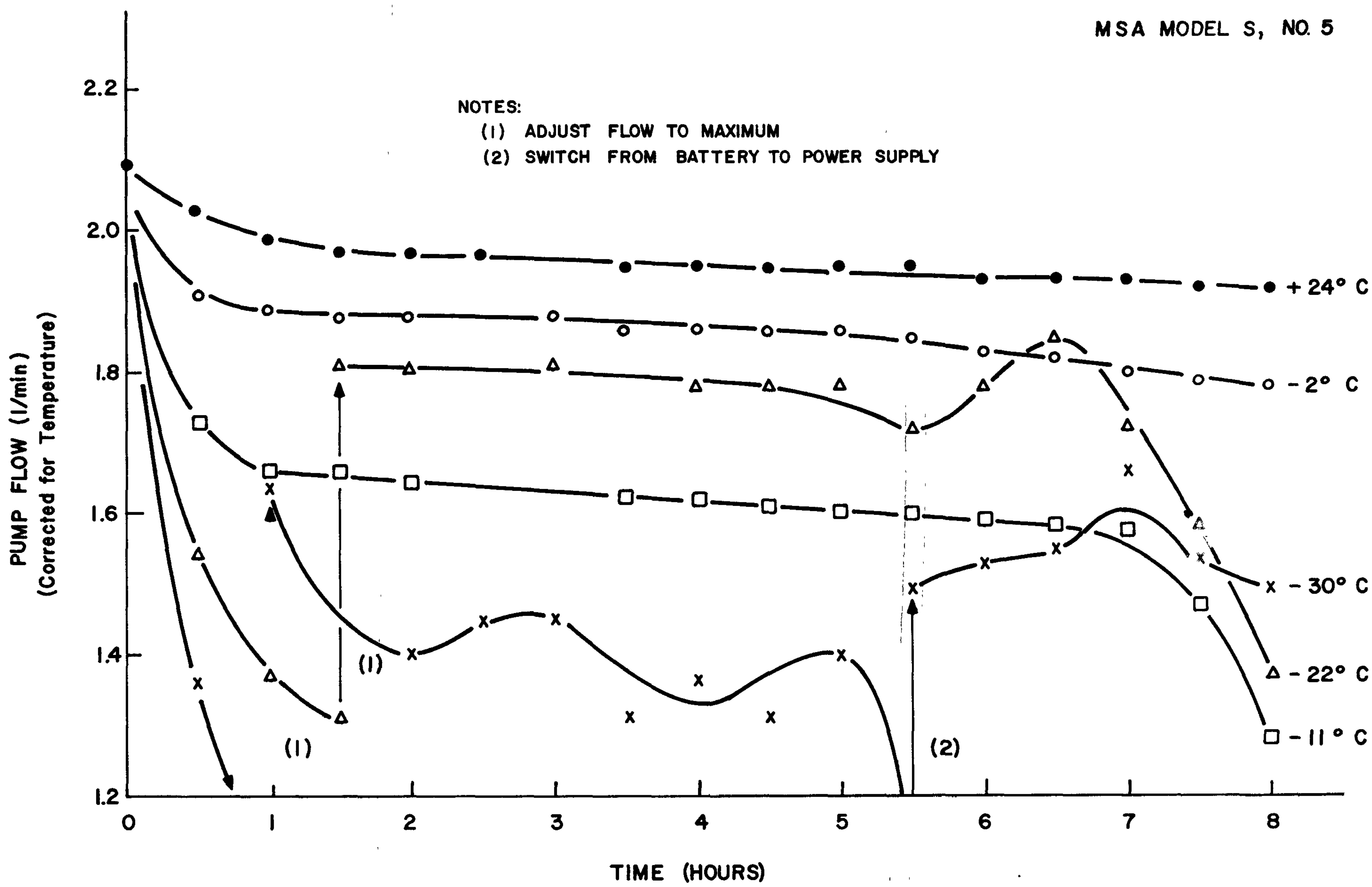

Figure 24 Flow Rate Stability, Corrected for Temperature, Model S, No. 5

It is significant that the Model S units were also tested in an operating mode at -40° and -50°C for an 8 hour period. Although performances were unsatisfactory, there is no evidence of damage due to these exposures.

Flow Rate/Pressure Drop Characteristics--
The flow rates of the Model S units were measured as a function of the pressure drop across each unit at several test temperatures. The procedure was the same as for the Model G. Each pump was adjusted for a flow rate of 2ℓ/min at a pressure differential of 4 inches of H_2O at 24°C and each pump was equilibrated at the test temperature for a 1.5 hour period, non-operating. The results of these tests are shown in Figures 25 through 29. In each plot flow rates measured at 24°C, 0°C, and -20°C, and flow rates corrected for the temperature difference between 24°C and the test temperature are included. As was the case for the Model G pumps, none of these units would operate at -30°C and below after equilibrating, non-operating, for 1.5 hours. The motors would usually operate; however, the rotometers only pulsated and the pump differential pressure was negligible. These data show 0°C performances comparable to room temperature performances. There is significant degradation at -20°C and considerable pump to pump variance.

Reliability of Calibration Over Temperature--
The data plotted in Figure 30 were derived from the flow rate stability data discussed earlier. Thus, for each pump, each data point was acquired on a separate date. The pumps were initially calibrated at 2.1ℓ/min at 4 inches of H_2O at room temperature and the data plotted in Figure 30 are the 1.5 hour data points for each test temperature. (At -40°C most of the data is the 1 hour data point because a flow rate adjustment was required before the 1.5 hour point was reached.) Thus, these results reflect between-days variances as well as variances due to temperature. In view of our experience with the flow rate/pressure drop data (inoperative pumps at low temperatures), these between-days variances were accepted as preferable to variances due to battery degredation which would occur if the pumps were operated continuously while equilibrating.

Data from all five Model S pumps are plotted in Figure 30. The two curves included are intended to be somewhat characteristic of unit No. 1 as a worst-case example and unit No. 4 as the best example. These curves suggest that the flow rate will decrease by about 12 to 19 percent at -20°C and about 19 to 35 percent at -30°C. Inherent in these data are contributions due to battery degredation, but these were minimized by utilizing the 1.5 hour data.

Continuously Sample Cold Air--
The MSA Model S units were subjected to the same routine of frequent operation at -20°C, 2ℓ/min and 4 inches of H_2O as the Model G units. These procedures were repeated on 13 separate days. There were no failures during the 8 hour runs and the flow rates remained characteristic of the -20°C performances observed during other periods of testing.

Ease of Recalibration--
The flow rate of the Model S is readily adjustable at temperatures as low as -30°C. At lower temperatures these pumps tend to be either erratic, to pulsate, or not to pump at all, and flow adjustments become impractical.

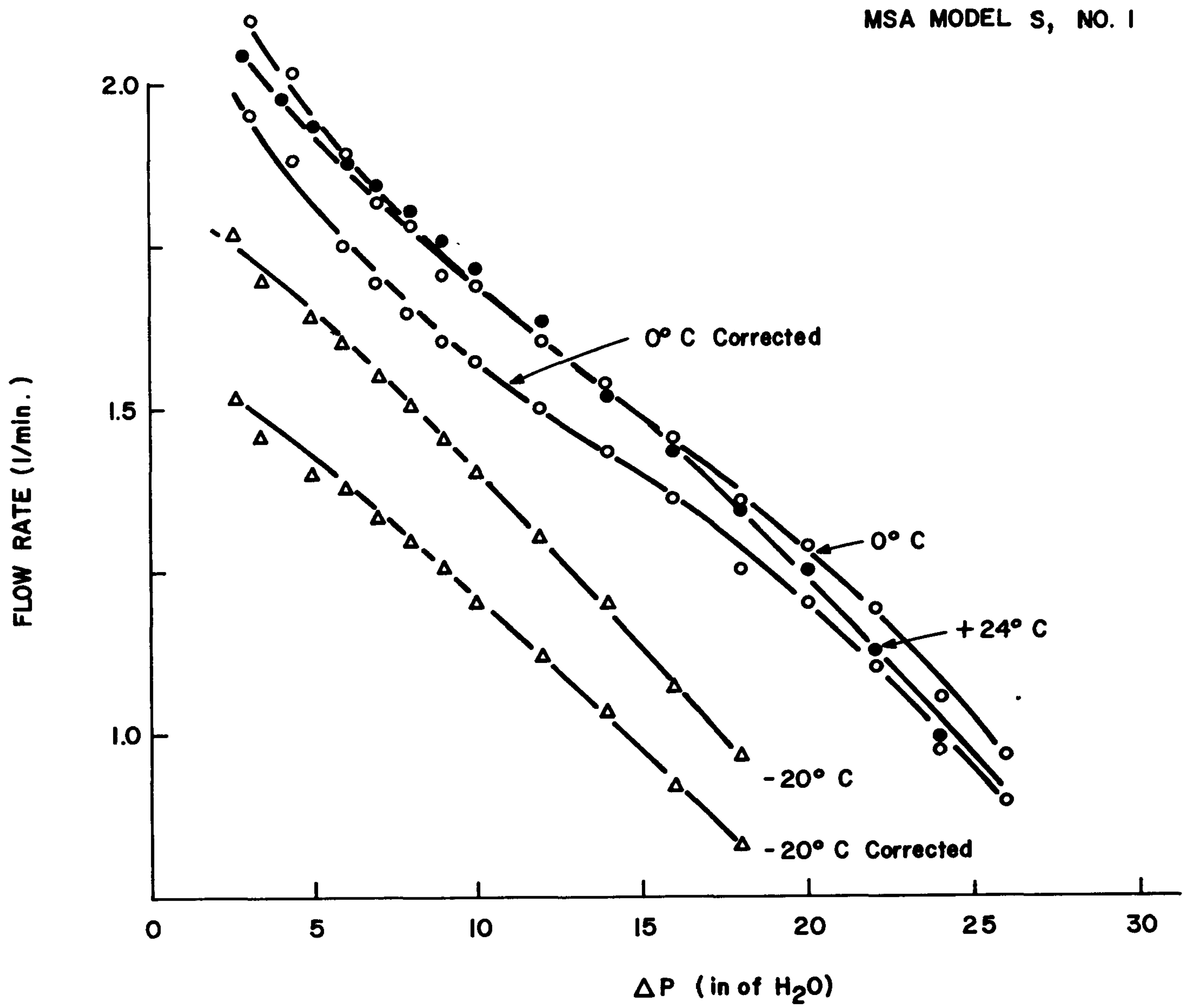

Figure 25 Flow Rate Versus Pressure Differential, Model S, No. 1

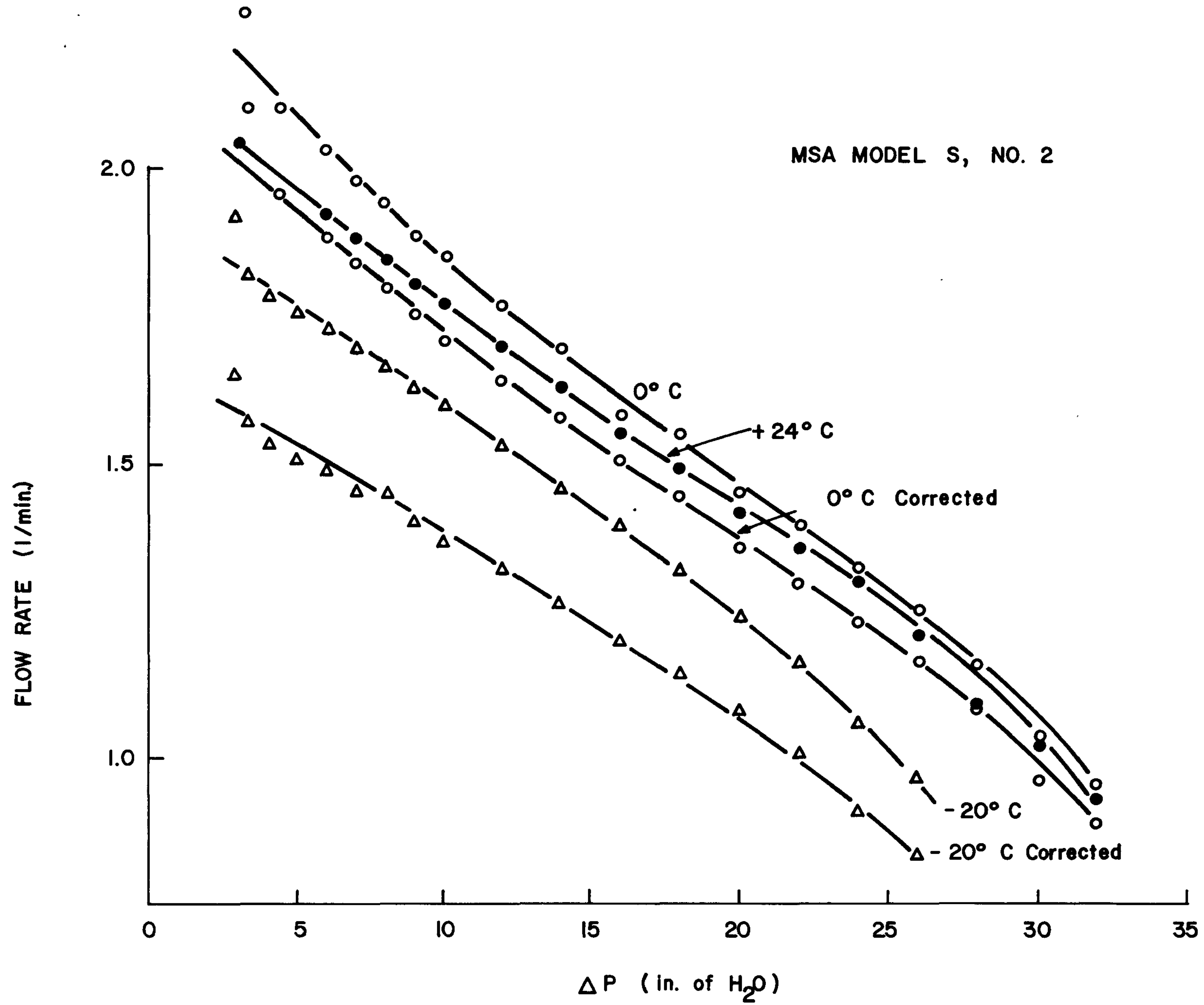

Figure 26 Flow Rate Versus Pressure Differential, Model S, No. 2

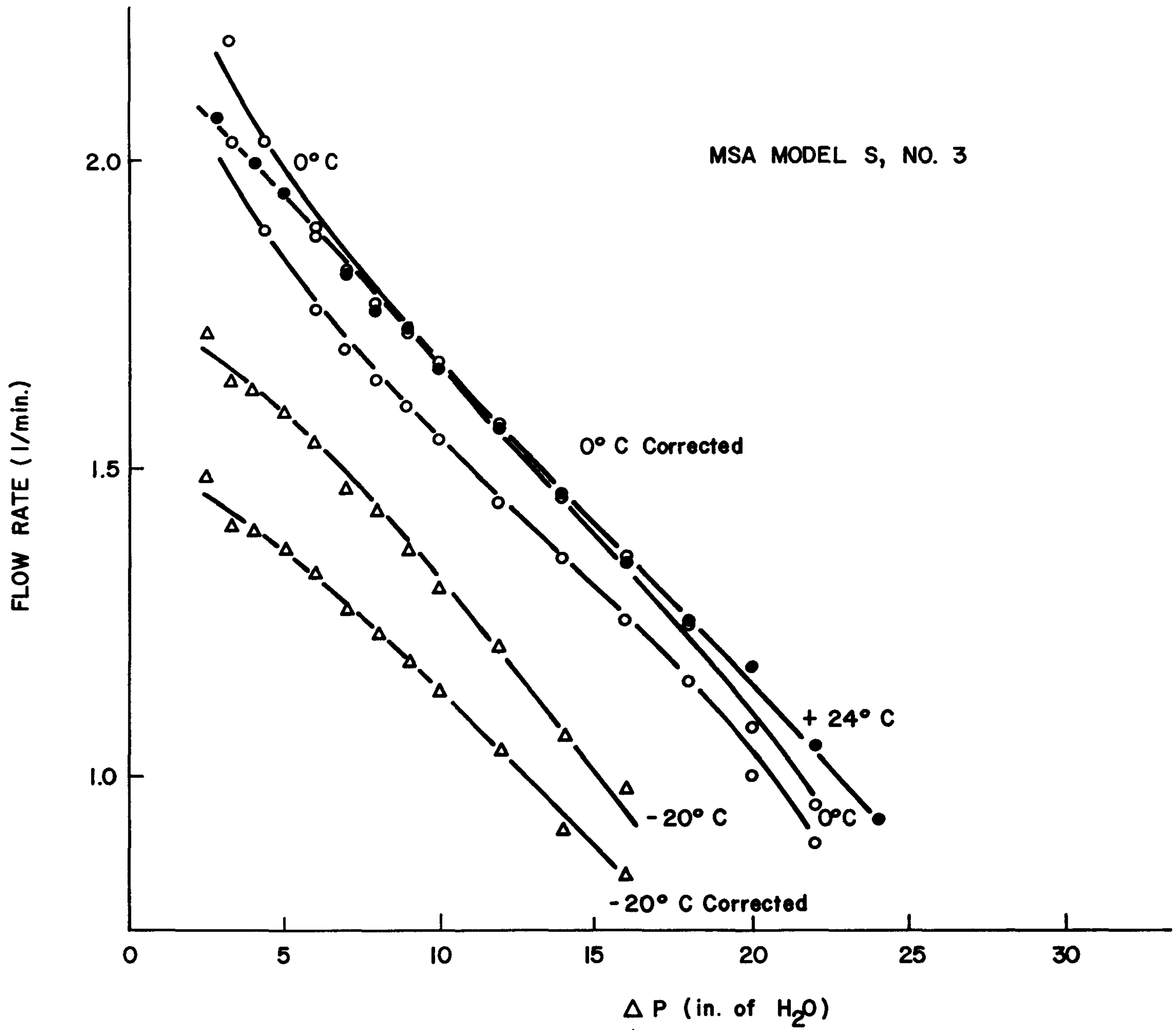

Figure 27 Flow Rate Versus Pressure Differential, Model S, No. 3

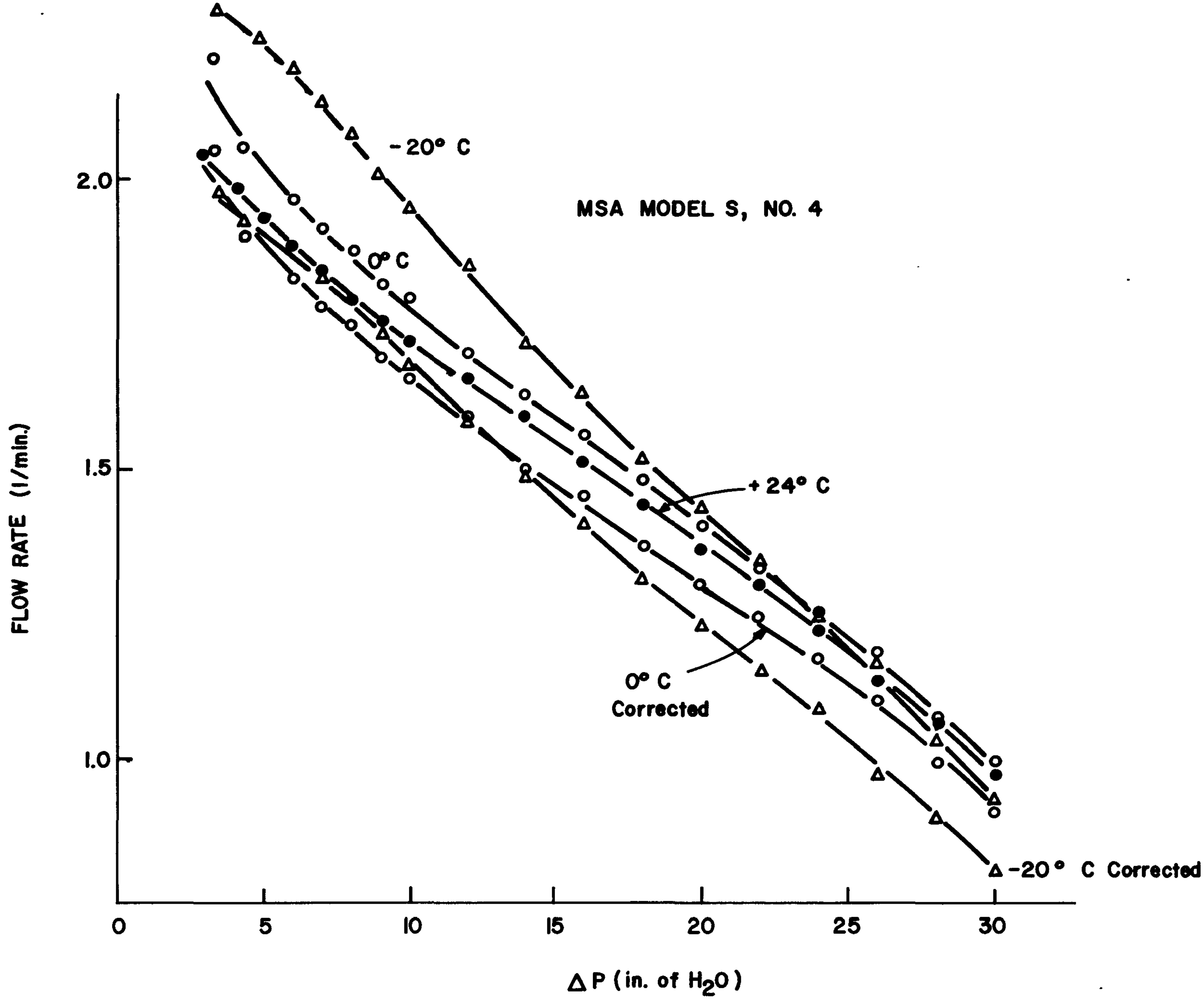

Figure 28 Flow Rate Versus Pressure Differential, Model S, No. 4

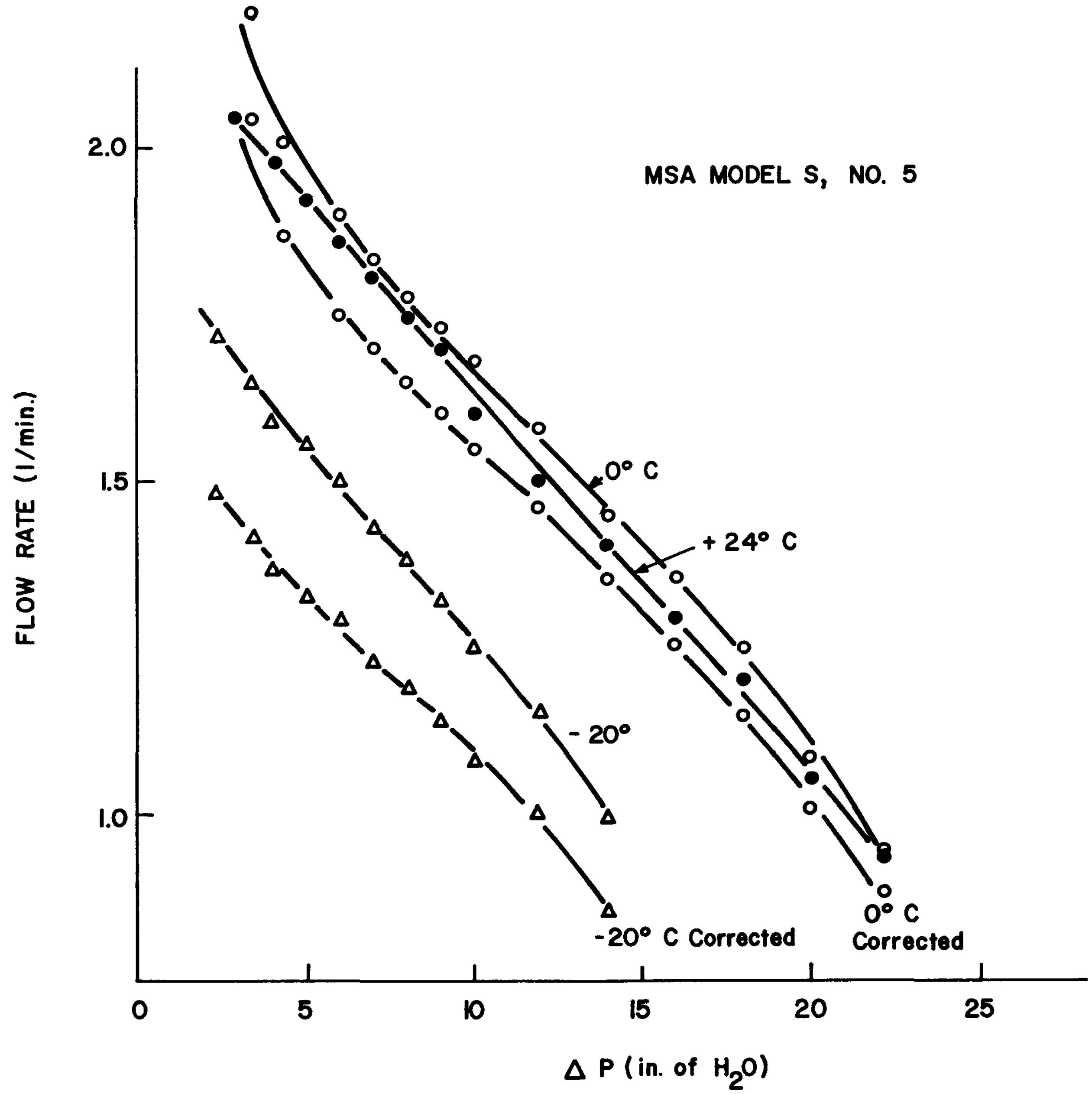

Figure 29 Flow Rate Versus Pressure Differential, Model S, No. 5

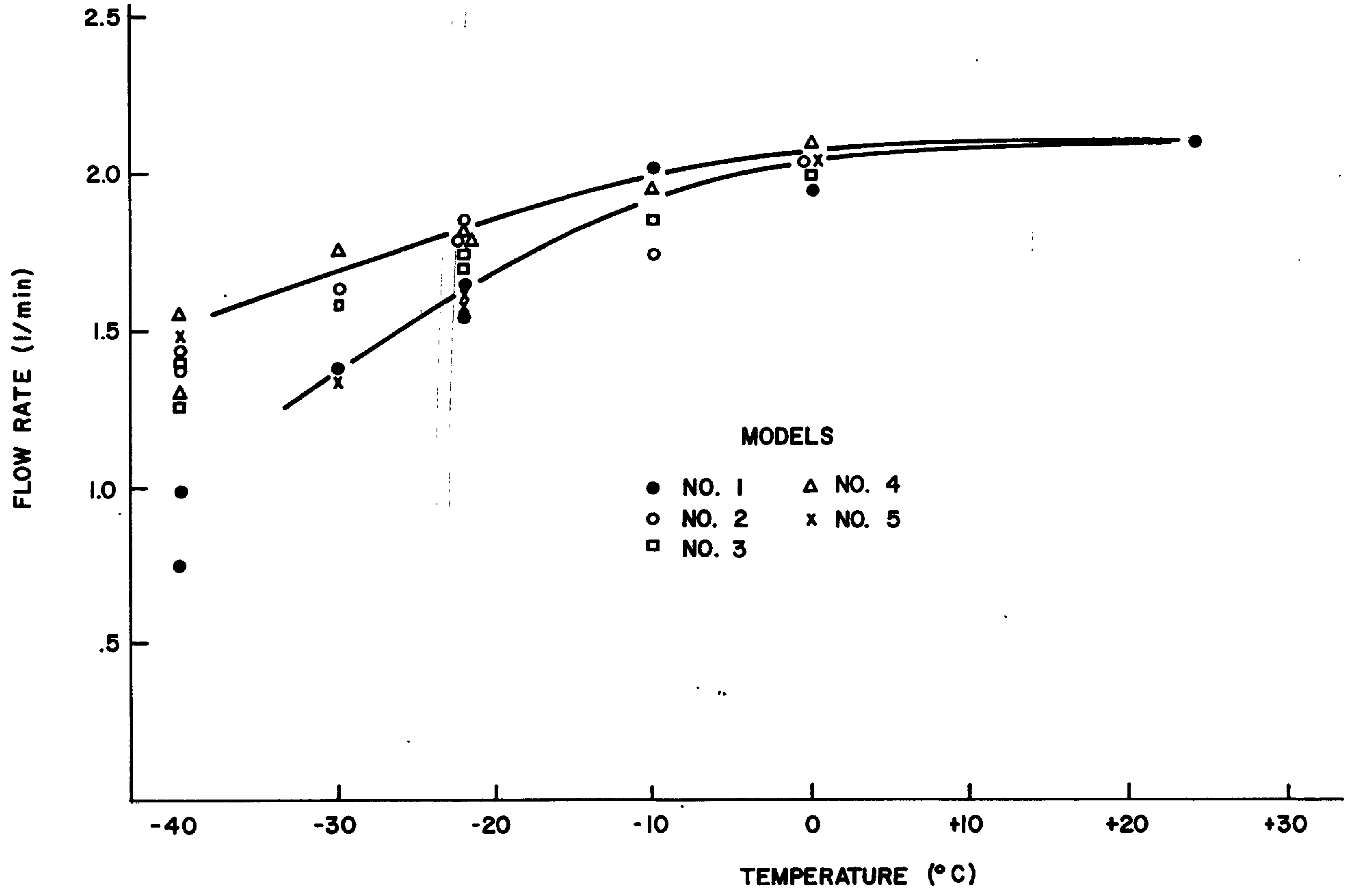

Figure 30 Flow Rate as a Function of Temperature, Model S

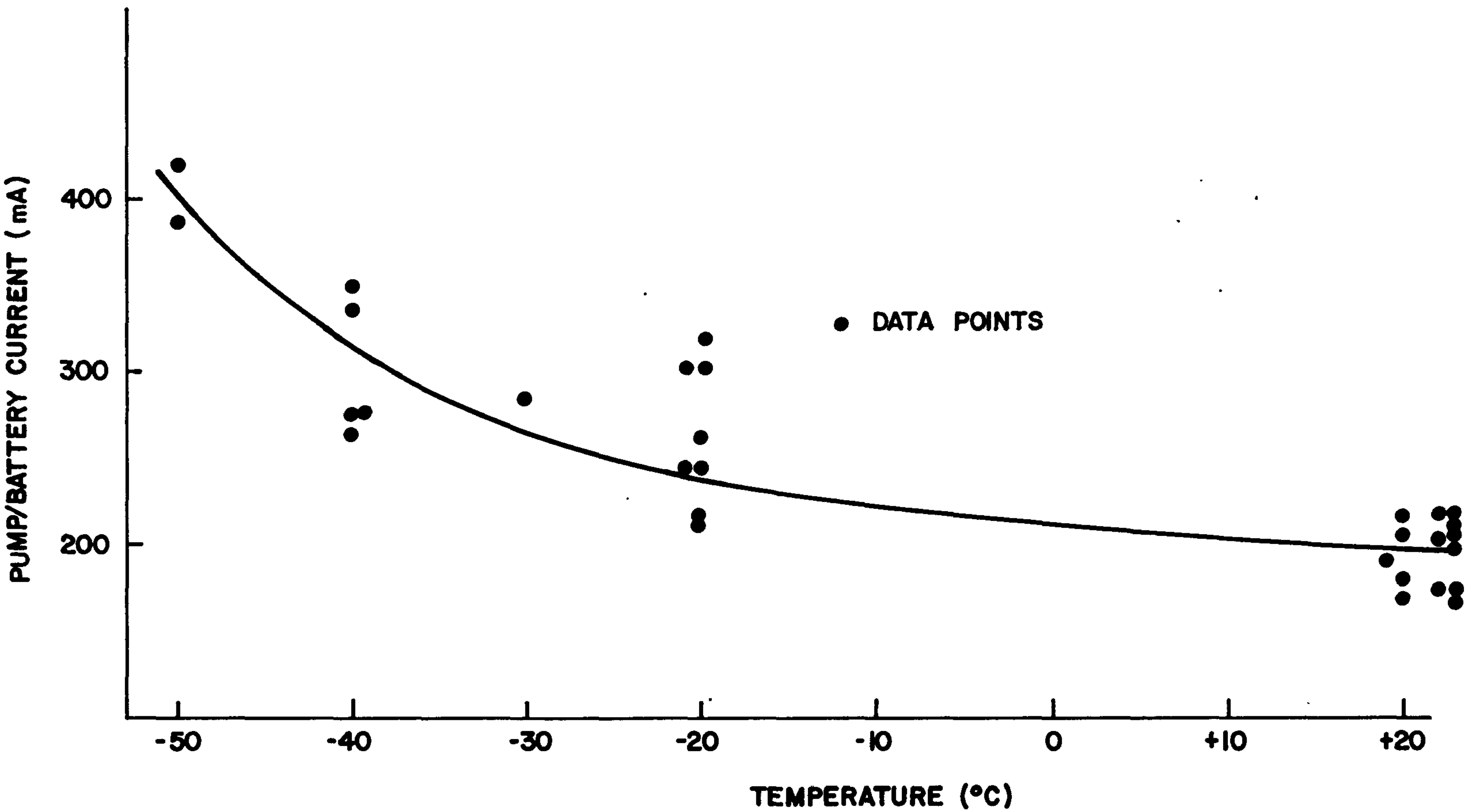

Figure 31 Pump/Battery Currents in the MSA Model S Units

Battery Performance--
The battery packs for the Model S units were identical and interchangeable with the battery packs in the Model G units. The general discussion of Ni-Cd batteries included in the preceding section on the Model G battery performance is equally valid for the Model S units. Figure 31 shows the pump/battery currents observed in the Model S units as a function of temperature. These results are almost identical to the results observed and plotted in Figure 17 for the Model G units.

Diaphragm Reliability, Bearing Design, Lubricants, and Case Ruggedness--
The diaphragms, bearings, lubricants, and cases of the Model S units are apparently identical to those of the Model G and the same conclusions apply. There is no evidence of diaphragm or bearing unreliability. Clearly, either could contribute to the increased current demand at low temperatures and it is likely that the lubricant characteristics contribute significantly. These aspects of the pumps were not explicitly measured. No significant case damage was observed other than the very slight crazing on the pump housing and a slight crack at one of the battery pack screws. The latter was very likely due to over-torquing on the part of RTI.

RAC Model 2392PS

A single RAC personal sampling pump was available for the evaluation program. This unit has a MESA approval for use in methane-air mixtures and is configured for use as a 2ℓ/min pump, e.g., it has a rotometer calibrated between 1.6 and 2.0 ℓ/min with a resolution of about 0.1ℓ/min. Consequently, it was tested similarly to the CMDPSU units. The RAC unit also has a similar series arrangement of rotometer, control valve, damper, and pump as the CMDPSU units. Figure 32 is a photograph of the RAC unit.

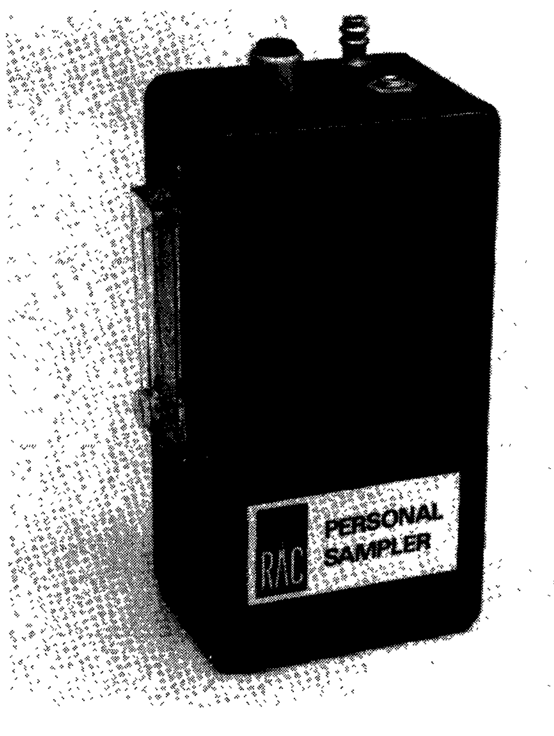

Figure 32 Photograph of the RAC Unit

Flow Rate Stability with Time--
Figure 33 is a plot of the measured flow rate corrected for the temperature difference between room temperature and the test temperature for the RAC unit as a function of both time and temperature. As illustrated, the room temperature performance was excellent. At 0°C, the flow rate was significantly reduced but was stable over the 8-hour period. The flow rate was about 1.55ℓ /min at room temperature which corresponds to 1.43ℓ /min at 0°C. At -10°C, its performance was marginal and both a flow rate adjustment and a power supply substitution was made in an attempt to maintain a satisfactory flow rate. At low temperatures, flow rate adjustments have little effect on the RAC unit and the power supply substitution was also of marginal value. At -20°C, a flow rate adjustment at 1.5 hours had no effect at all. The pump continued to operate from its battery pack at about 1.4ℓ /min (measured at room temperature) for about 5.5 hours. At -30°C, the flow rate was adjusted to a maximum and a power supply was substituted for the battery pack after 1.5 hours; thus, a flow of about 1.2ℓ/min measured at room temperature was maintained. This corresponds to about 1.01ℓ/min at -30°C.

At -50°C the RAC failed to pump after 0.5 hours. An examination revealed that a push rod-socket interface coupling the motor to the pump had separated, probably because the flexible socket was excessively stiff at -50°C. Normal operation was restored by simply reinserting the push rod in the socket. It was also observed that the two halves of a rubber pulsation damper had partially separated and leaked. There were no further tests run on the RAC unit.

The flow adjustment on the RAC unit is best described as a pinch or clamp mechanism that clamps and restricts the sample flow tubing. At low temperatures the tubing tends to remain "set" and releasing the clamp mechanism does not provide positive control over the flow.

Flow Rate/Pressure Drop Characteristics--
Figure 34 is a plot of the flow rate of the RAC unit as a function of the differential pressure across the pump with temperature as a parameter. The pump was initially adjusted for a flow of 2ℓ/min at 4 inches of water at 21°C. It was equilibrated, non-operating, at each test temperature for about 1.5 hours. After equilibrating, the pump was started and a set of data acquired corresponding to the test temperature. This procedure was repeated for other test temperatures.

The data in Figure 34 includes the 21°, 0°, -10°, and -20°C curves. Curves corresponding to both the measured flow rates (measured at room temperature) and curves corrected to correspond to the test temperatures are included.

Reliability of Calibration over Temperature--
The reliability of calibration of the RAC unit as a function of temperature is illustrated in Figure 35. These data were acquired as described previously, i.e., these are the 1.5 hour data points from the flow rate stability experiments. The data points show flow rate degradations from the calibration

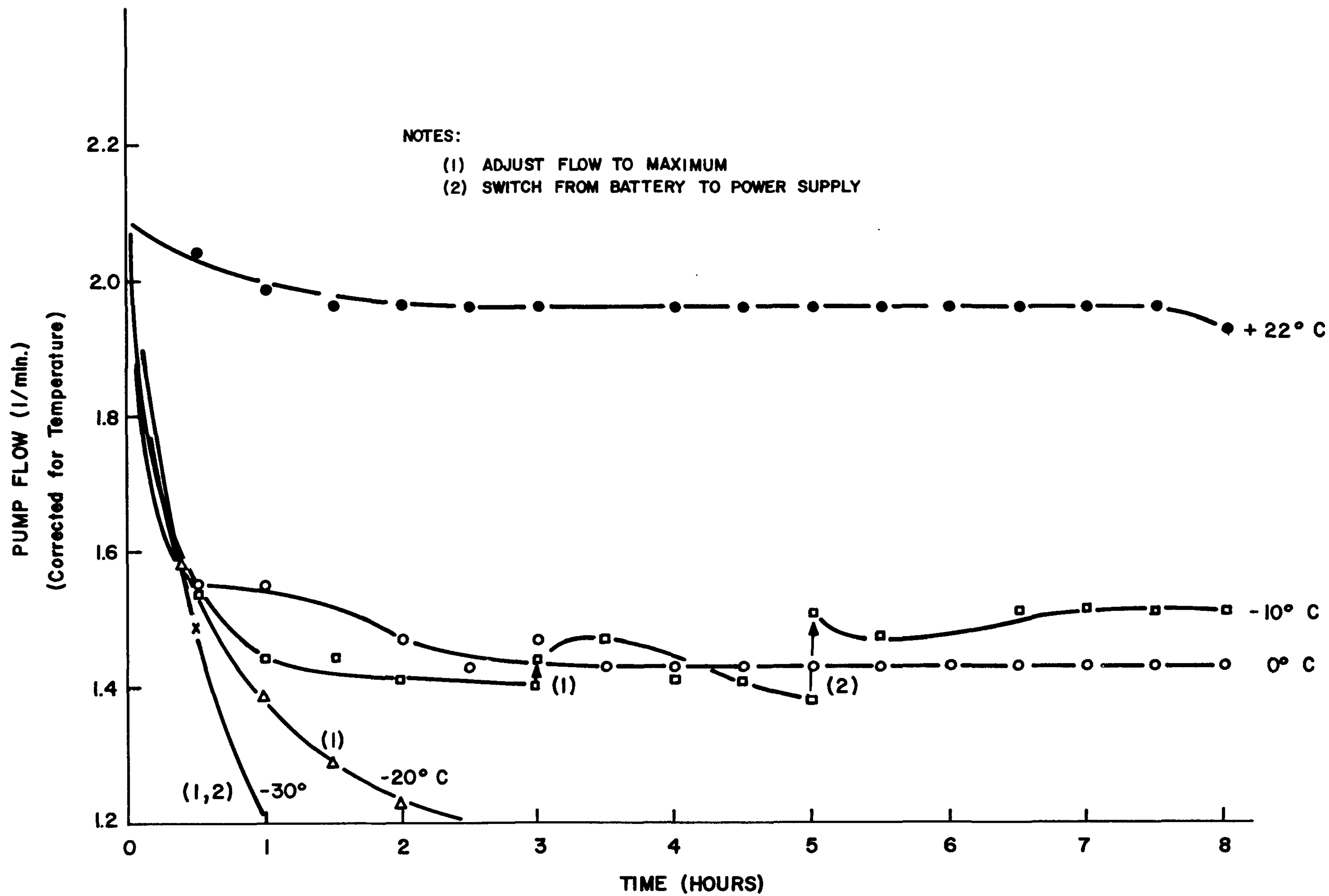

Figure 33 Flow Rate Stability, Corrected for Temperature, RAC Model 2392-PS

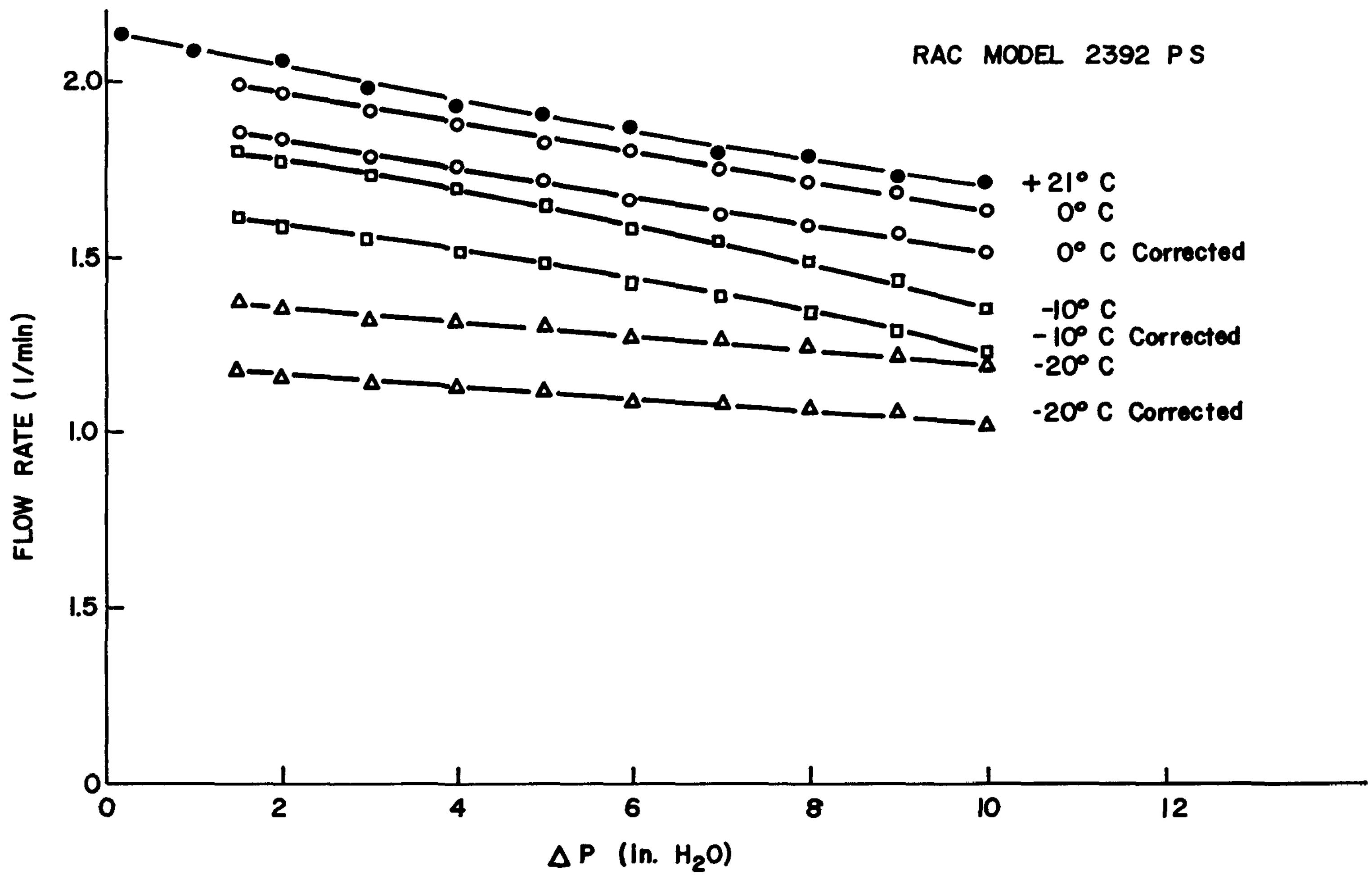

Figure 34 Flow Rate Pressure Differential, RAC Model 2392-PS

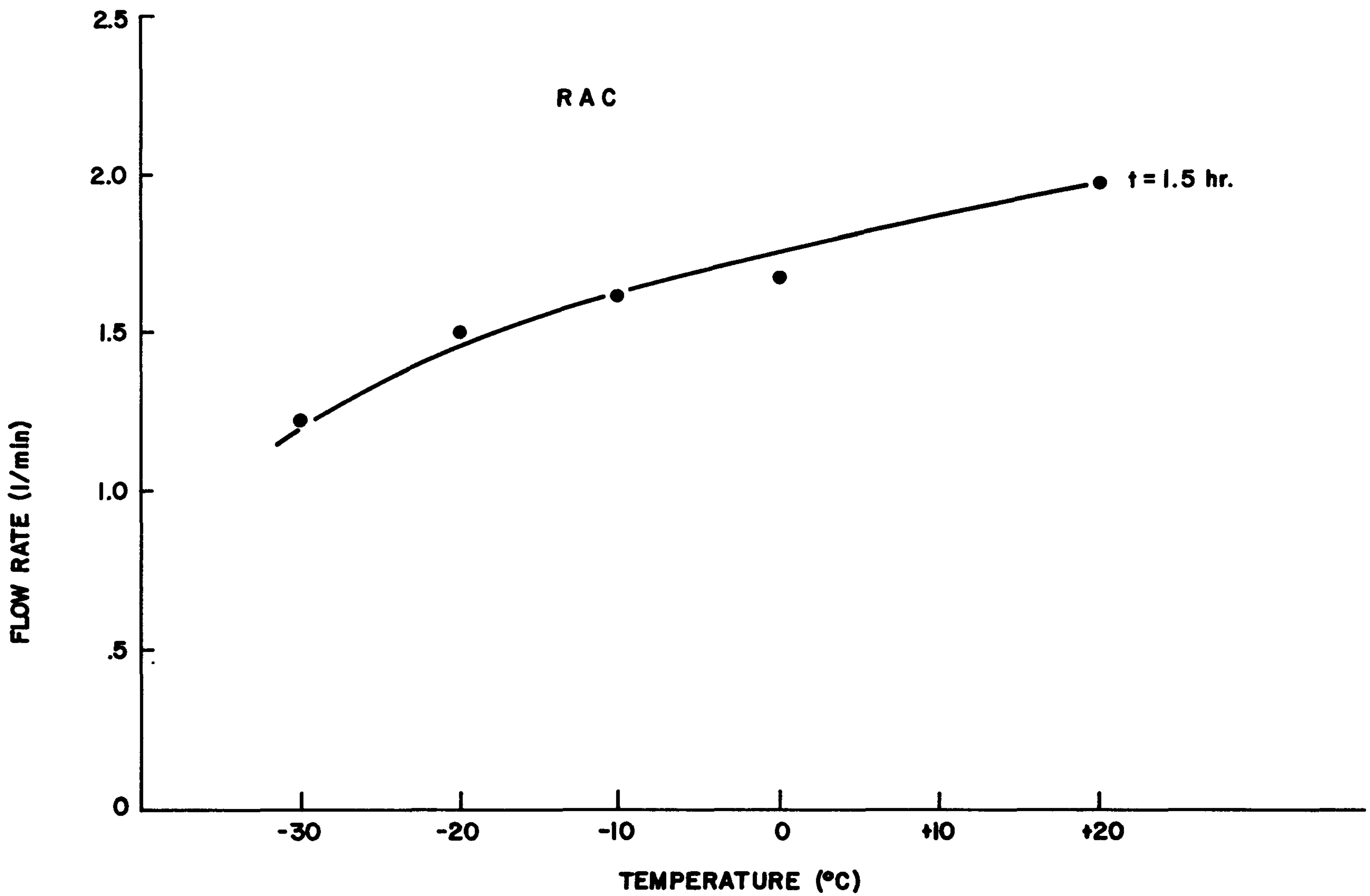

Figure 35 Flow Rate Calibration as a Function of Temperature, RAC Model 2392-PS

point (t=0) of 20, 23, 28, and 42 percent at 0°, -10°, -20°, and -30°C, respectively.

Continuously Sample Cold Air--
In addition to the operations for the acquisition of experimental data, the RAC unit was operated for only one 8 hour period at -20°C. It was not operating at the end of 8 hours. The -20°C flow rate stability data shows reasonable performance for about 5.5 hours and the motor was inoperative at 7 hours. From these and other data, we conclude the pump is not suitable for continuously pumping -20°C air for 8-hour increments.

Ease of Recalibration--
The flow rate adjustment on the RAC unit is a pinch or clamp mechanism that restricts the tubing that carries the sample from the rotometer to the damper and pump. The flexible sample tubing passes through this clamp assembly which acts to restrict the tubing. The degree of restriction is controlled by a screwdriver setting. At low temperatures the tubing tends to take a "set" and subsequent flow rate adjustments tend to be ineffective.

Battery Performance--
Batteries in the RAC unit are contained in a molded housing and are not accessible. From the housing size and open circuit voltage, one can conclude that the battery pack consists of three size C Ni-Cd cells. Pump currents were not measured; however, when a power supply was substituted for the battery pack at -10°C (after 5 hours), -30°C (after 1.5 hours), and -50°C (after 0.5 hours), the terminal voltage was greater than 1.2 volts per cell (assuming 3 cells) in every instance. It is significant that the substitution of the power supply did not restore the desired performance. Thus, while the battery pack is probably inadequate to provide the desired performance at low temperatures, it is not the principal limiting factor.

Diaphragm Reliability and Bearing Design--
A subjective assessment of the diaphragm reliability suggests that exposure and operation at low temperatures can be tolerated. There is no evidence of diaphragm failure nor is there any evidence of problems with the motor bearings during these evaluations.

Lubricants--
There was no evaluation of the bearing lubricant. It is a likely source of pump loading at low temperatures.

Case Ruggedness--
Except for the separated pulsation damper, there is no evidence of damage to any component in the RAC personal sampling pump.

MSA Model C-200

The MSA Model C-200 personal sampling pump is designed for a flow range of 25 to 200 ml/min through a flow resistance of up to 2.5 in. of H_2O. Five units were provided for the evaluation program. These were adjusted by the manufacturer for a flow rate of 200 ml/min at 1.5 inches of H_2O and most tests were conducted at this setting. The pump incorporates a counter which indicates the number of pump strokes and, thus, the volume of air pumped. Figure 36 is a photograph showing two of the C-200's. A small mercury battery evident in Figure 36 is used in the C-200 in a voltage regulating circuit. It was removed from the pump for testing purposes.

Flow Rate Stability with Time--

Without altering the flow rate adjustment of the C-200's as received from the manufacturer, these pumps were operated for 8 hours against a flow restriction of 1.5 inches of H_2O at several test temperatures. The results of these tests are plotted in Figures 37 through 41. These curves show generally excellent performances at room temperature and good performances at -2°C. At -10°C the performances are mixed, i.e., some are marginal and some are unsatisfactory. In no instances were the performances acceptable at lower temperatures.

It is important to note that the flow rate data plotted in Figures 37 through 41 are corrected for temperature, i.e., the flow rates were measured at room temperature and multiplied by the ratio of the absolute test temperature to the absolute room temperature before plotting. During these tests a flow rate

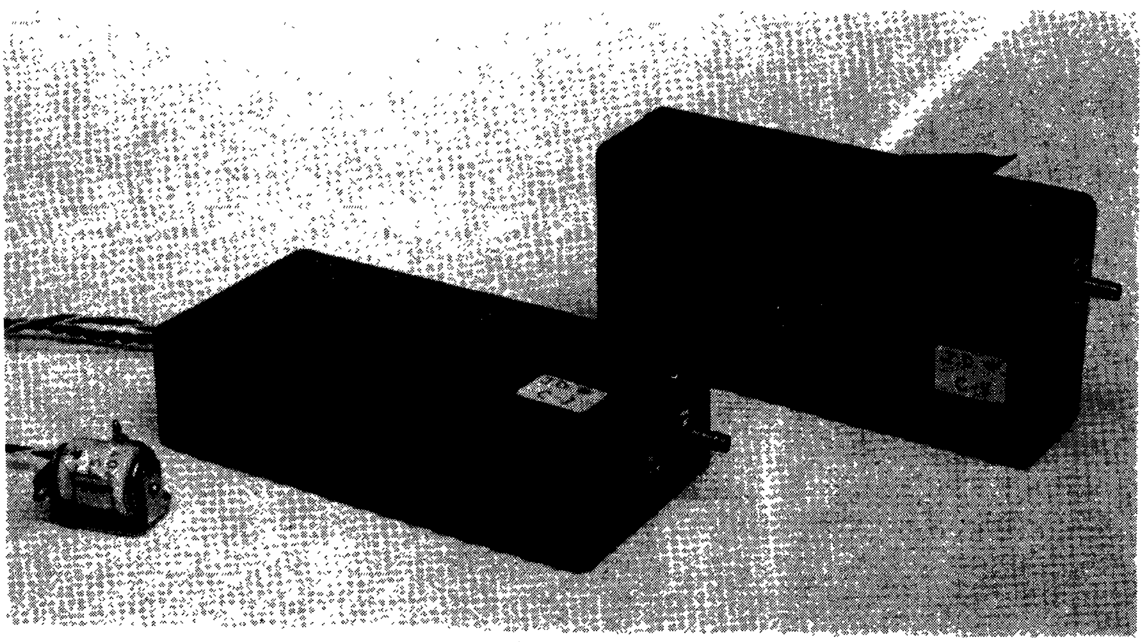

Figure 36 Photograph of the MSA Model C-200

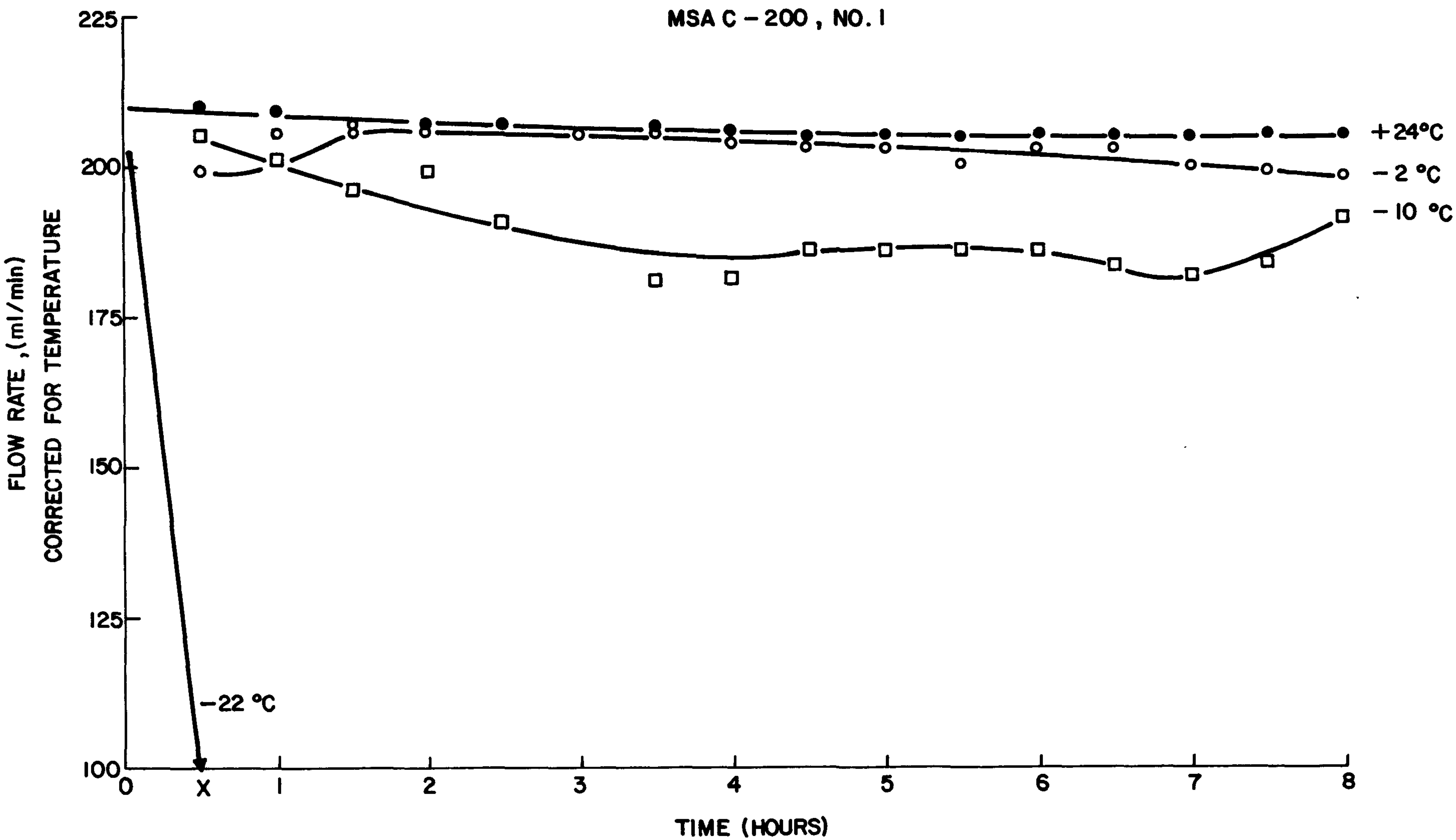

Figure 37 Flow Rate Stability, Corrected for Temperature, Model C-200, No. 1

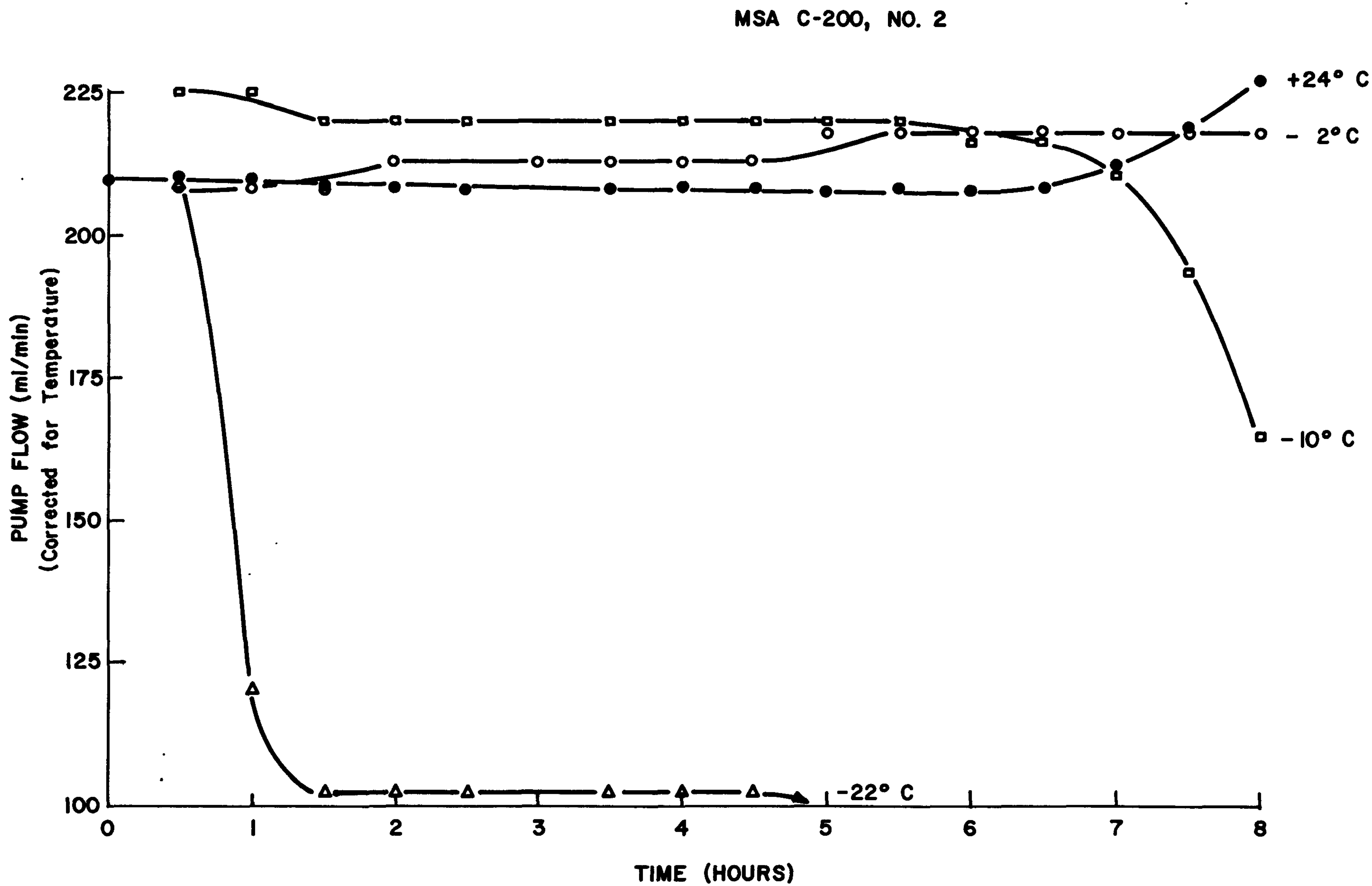

Figure 38 Flow Rate Stability, Corrected for Temperature, Model C-200, No. 2

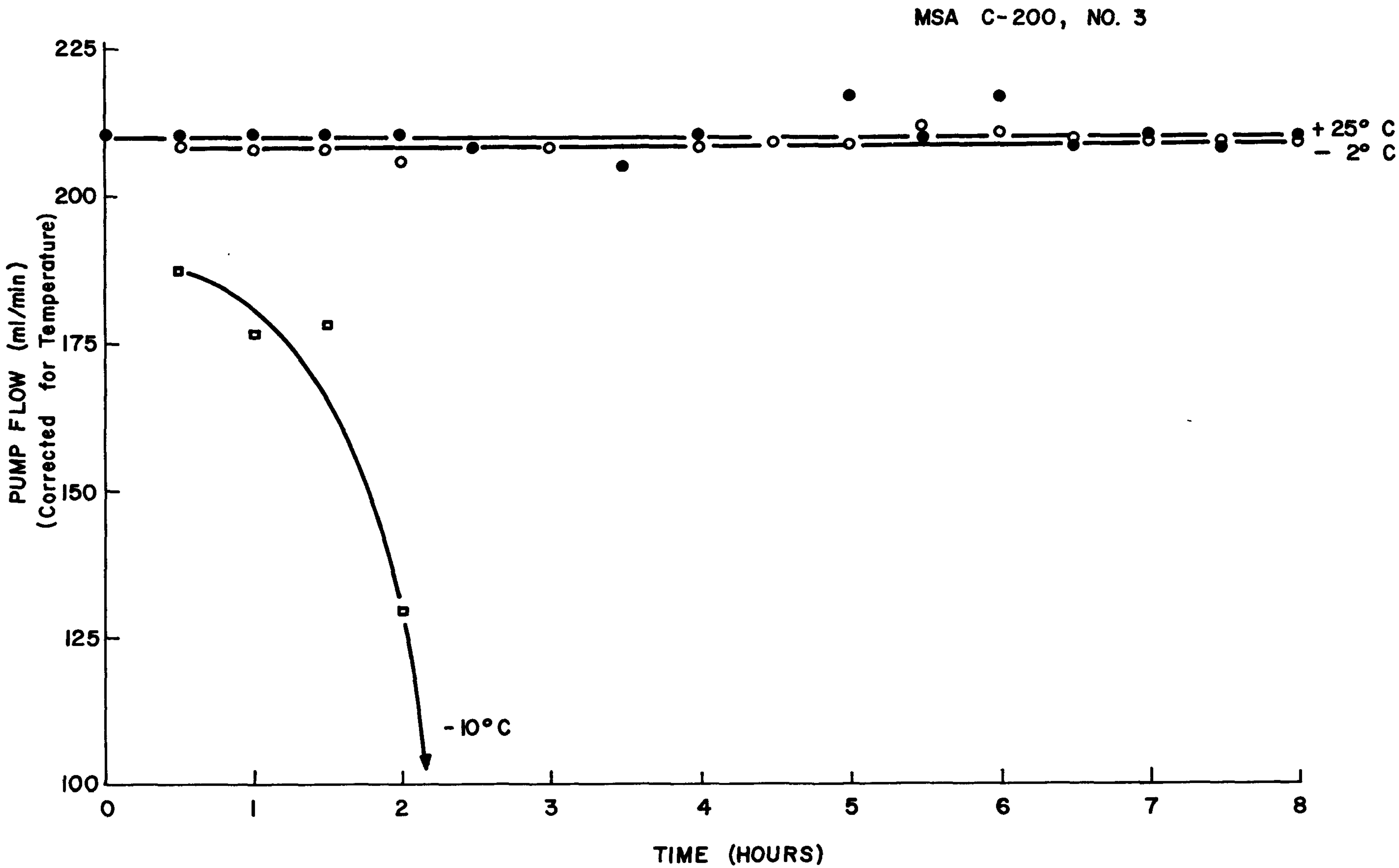

Figure 39 Flow Rate Stability, Corrected for Temperature, Model C-200, No. 3

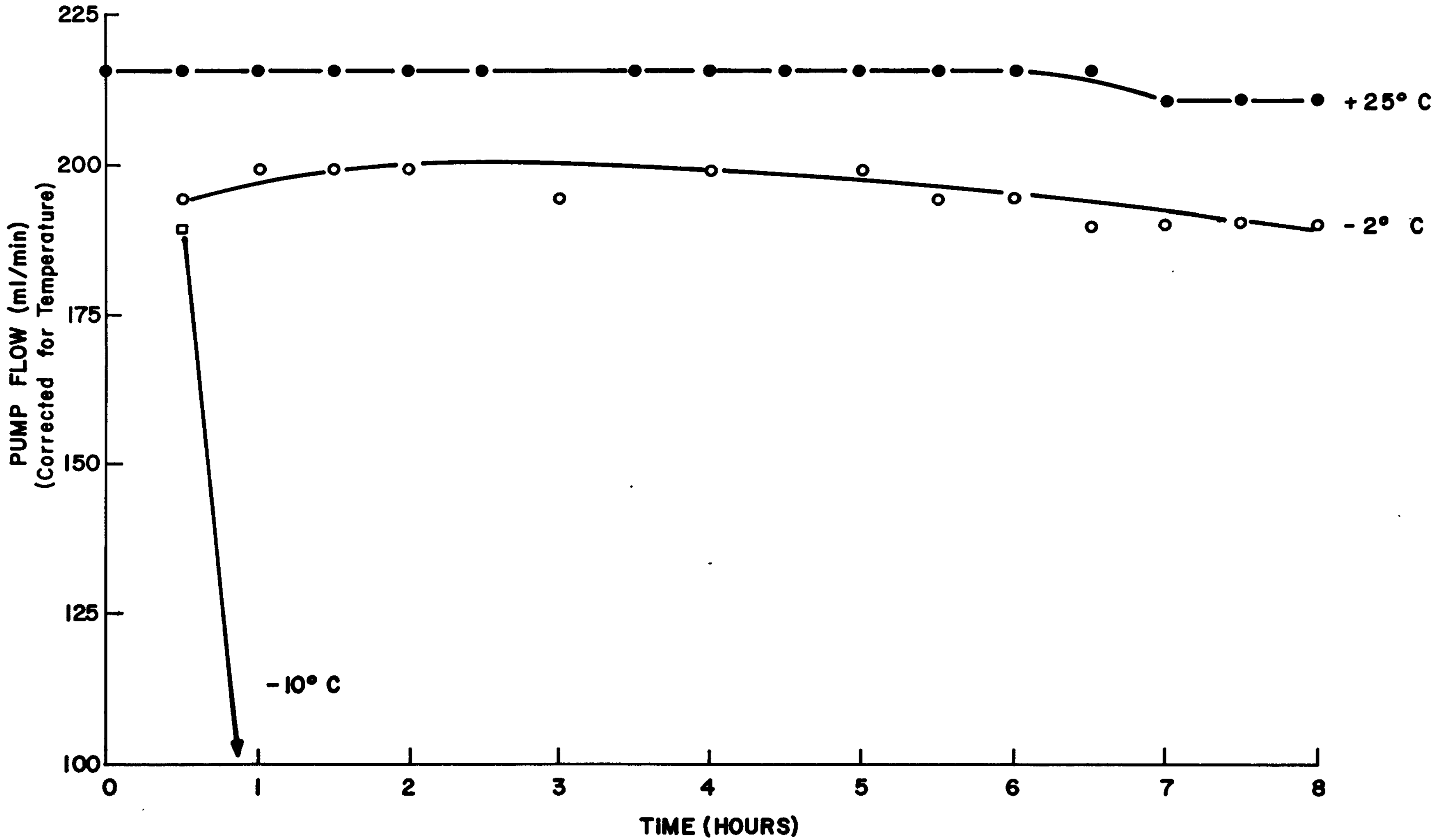

Figure 40 Flow Rate Stability, Corrected for Temperature, Model C-200, No. 4

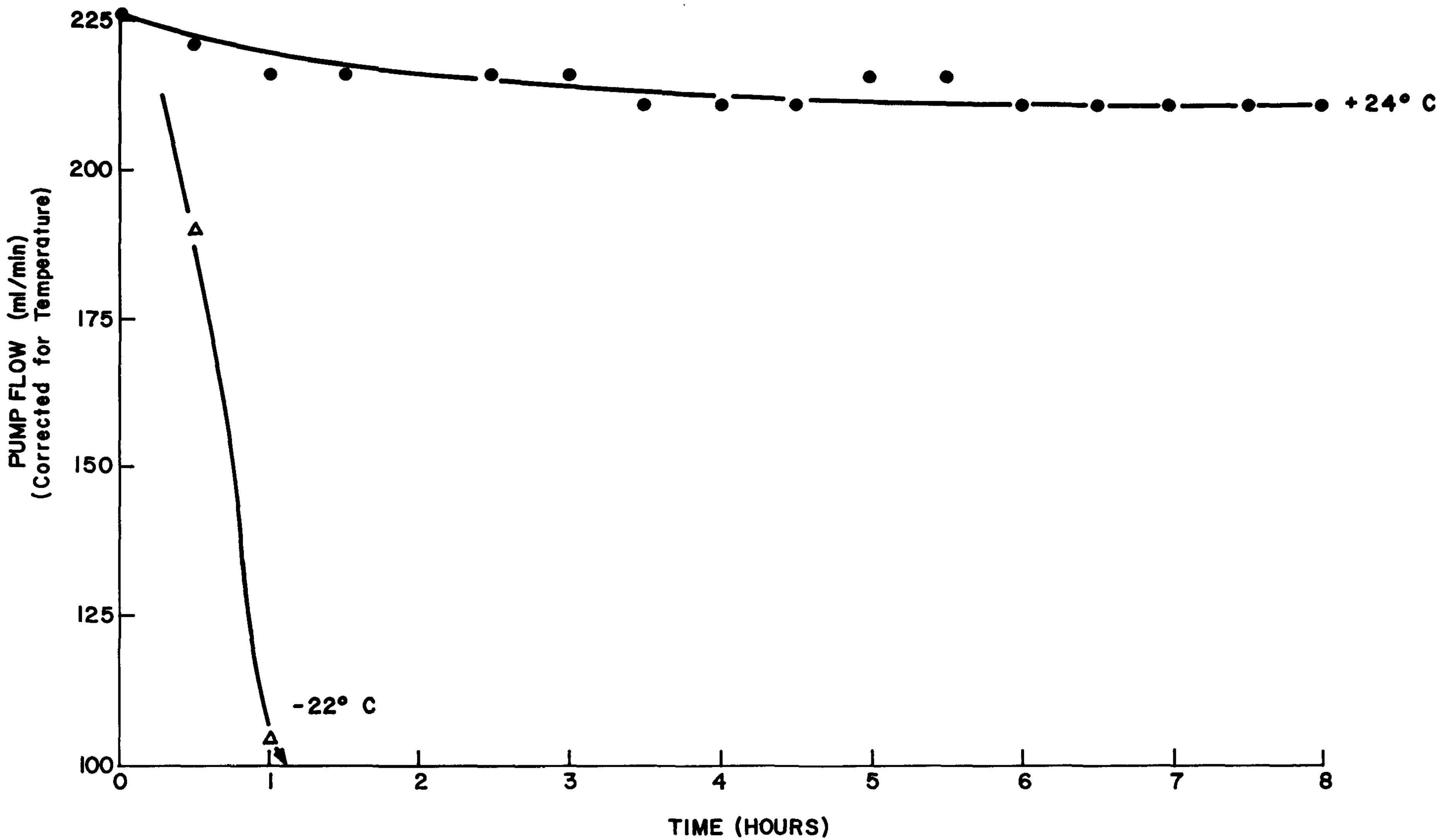

Figure 41 Flow Rate Stability, Corrected for Temperature, Model C-200, No. 5

was also determined by observing each pump's counter for one minute and calculating a flow rate based upon the manufacturer's calibration. (Number counts/minute times ml/count = ml/minute.) The manufacturer's calibration was observed to be very accurate at room temperature and 1.5 inches of H_2O, and corresponded reasonably well with the corrected value at lower temperatures.

A significant factor in the failure of the C-200's to perform satisfactorily at low temperatures is the mercury (Hg) reference cell used in the pump's electronics. Two voltages are available from the Hg cell and these were observed to decrease significantly with a decrease in temperature. In units 3 and 4 at -10°C, for example, the two Hg cell voltages were observed to decrease from about 4.0 and 2.7 volts to 1.7 and 0.4 volts, respectively, in 1 to 2 hours and the pumps stopped operating.

The single size C Ni-Cd cell was demonstrated to be suitable to operate the C-200 at lower temperatures. The Hg reference cell was removed from the No. 1 unit and reconnected to the pump with long wires that facilitated testing the C-200 in the temperature control chamber with the Hg cell at room temperature outside the chamber. The results of these tests are illustrated in Figure 42. (The +24°C data from unit No. 1 are repeated in Figure 42.) The -20° and -30°C data in Figure 42 were acquired with the Hg reference cell at room temperature. Although there is significant degradation in the -20°C data, the pump did operate for 8 hours. During this run the Ni-Cd cell voltage decreased from an open circuit room temperature value of 1.39 volts (1.38 volts driving the pump at room temperature) to 1.23 volts after 8 hours of operation at -20°C. At -30°C the Ni-Cd cell voltage was 1.26volts when the run was terminated after 2 hours. These observations suggest that the Ni-Cd cell was not exhausted and not the principal reason for the unsatisfactory performance.

Flow Rate/Pressure Drop Characteristics--
The flow rate/pressure drop characteristics of the five C-200 pumps are shown in Figures 43 through 47 for room temperature and 0°C. In Figures 43 and 44, the flow rates computed from the counters of units 1 and 2, respectively, are also included. The constant flow rates indicated by the counters show the pump speed to be constant and indicate that a very stable constant flow rate can be anticipated for a given temperature and pressure differential. The measured flow rates at 25° and 0°C are observed to vary reasonably linearly with pressure differential.

Continuously Sample Cold Air--
The C-200 units will not satisfactorily sample cold air at -10°C or below. Their ability to sample 0°C air continuously has not been demonstrated but the experimental results reported herein suggests that it will. There is no evidence to suggest otherwise.

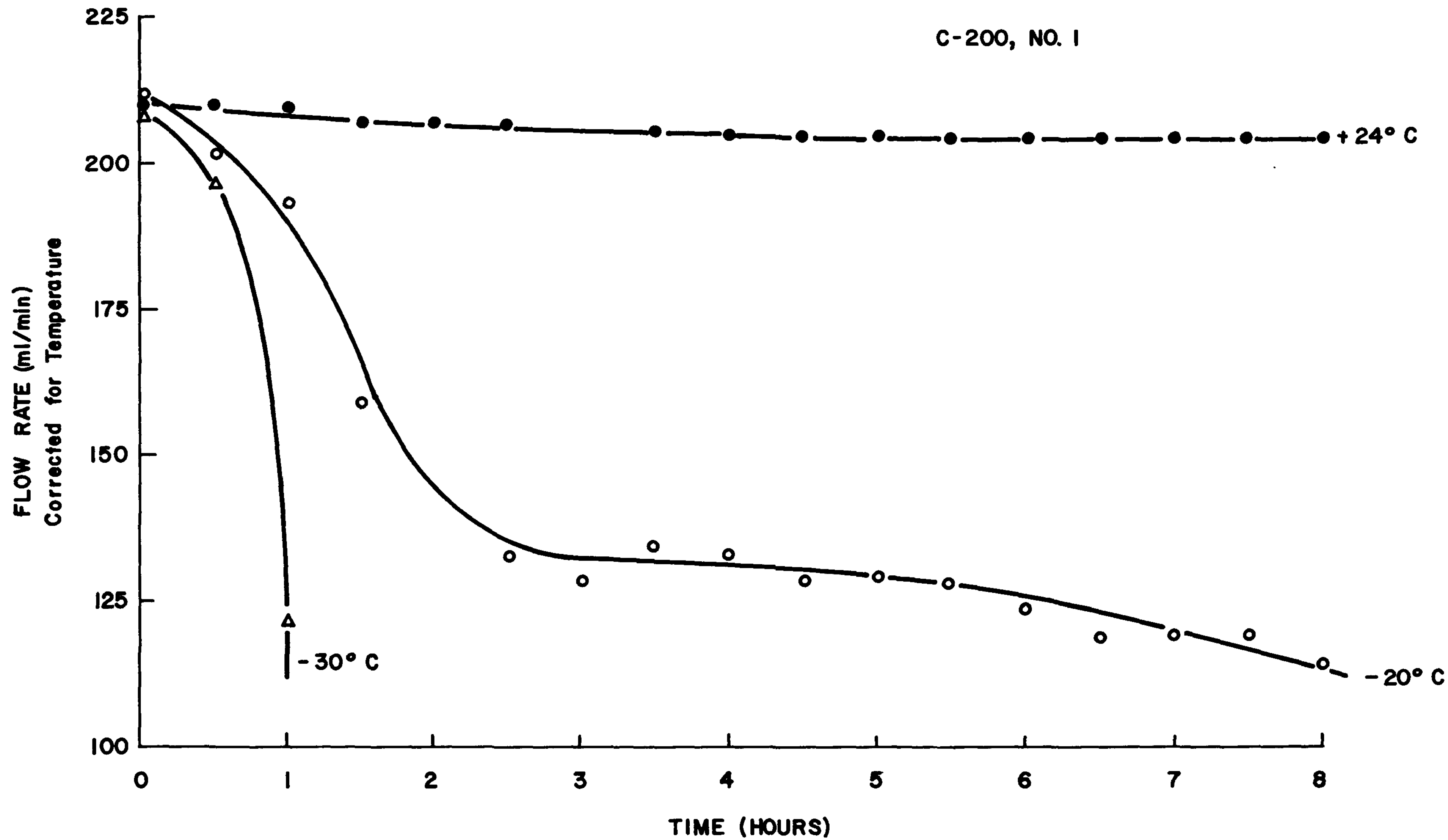

Figure 42 Flow Rate Stability of the C-200 Unit No. 1 with the H_g Cell at Room Temperature

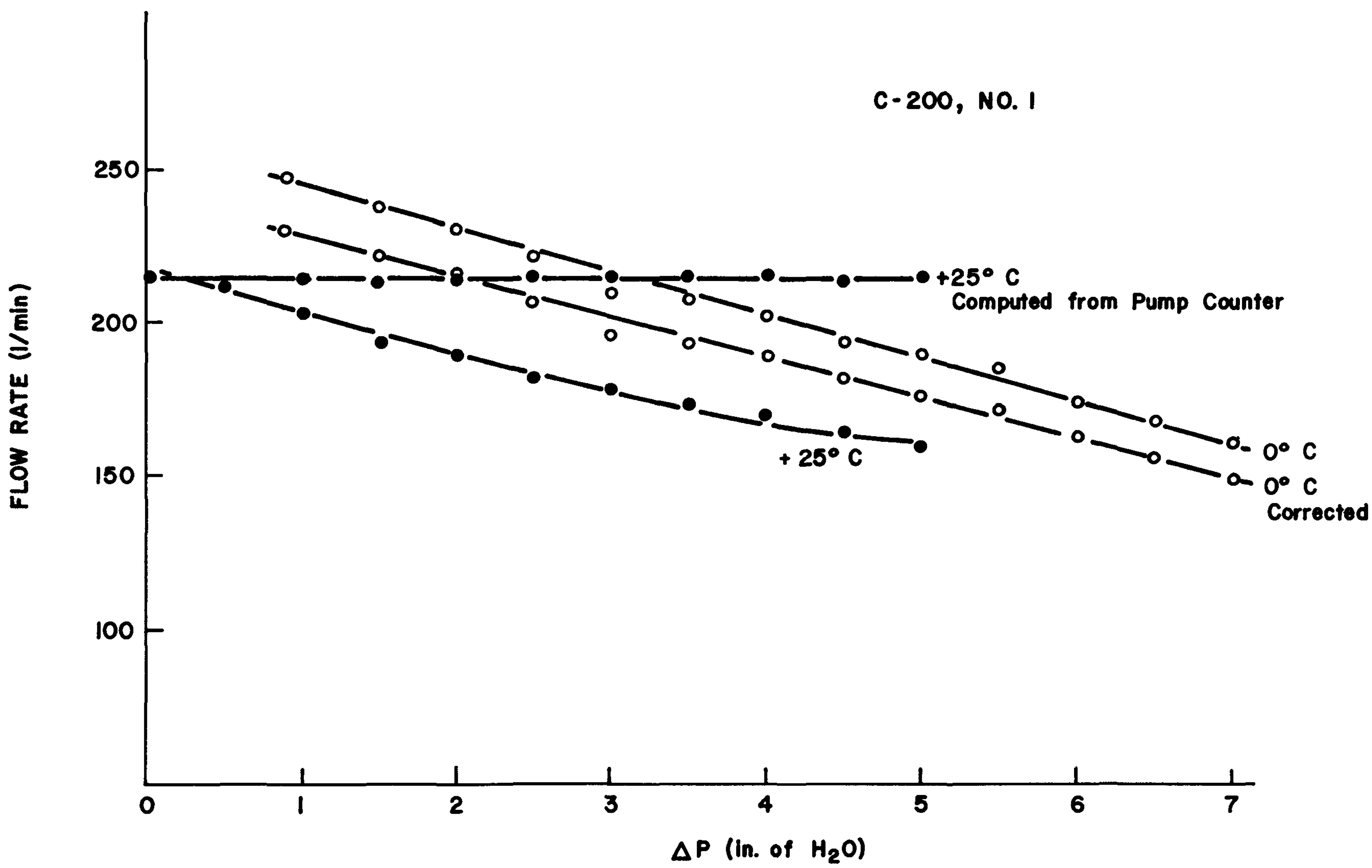

Figure 43 Flow Rate Versus Differential Pressure, Model C-200, No. 1

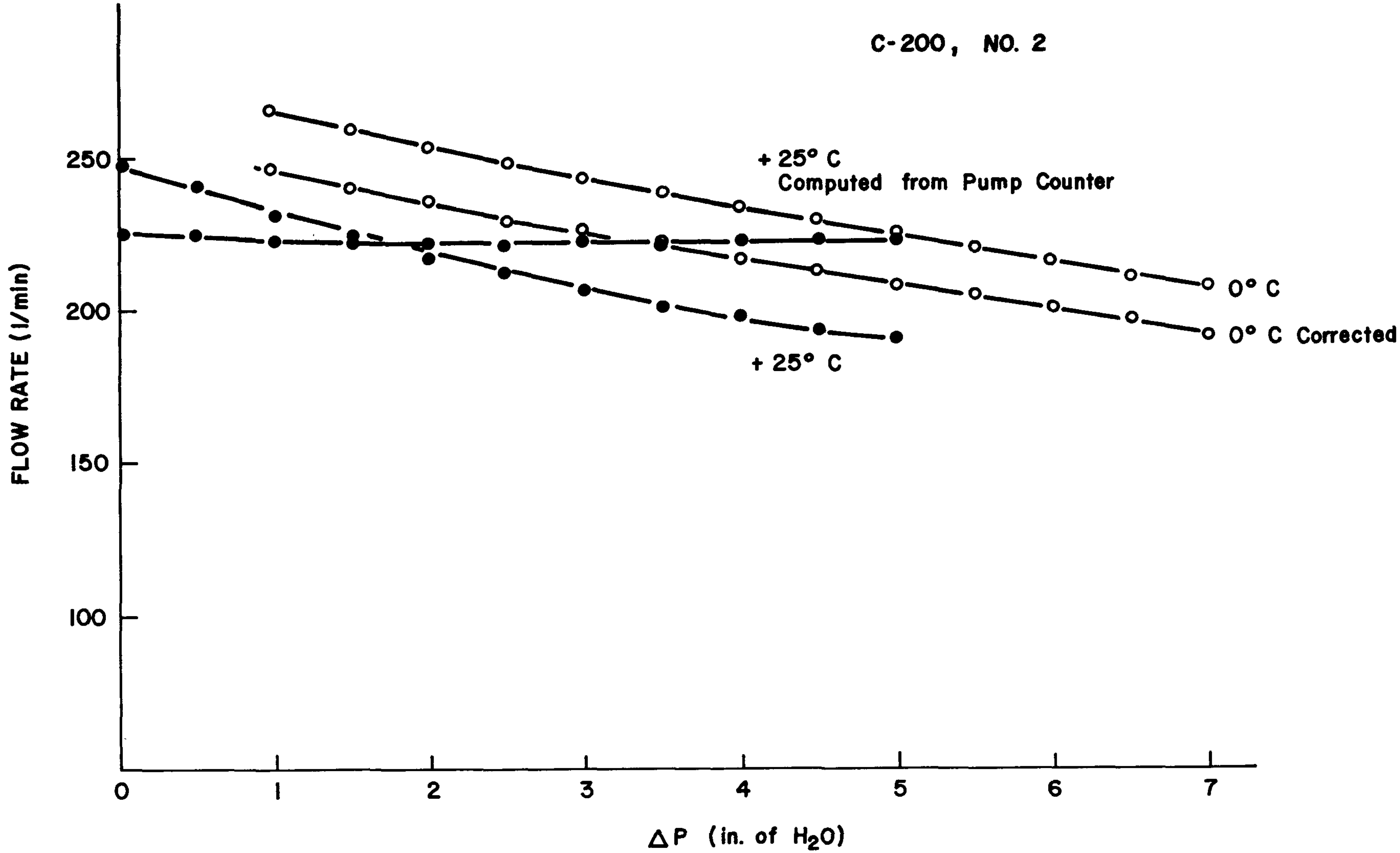

Figure 44 Flow Rate Versus Differential Pressure, Model C-200, No. 2

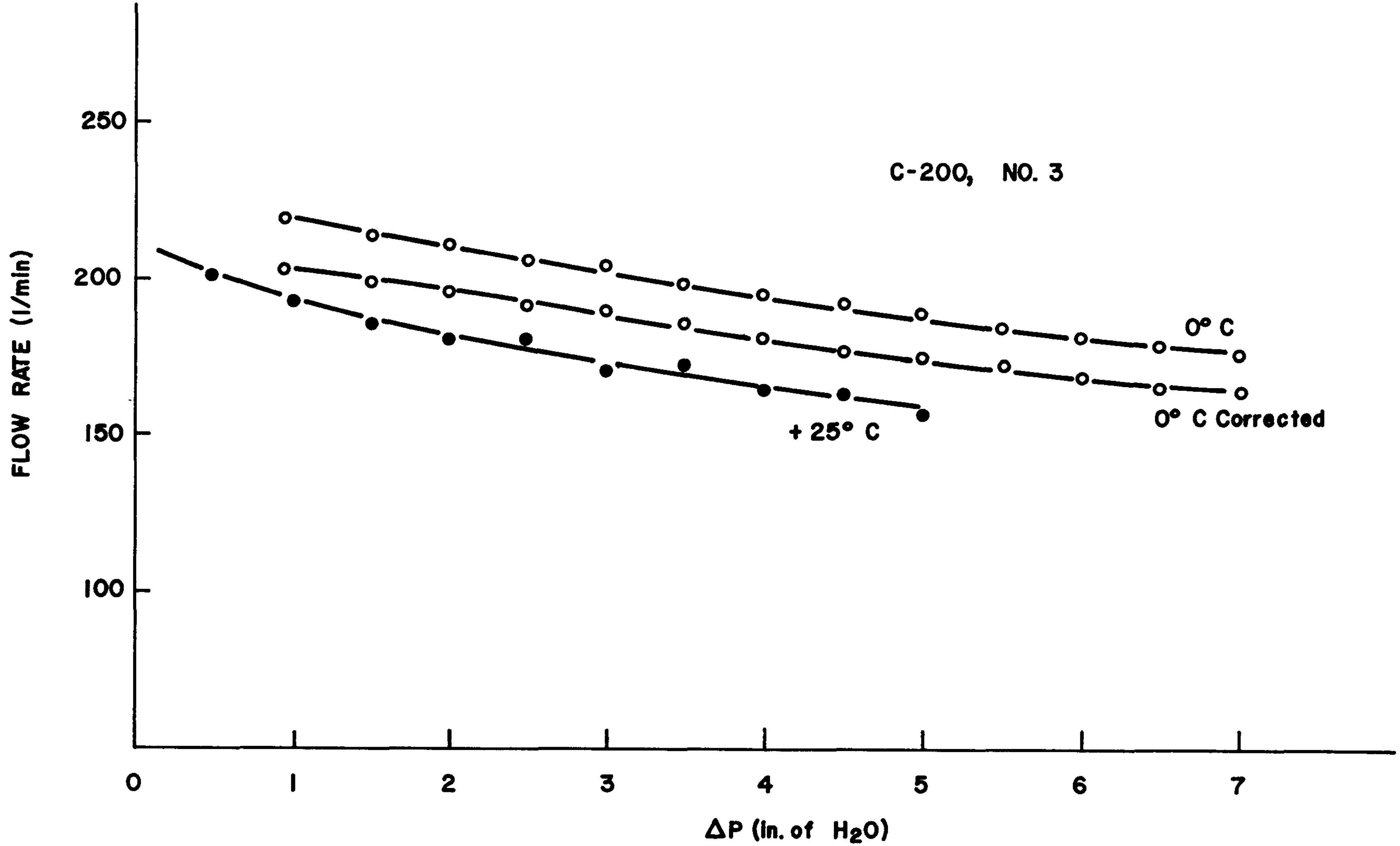

Figure 45 Flow Rate Versus Differential Pressure, Model C-200, No. 3

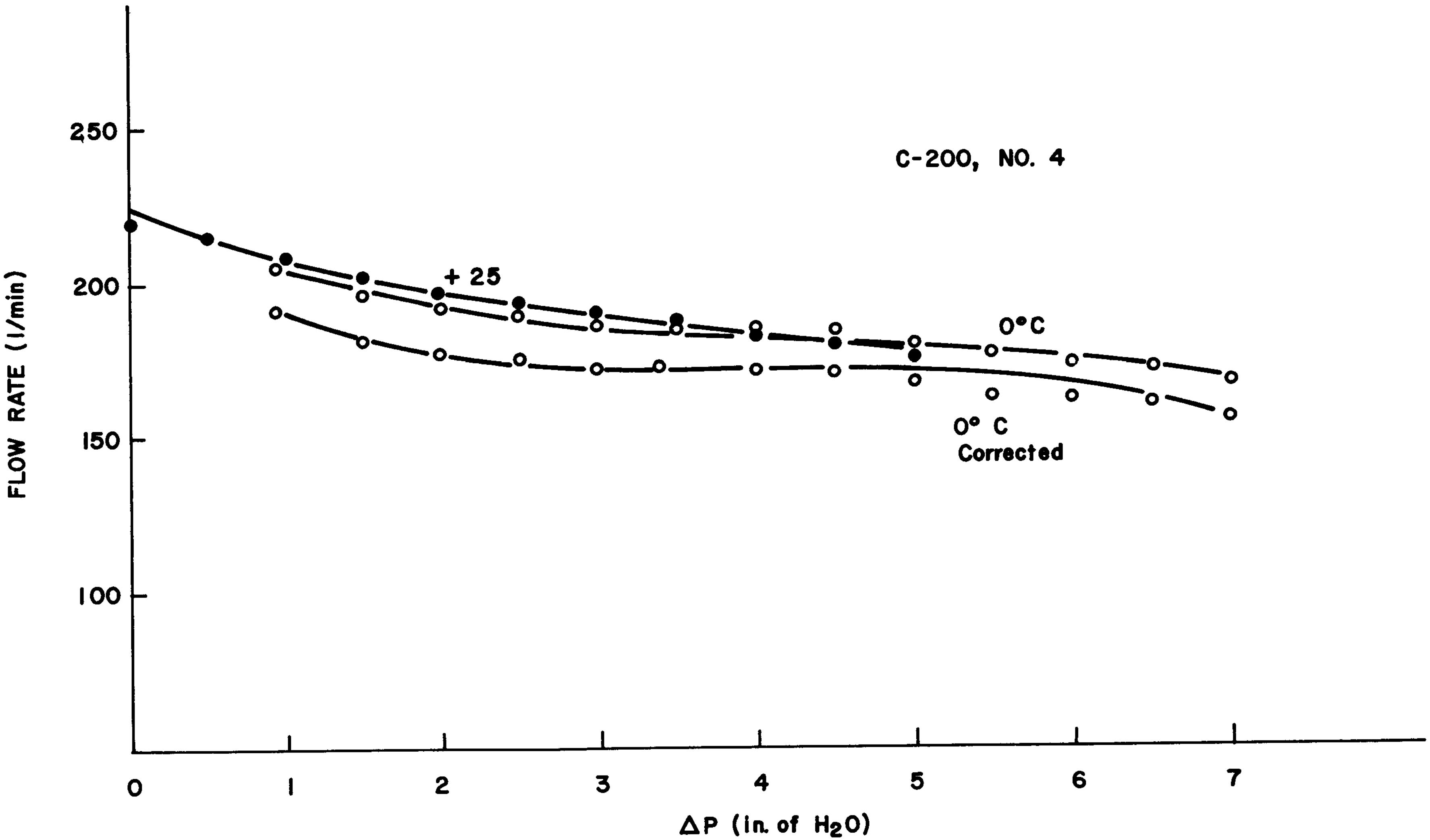

Figure 46 Flow Rate Versus Differential Pressure, Model C-200, No. 4

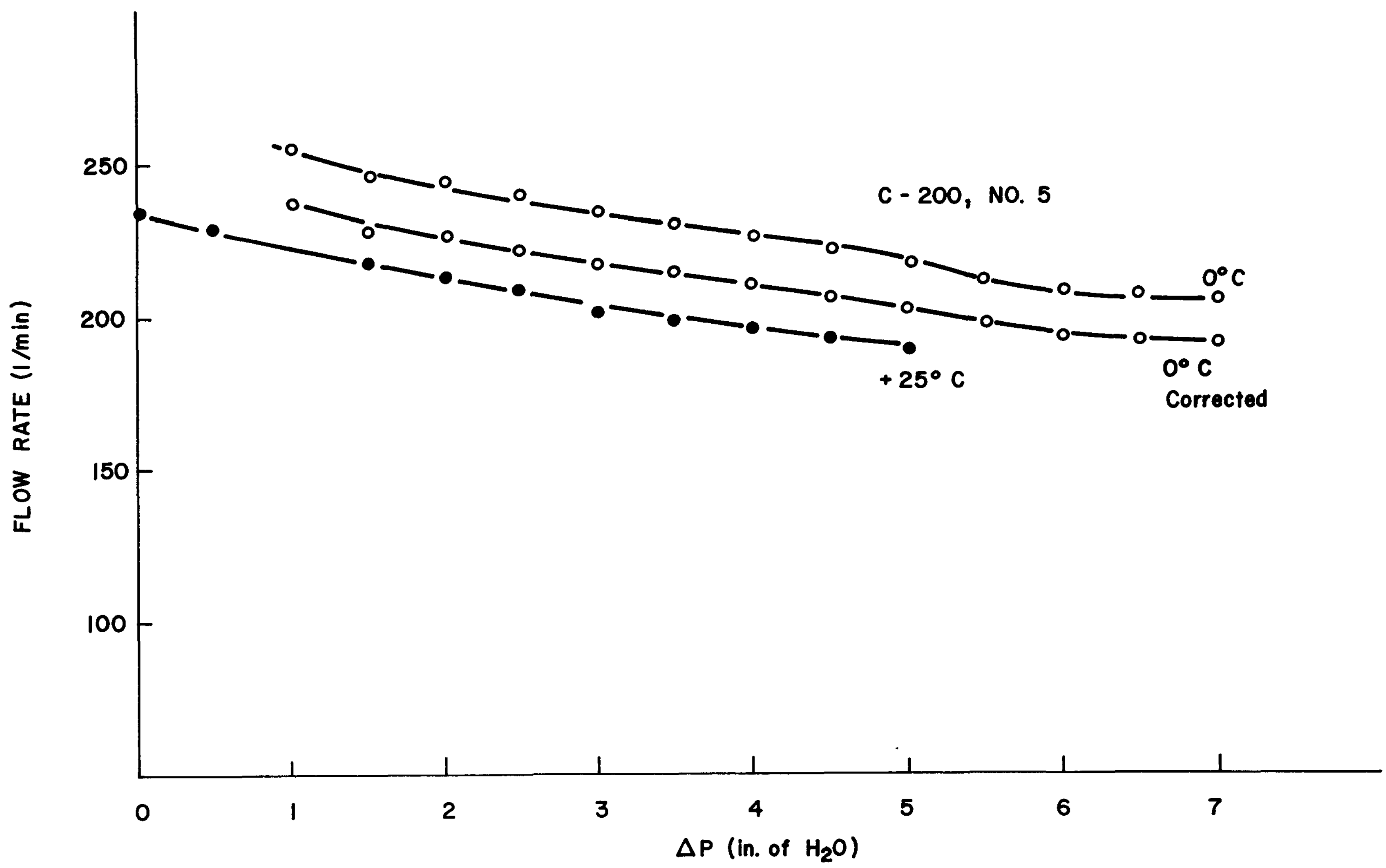

Figure 47 Flow Rate Versus Differential Pressure, C-200, No. 5

Ease of Recalibration--
The flow rate of the C-200 is readily changed with the screwdriver adjustment accessible on the pump case. It is as easily adjusted at -10° and -0°C as at 25°C. The only indication of flow is the counter readout and this is somewhat less convenient than a rotometer. However, adjustments in the field environment are more complex with either a counter or a rotometer because the air density, which changes with temperature, and must be taken into account.

Battery Performance--
The pump motor in the Model C-200 is powered by a single size C Ni-Cd cell rated at 2,000 mA-hrs. The pump current, according to the manufacturer, is less than 60 mA and the pump should operate for a period of at least 33 hours, (i.e., 2,000 mA-hrs./60 mA = 33 hrs). The C-200's were observed to operate for more than 24 hours at both room temperature and 0°C. A preceding section of this report stated that a Ni-Cd cell will deliver approximately 90 percent of its room temperature capacity at 0°C. Thus, one can estimate that the C-200 will operate for a period of about 30 hours at 0°C. The principal reason for the C-200's marginal performance at subzero temperatures is the low temperature characteristics of the Hg reference cell and not the Ni-Cd cell.

Diaphragm Reliability and Bearing Design--
The C-200 is somewhat restricted to temperatures of 0°C and above and there is no evidence that the diaphragms or bearings were effected by these temperatures or by their exposure to lower temperatures during testing.

Lubricants--
Lubricants were not explicitly tested during these evaluations. They are a likely source of problems at subzero temperatures, but not at 0°C and above.

Case Ruggedness--
There is no evidence of damage to any component or the case of the C-200 as a result of the low temperature exposures encountered during these evaluations. The appearance and layout of the C-200 leaves an impression of ruggedness and reliability.

DuPont Model P-125

The DuPont P-125 sampling pump incorporates an electronic flow controller that senses the air flow and controls the speed of the pump motor to achieve a constant flow. Other distinctive features include a battery charge status indicator and a flow monitoring indicator that trips and latches if the flow is interrupted or cannot be maintained near the calibrated value for a period of time. The P-125 is specified as adjustable to flow rates of 25 to 125 ml/min with a pressure drop of up to 25 in. of H_2O. Significantly, the P-125 is specified for an operating temperature range of -7° to 49°C. Figure 48 is a photograph showing two P-125 pumps, one with a cover removed to show the inside including the On-Off switch. Five units were available for this evaluation.

Figure 48 Photograph of the Du Pont Model P-125

Flow Rate Stability with Time--
The flow rate stability of the P-125's was measured at 100 ml/min and 10 in. of H_2O, i.e., somewhat near the middle of the specified capability. These data are shown in Figures 49 through 53 for the five pumps. (As stated previously, flow rate measurements were made at room temperature; however, the values plotted in Figures 49 through 53 are corrected for the difference between room and test temperatures.)

The performances at room temperature are notably stable for 8-hour periods of operation. With the exception of unit No. 5, the maximum deviation was 1 percent. Unit No. 5 was 5 percent low, and the low flow indicator was ON (lit) after 8 hours. The performances were also generally good at a nominal 0° and -22°C. At 0°C, maximum deviations from 100 ml/min over the 8-hour period ranged from -7 to +16 percent with an average of +4 and a standard deviation

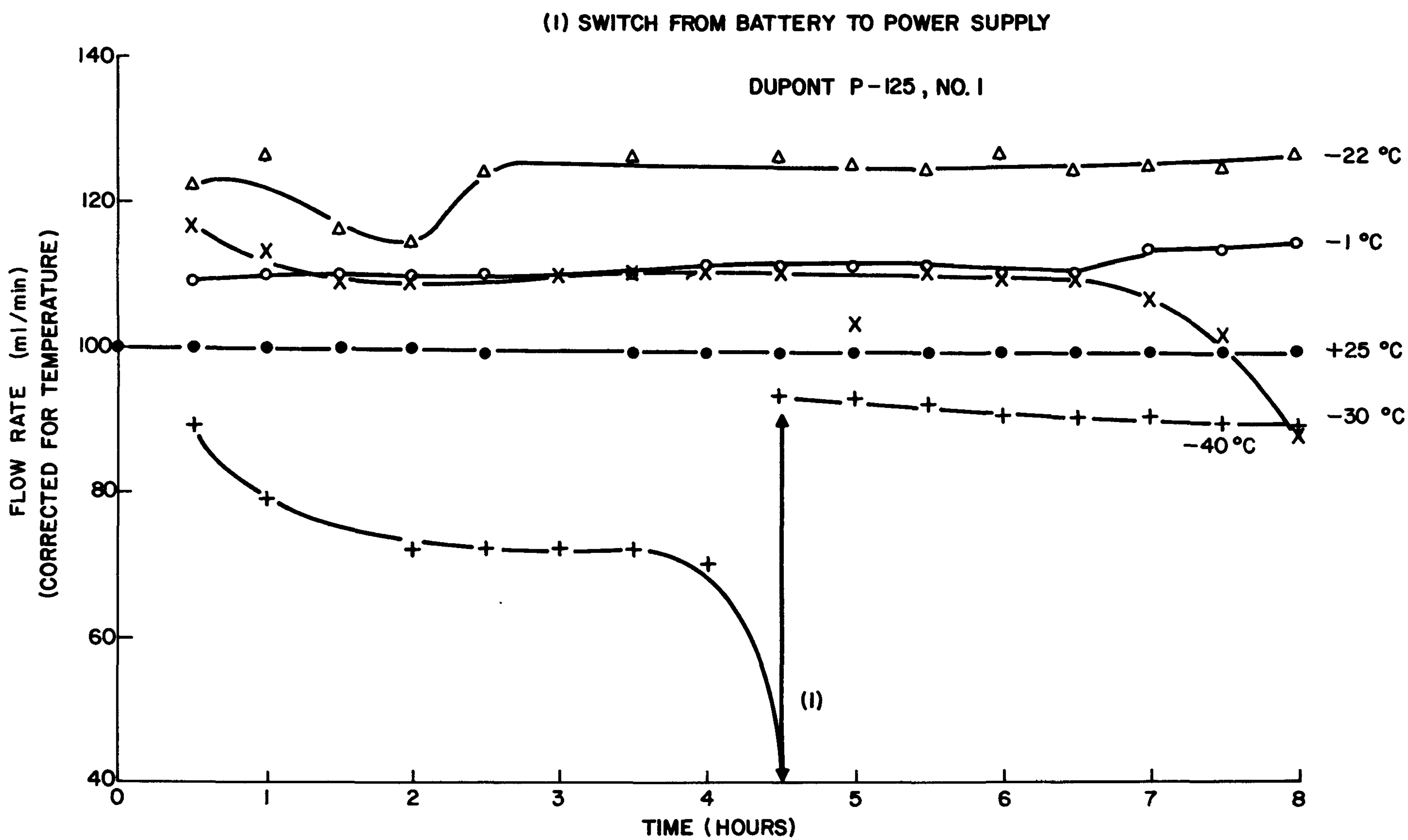

Figure 49 Flow Rate Stability, Corrected for Temperature, Model P-125 No. 1

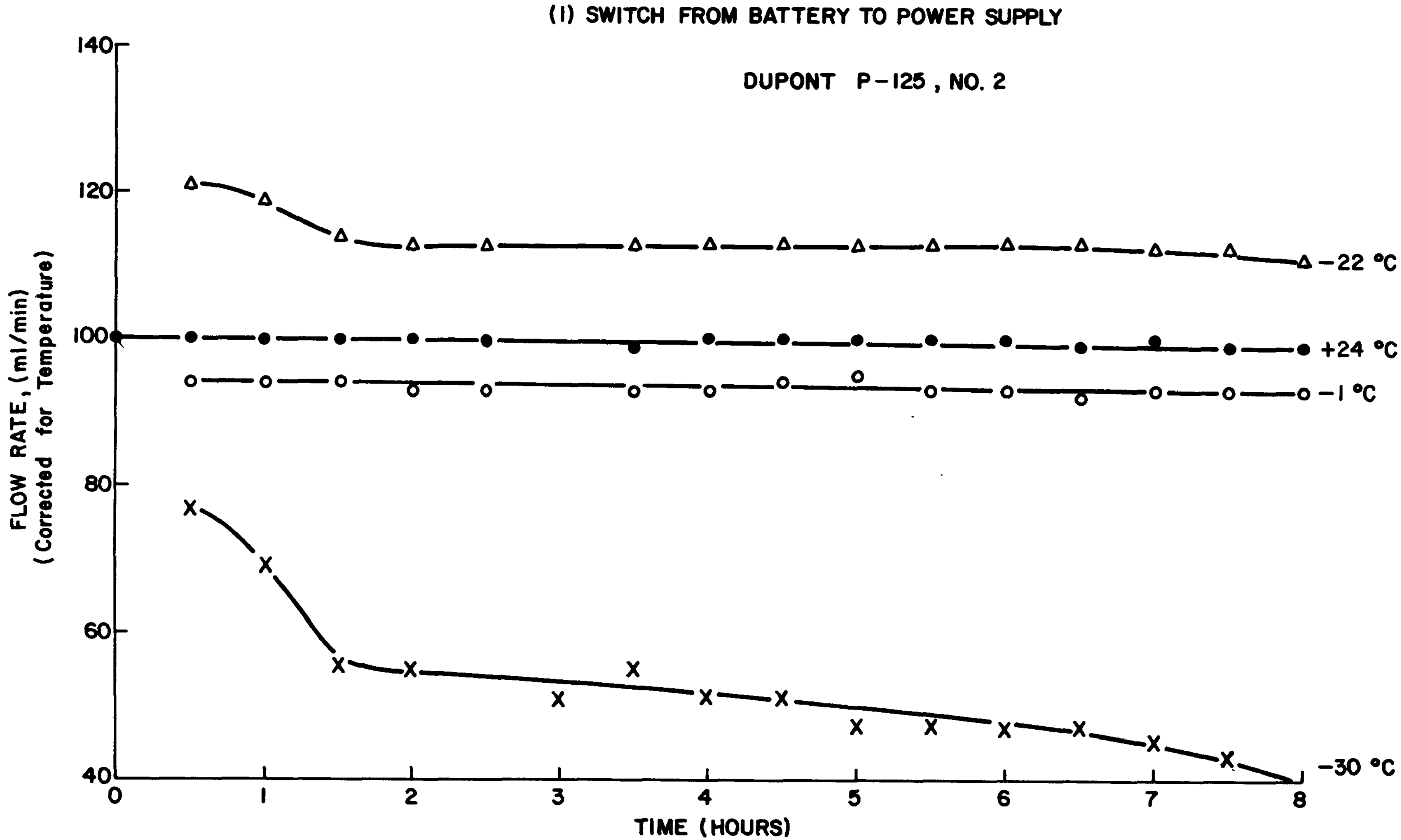

Figure 50 Flow Rate Stability, Corrected for Temperature, Model P-125, No. 2

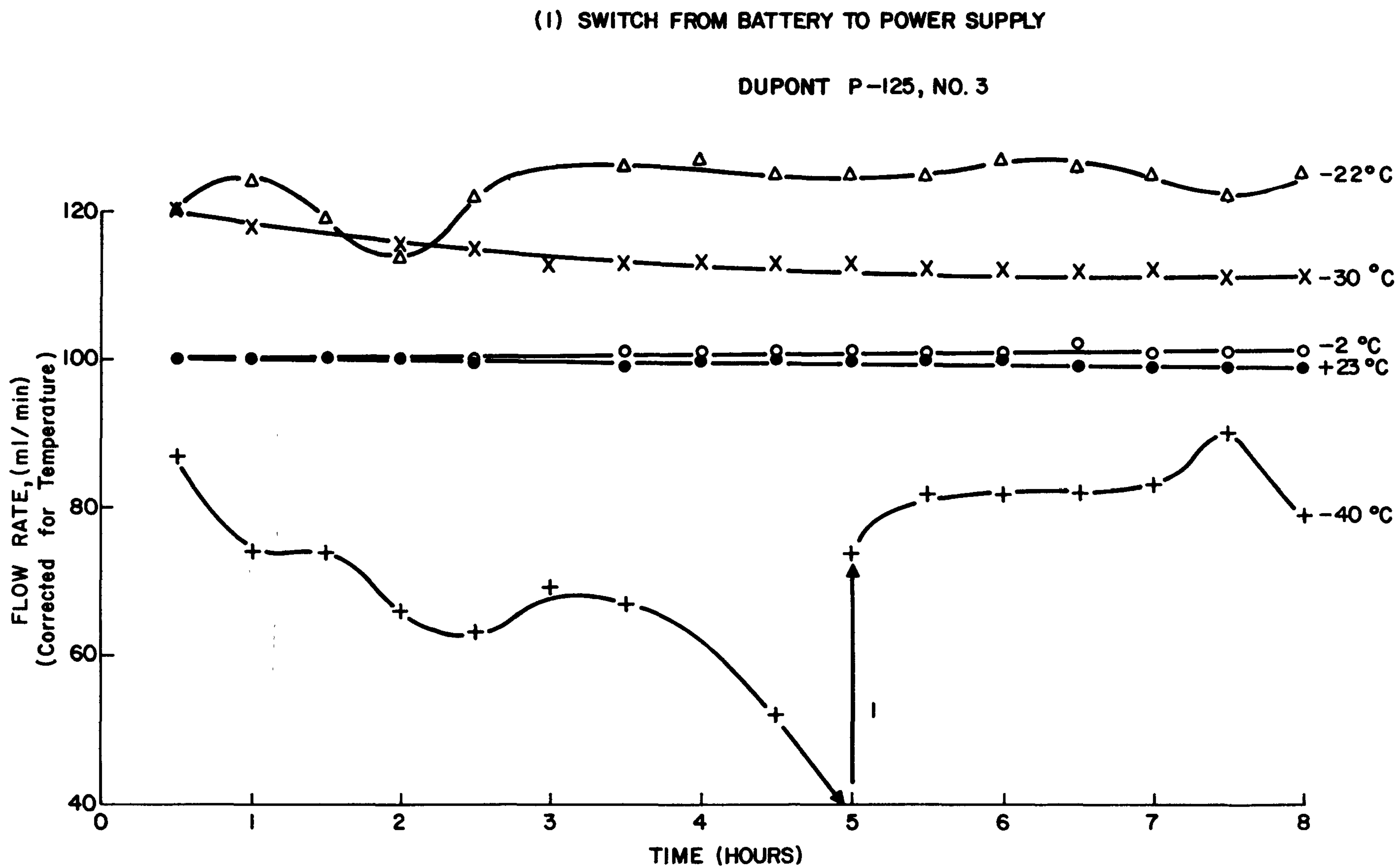

Figure 51 Flow Rate Stability, Corrected for Temperature, Model P-125, No. 3

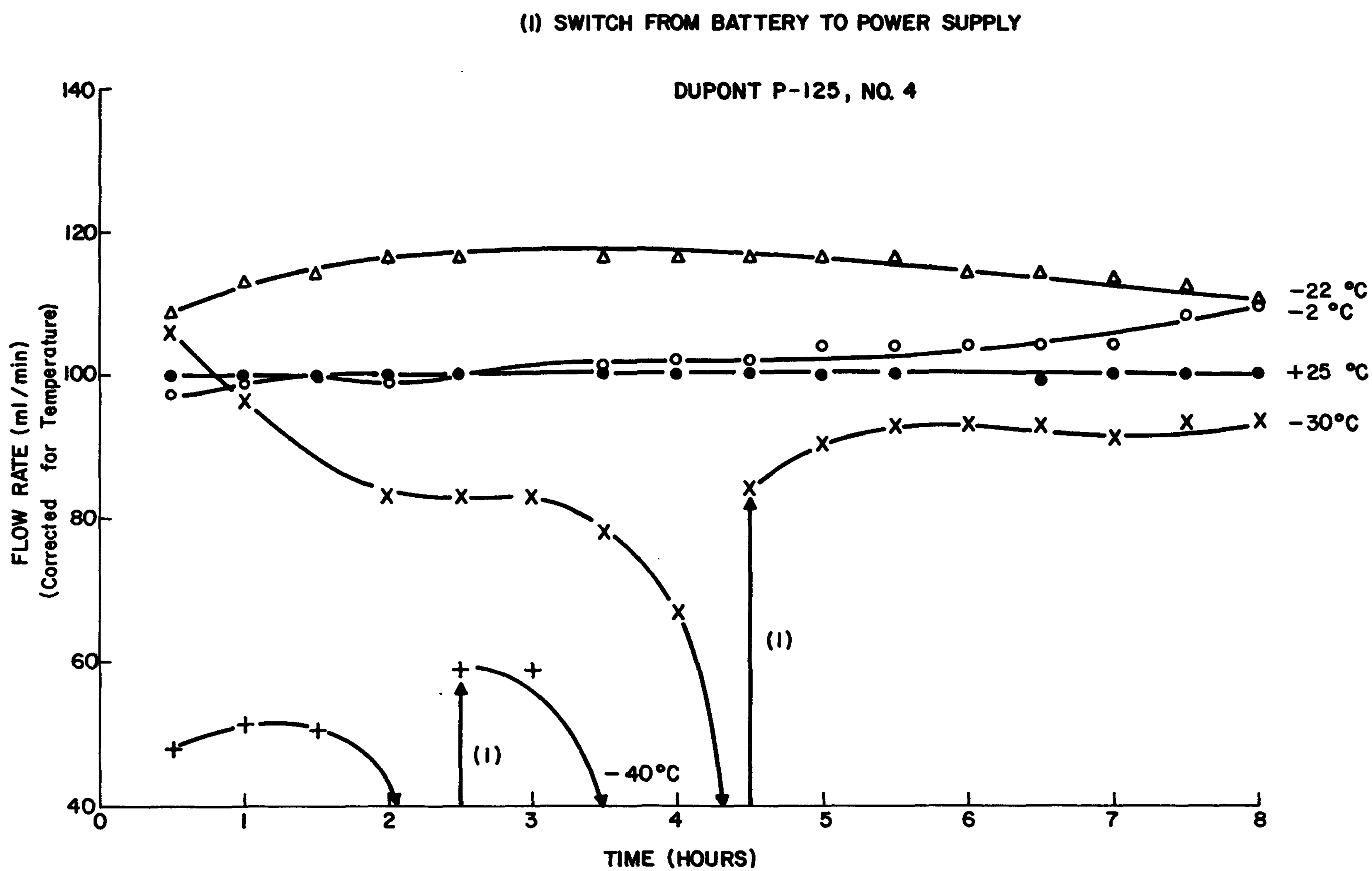

Figure 52 Flow Rate Stability, Corrected for Temperature, Model P-125, No. 4

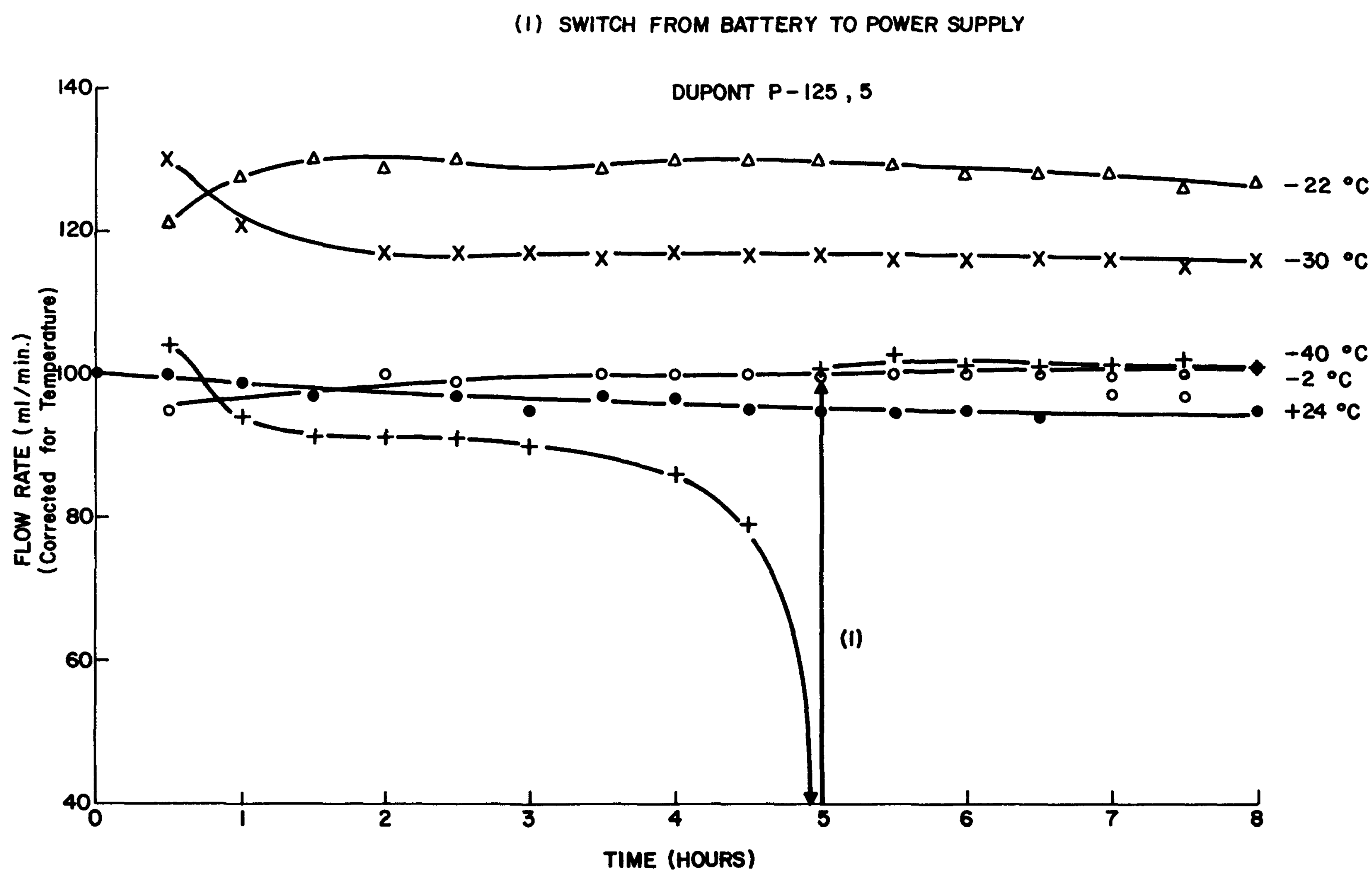

Figure 53 Flow Rate Stability, Corrected for Temperature, Model P-125, No. 5

of +8.7 percent. At -22°C, the temperature corrected flow rates tended to be high by about 15 to 25 percent, but they were stable over an 8-hour period.

It is notable that three of the five P-125's maintained a useful flow rate at -30°C for an 8-hour period, and that useful flow rates could be maintained at -30° and -40°C by substituting a power supply for the battery pack. Thus, it is evident that the battery pack is a principal performance limiting factor in the DuPont P-125 at -30° and -40°C. Therefore, useful sampling at these temperatures may be possible with a larger battery pack. During the -30°C experiments, battery voltages were monitored on unit Nos. 3, 4, and 5.

In Nos. 3 and 5, the voltages decayed from initial values of about 1.4 V/cell to about 1.1 V/cell after 8 hours, and the flow rates remained high. In Unit No. 4, the battery voltage decayed from 1.35 V/cell to 1.02 V/cell after 4 hours and to 0.84 V/cell when a power supply substitution was made, and acceptable performance restored at 4.5 hours. Comparable observations were made for all five units at -40°C.

No data was acquired at -50°C. However, all units were maintained in an operational mode for 8 hours at -50°C. None of the pumps were running after 8 hours. Unit No. 4 was observed to have a ruptured diaphragm and the flow controller on Unit No. 2 appears to have failed during this exposure. (Unit No. 2 runs constantly at full speed at room temperature, and there is no evidence of failure elsewhere in the unit.)

Flow Rate/Pressure Drop Characteristics--
The flow rate of the five P-125's as a function of pressure drop, with temperature included as a parameter, are shown in Figures 54 through 58 for Units 1 through 5, respectively. As in previous data, the 0° and -20°C data are included both as measured at room temperature and as corrected. In the aggregate, these data show remarkably linear characteristics between +25° and -20°C. These results are further evidence of the P-125's generally excellent performance at temperatures as low as -20°C.

A tendency toward higher flow rates at lower temperatures is evident in both the flow rate/pressure drop and the flow rate stability data. The exception is the flow rate/pressure drop data for Unit No. 2. These data are also incompatible with the flow rate stability data for Unit No. 2. No explanation for this difference is offered except to note that the flow controller on Unit No. 2 eventually failed.

Reliability of Calibration over Temperature--
The data plotted in Figure 59 are the 1.5 hour data points from the flow rate stability data. The rationale for selecting these data points was discussed in a previous section, i.e., these data include day-to-day variances in preference to variances due to battery degradation. A single curve corresponding to the data plotted for Unit No. 1 is drawn and is considered somewhat characteristic of the other P-125's. It shows a characteristic increase in flow rate (measured at room temperature) with decreasing temperature that peaks in the general vicinity of -20°C, and a subsequent decrease back toward the room temperature value. Unit No. 1, for example, was

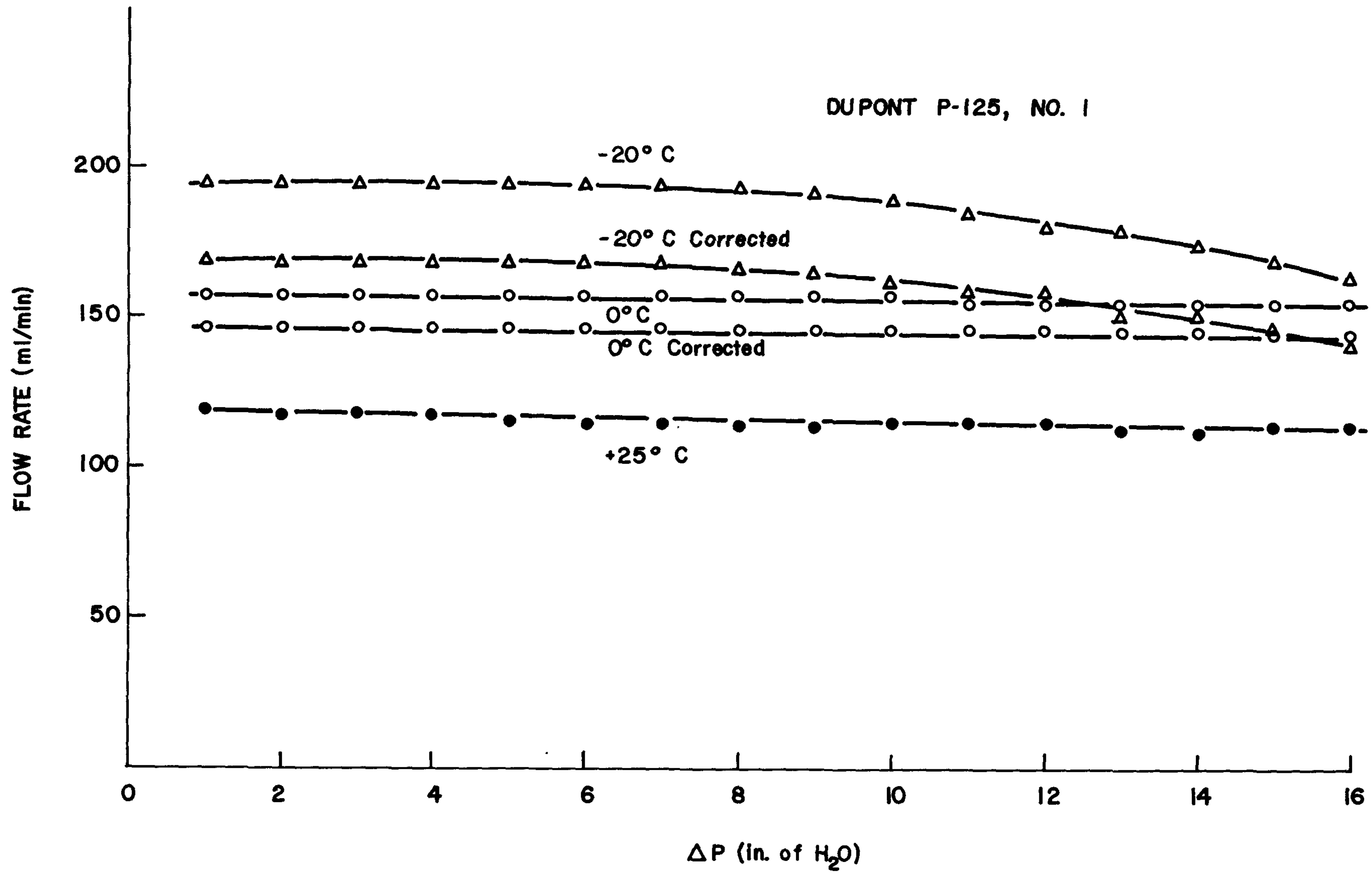

Figure 54 Flow Rate Versus Differential Pressure, Model P-125, No. 1

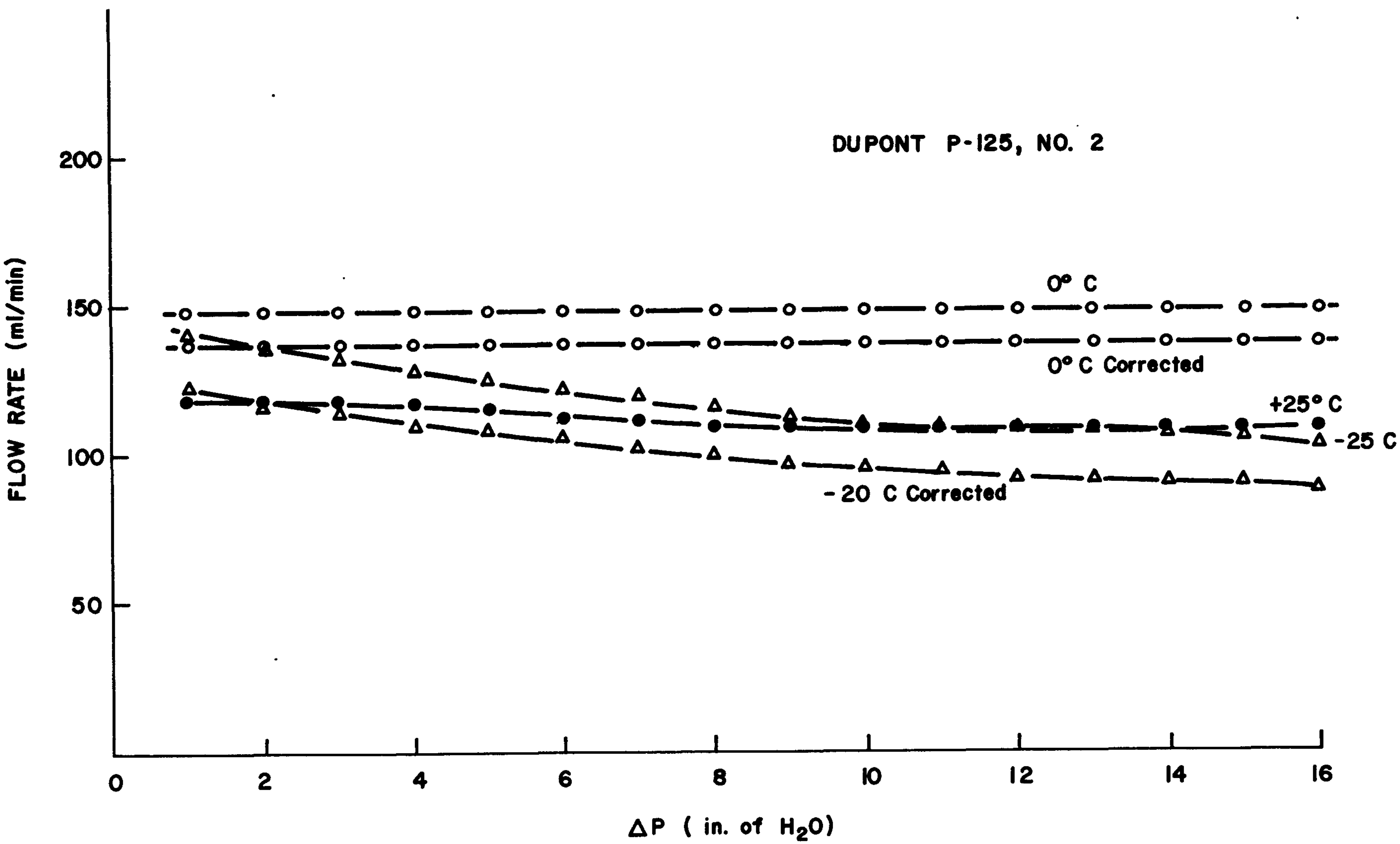

Figure 55 Flow Rate Versus Differntial Pressure, Model P-125, No. 2

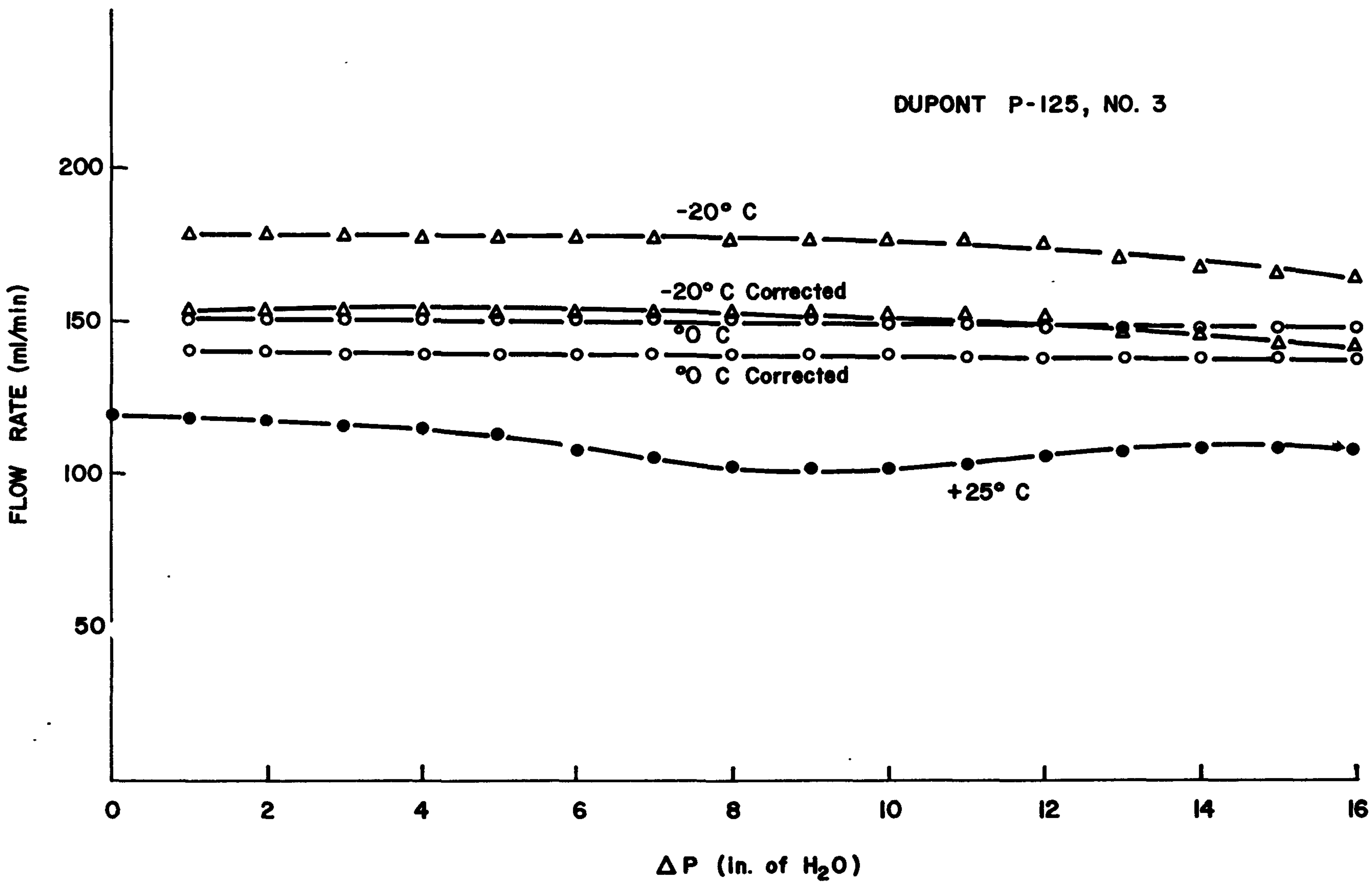

Figure 56 Flow Rate Versus Differntial Pressure, Model P-125, No. 3

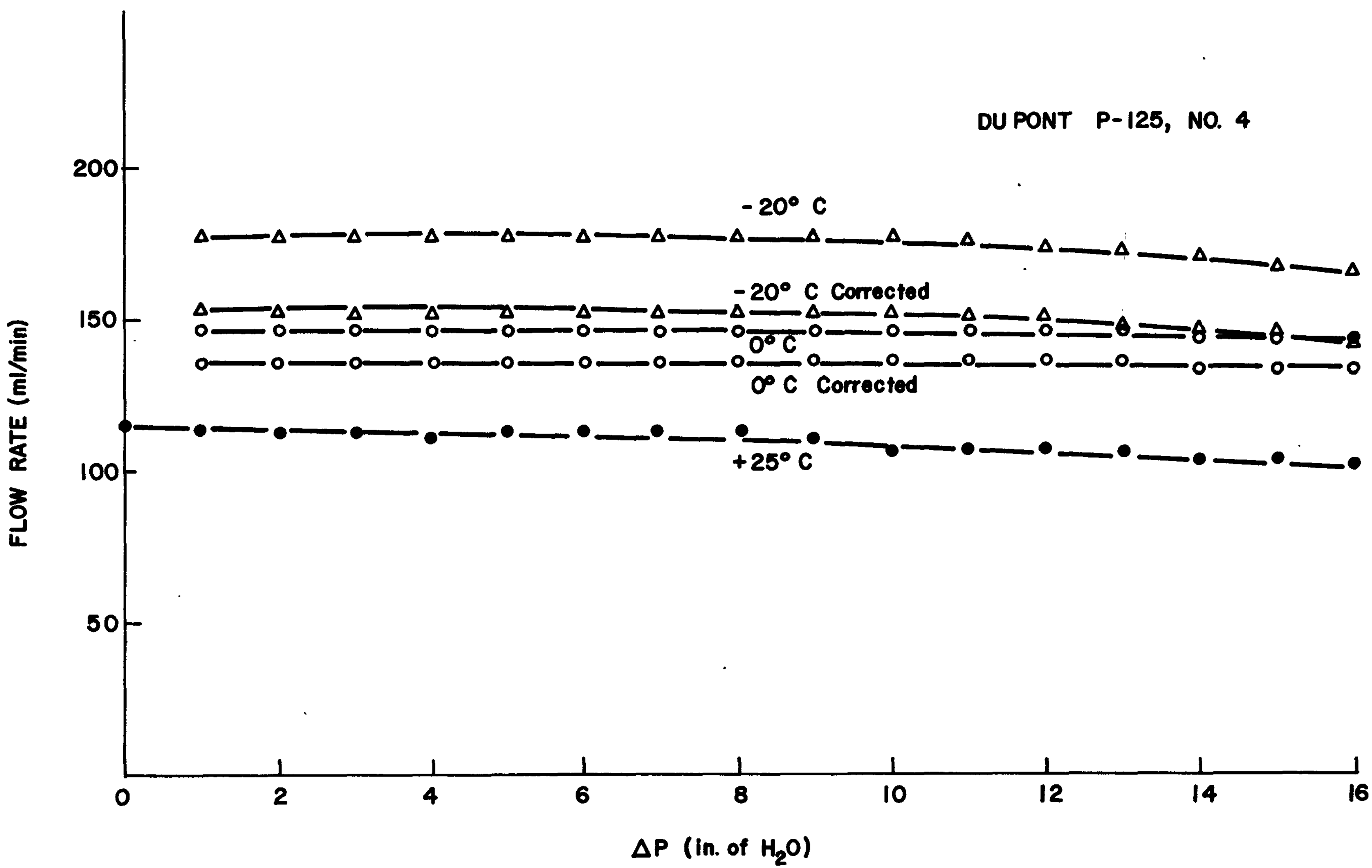

Figure 57 Flow Rate Versus Differntial Pressure, Model P-125, No. 4

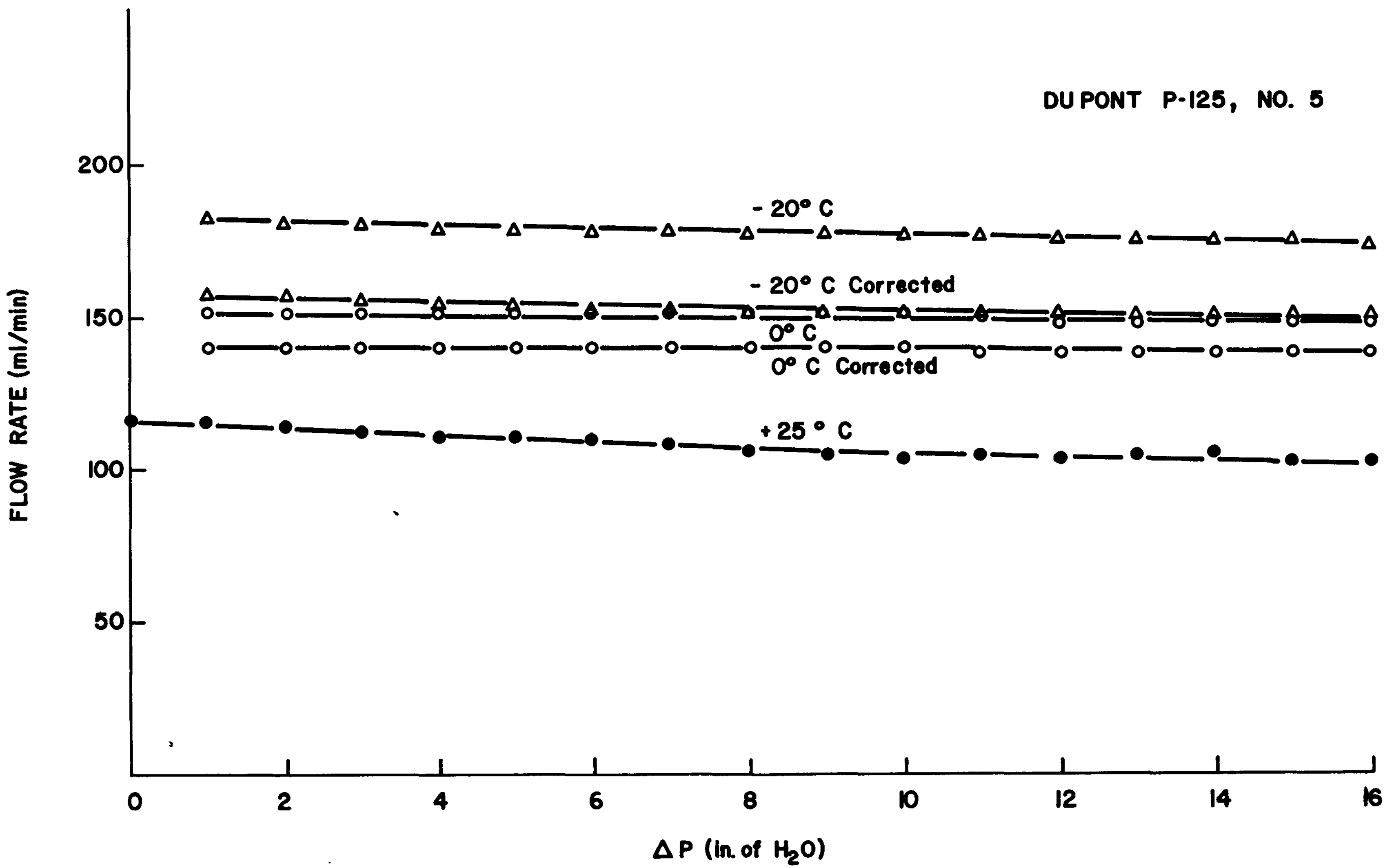

Figure 58 Flow Rate Versus Differential Pressure, Model P-125, No. 5

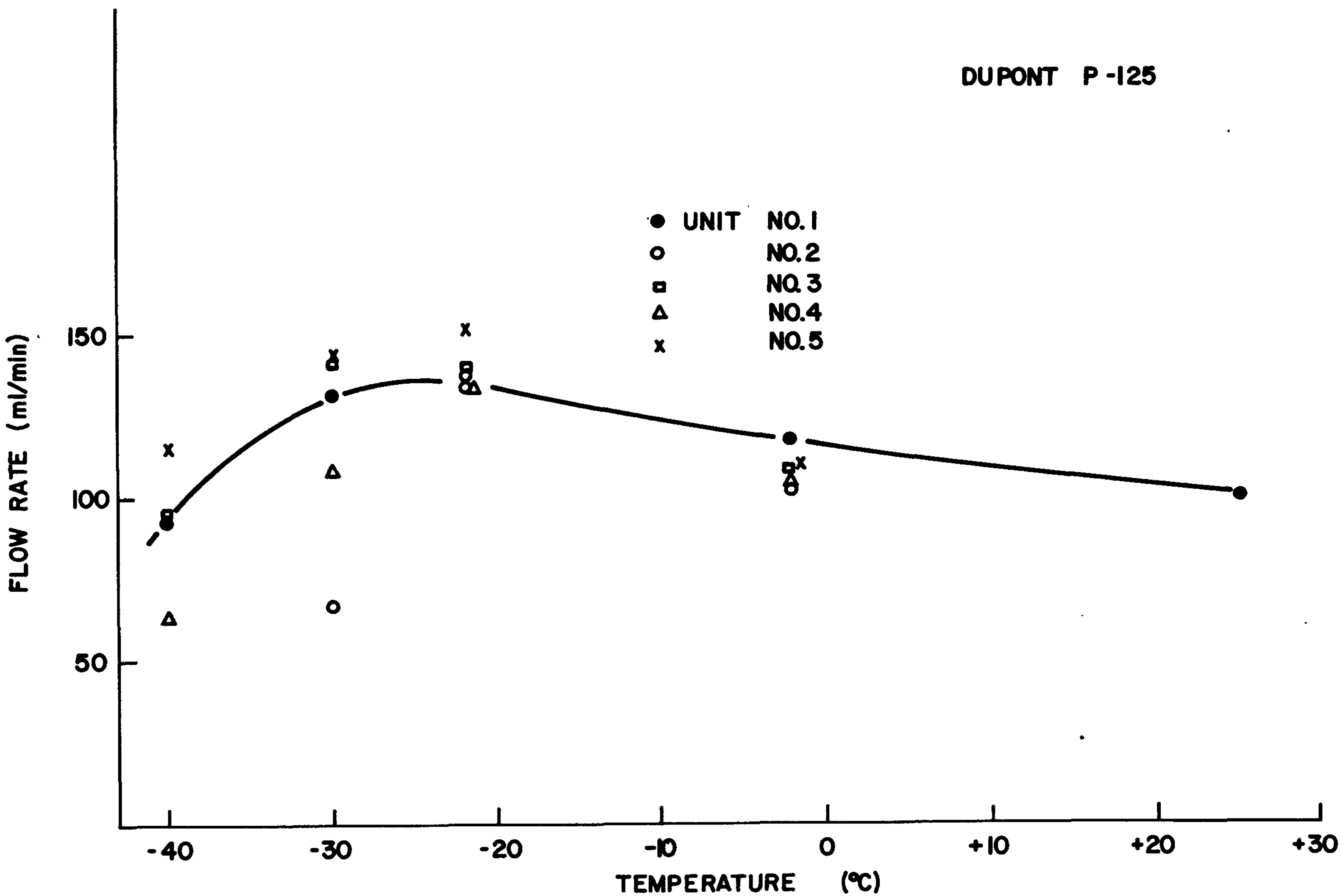

Figure 59 Flow Rate Calibration as a Function of Temperature
Model P-125

pumping 119, 136, 132, and 95 percent of its 25°C value at temperatures of -2°, -22°, -30°, and -40°C, respectively. If these data are corrected forthe difference between room temperature (the measurement temperature) and the test temperature, the corresponding readings would be 108, 114, 107, and 74 percent.

Continuously Sample Cold Air--
After the completion of other testing, including an 8-hour period at -50°C in an operating mode, three of the P-125 units were placed in an environmental chamber at -20°C on six separate days and observed to operate routinely for 8-hour periods. (Of the other two units, one had a ruptured diaphragm and the other a defective flow controller.) There is no evidence of failures occurring and performances are generally good at -20°C.

Ease of Recalibration--
The flow rate adjustment on the P-125 is located inside the housing and it is not designed for adjustments in the field environment. Flow rate adjustments at -20°C were easily accomplished in the laboratory where the flow rate could be monitored.

Battery Performance--
The P-125's are powered by 4, size AA Ni-Cd batteries. Size AA cells are characteristically rated about 450 to 500 mA-hr. A distinctive feature of the P-125 is an LED indicator that indicates that the batteries have an adequate charge for a day's operation.

The results of these evaluations indicate that the P-125 battery pack is adequate to operate the pump satisfactorily for 8 hours at -20°C and, with some selection, to operate the pump satisfactorily at -30°C for 8 hours. At -30°C, and even at -40°C, pump performance degradation was clearly due to battery degradation, and performance could be restored by substituting a power supply for the battery pack. (Three of the five units evaluated performed well at -30°C using these internal battery packs.) Thus, in contrast to the other pumps evaluated, the battery pack was the principal performance limiting factor at low temperatures. One can conclude, therefore, that good performances can likely be achieved with the P-125 at -40°C with a larger battery pack. It is not reasonable to consider operating at -50°C from a battery pack.

Diaphragm Reliability--
A diaphragm ruptured in one of the P-125's while operating at -50°C. The others survived this exposure without any evident damage. While this fact is noted, the reader is advised again that no statement of reliability can be made with any significant degree of confidence.

Bearing Design and Lubricants--
Bearings and lubricants are likely sources of problems at low temperatures. Lubricants, particularly, become stiff and tend to "load" the bearings or pump. The fact that the battery pack was a principal performance limiting factor in the P-125 and that good performance was achieved at -40°C with a

power supply suggests that the bearings and lubricants are suitable for use at these low temperatures.

Case Ruggedness--
Other than the one ruptured diaphragm, there is no evidence of any damage or degradation to the pump case or components as a result of testing and exposure to low temperatures during these evaluations.

Accuhaler Model 808

The configuration of the Model 808 differs significantly from the other pumps evaluated. It utilizes a limiting orifice that attaches integrally to the pump to control the flow rate. The pump motor drives a pin-cam mechanism that, in turn, initiates the following cycle of events. An exhaust valve to a pump cavity opens and a diaphragm (i.e., a piston with a flexible diaphragm seal) is driven into the pump cavity causing it to exhaust. At maximum compression, i.e., minimum cavity volume, the exhaust valve closes and the piston/diaphragm drive mechanism springs back to a null position, opening the motor circuit. The piston/diaphragm mechanism, driven by a spring, returns to an extended, maximum volume position as air bleeds into the cavity through the limiting orifice. At the extended, maximum volume position, the motor is re-energized to repeat the cycle. Each cycle pumps a volume of air equal to the displacement of the piston-diaphragm assembly, and the cycle rate is largely controlled by the limiting orifice. Several sets of orifices are available and the orifice is readily changed with a wrench or nutdriver. Figure 60 is a photograph showing two of the Accuhaler Model 808 personal sampling pumps. A panel covering the batteries has been removed and wires added to facilitate testing from a power supply.

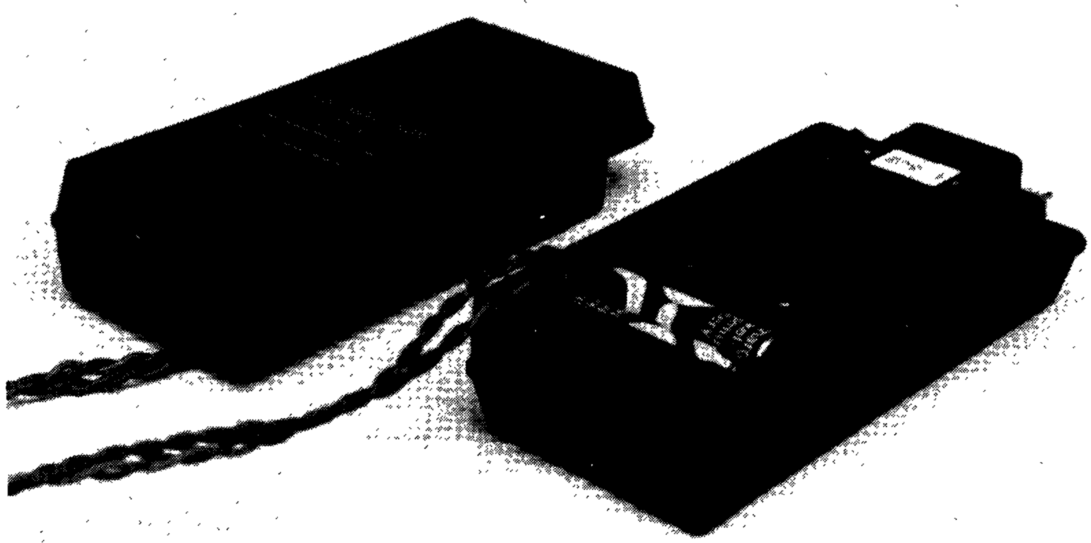

Figure 60 Photograph of the MDA Model 808

Flow Rate Stability with Time--
The flow rate stability of the Model 808's was measured using the test apparatus illustrated in Figure 61. (The sample flow through the Model 808 pulsates and cannot be measured with a rotometer.) The restricting valve was set independently to drop 1.5 in. of H_2O at a flow rate of 100 ml/min.

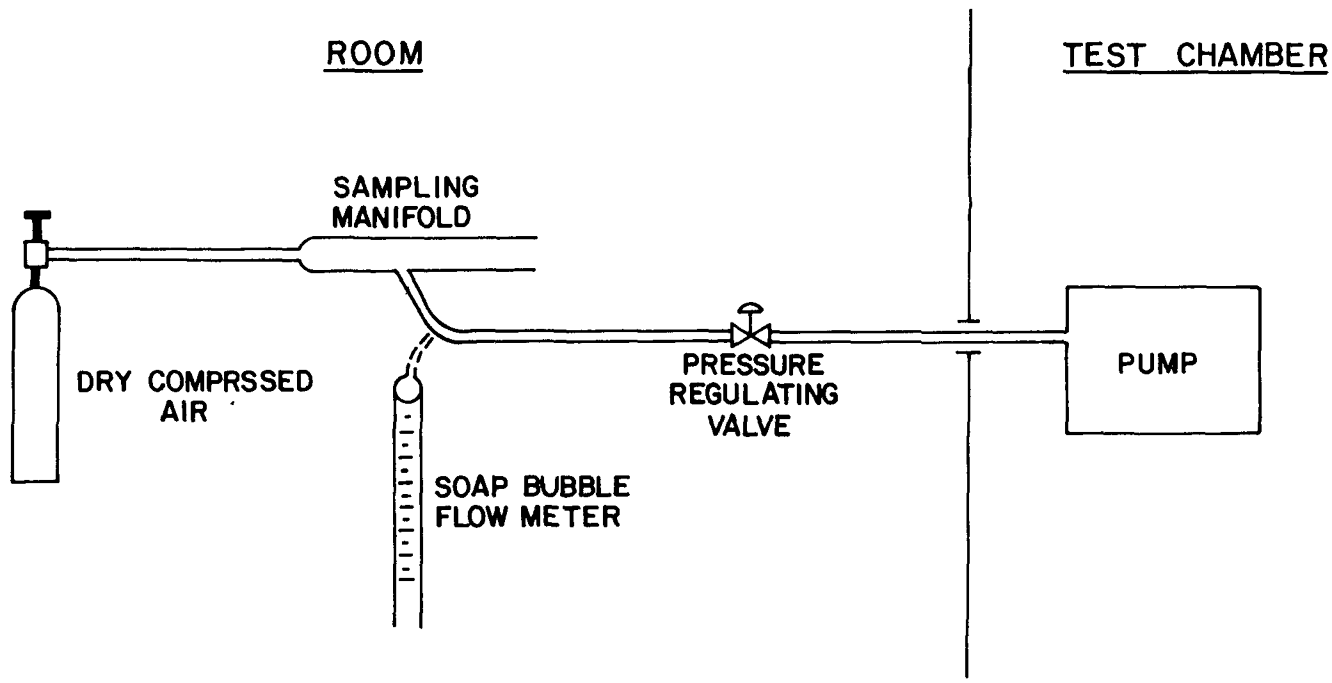

Figure 61 Test Apparatus for the Accuhaler, Model 808

Sample air was drawn through the restricting valve from the dry air manifold. When flow measurements were made, the sample was temporarily drawn from the soap bubble meter.

The limiting orifice that attaches to the pump is the only flow control option available to the user. For a given orifice, the stability of the pump is likely to be enhanced if the pressure drop across the orifice is larger than the drop across the sample collection medium (i.e., the restriction valve in Figure 61.) During these evaluations, the testing on the Model 808's was done with the restriction valve in Figure 61 set to drop 1.5 in. of H_2O at 100 ml/min, and a 100 ml/min limiting orifice was used on the pump. The flow rate stability and the variations in flow rate with pressure drop across the restriction valve would be enhanced by a more restrictive orifice. The flow rate would also be less.

The flow rate stability data for the Model 808 is shown in Figures 62 through 66. The flow rates were measured at room temperature, but the values plotted are corrected to the respective test temperature. At 25°C, the flow rates are reasonably uniform and tend to be within about 5 to 10 percent of 100 ml/min. Unit No. 3 is an exception. Its flow rate was low at all temperatures. Unit No. 5 is somewhat different as well in that a significantly large peak occurs early in the test period.

The pumps did not operate for an 8 hour period at 100 ml/min. It is clear that a lower flow rate would tend to extend the operating period significantly. The pump operates on a periodic basis--a quasi "duty cycle"--in that the battery circuit is closed, the motor cycles the cam for one-third of a revolution, and the circuit is opened until sufficient sample air bleeds through the collector and limiting orifice to allow the diaphragm to expand and close the circuit for another cycle. Therefore, the load on the battery pack is directly proportional to the flow rate, and the period of operation should also be directly proportional to the flow rate.

The temperature corrected flow rates plotted in Figures 62 through 66 show a very complex pattern as a function of temperature. In the other pumps, the flow rates measured at room temperature tended to increase at low temperatures because the air moving through the pump was colder and more dense than the measure air. In the Model 808's, the measured flow rates tended to decrease at low temperature (but obviously less than the temperature corrected values). There are several likely influences. It is likely that the diaphragm tends to stiffen at low temperatures and influence the rate at which the diaphragm/piston "system" returns to a closed-circuit position pulling in a sample. The motor speed and battery degradation are improbable influences because the motor can either cycle the cam or it does not.

The orifice characteristic may be an influence. It was observed that the flow rate/pressure drop characteristics of the orifice are such that, with the flow rate measured at room temperature, the characteristics do not change significantly with temperature. (Thus, if the flow were measured at the test temperature, it would be less by the ratio of the absolute test (sample) temperature to the measurement (room) temperature for a given pressure drop.) Thus, one of the two flow limiting factors is an integral part of the pump, and its characteristics effectively change with temperature.

It is also observed that the time the pump operates decreases with temperature. Several factors will influence the time of operation. Since the flow rates decrease with temperature, the motor will cycle less and demand less of the battery. However, each cycle is likely to require more energy at low temperatures because of diaphragm, bearing, and lubricant "stiffness." Moreover, the battery capacity also degrades with temperature.

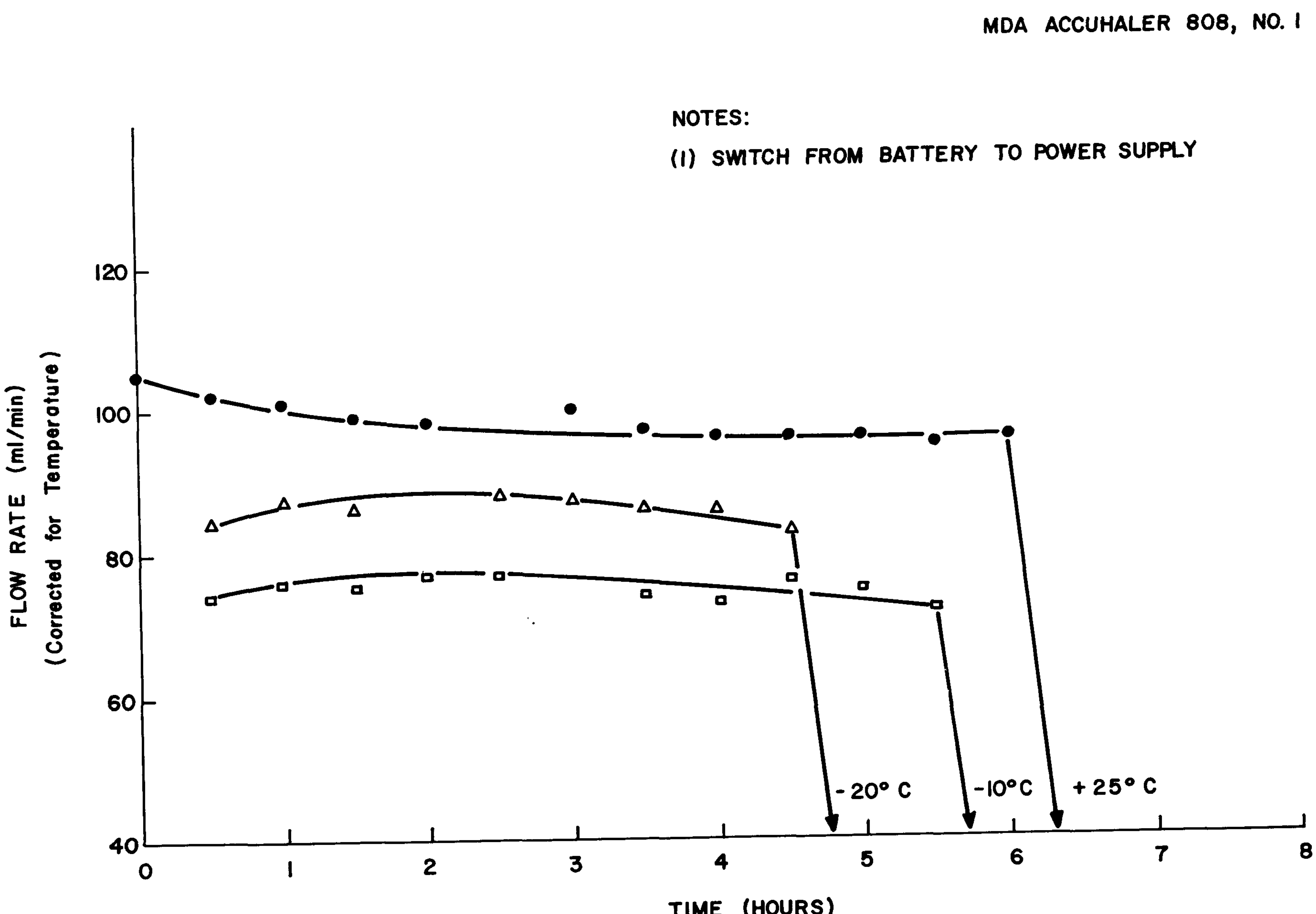

Figure 62 Flow Rate Stability, Corrected for Temperature, Model 808, No. 1

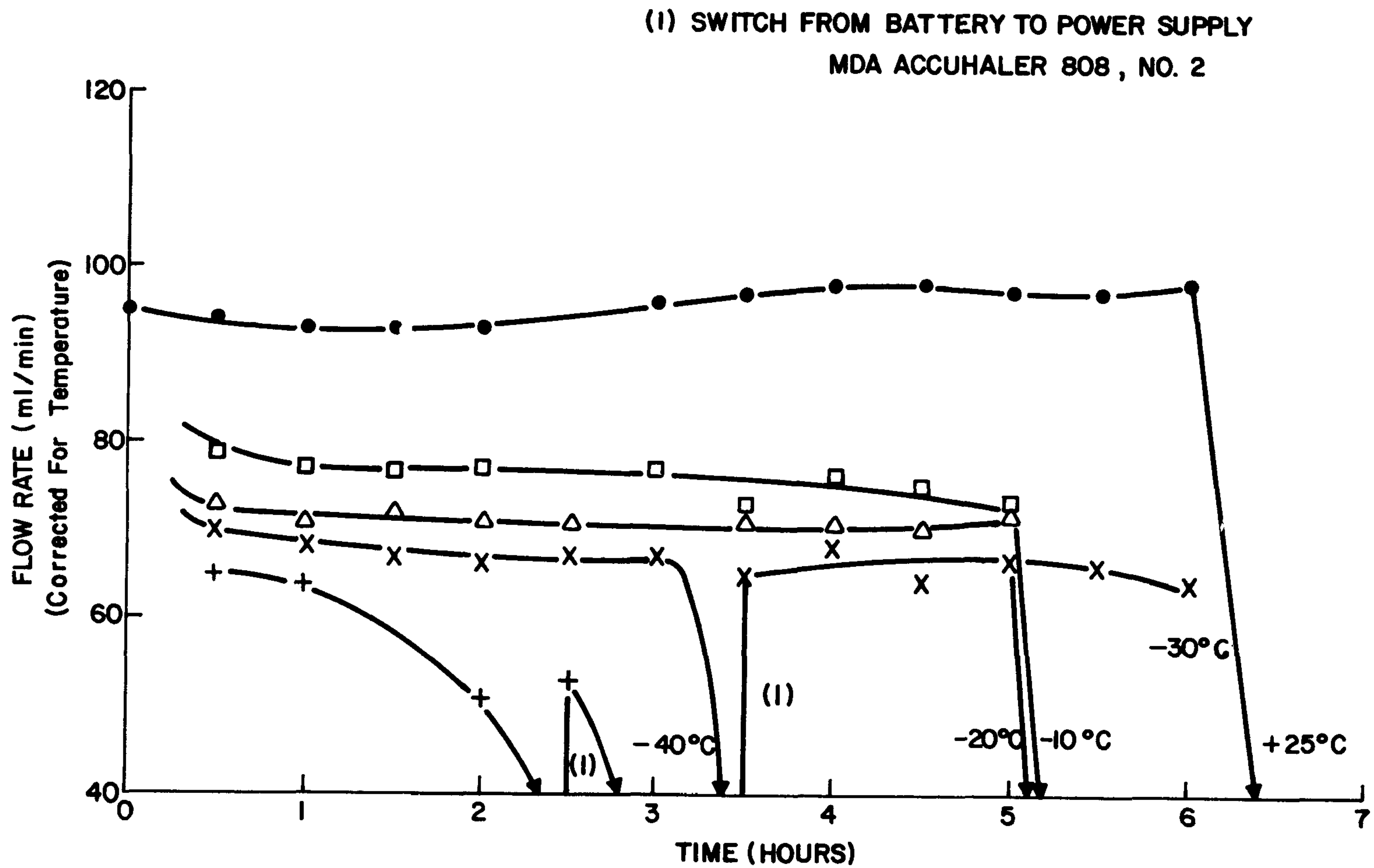

Figure 63 Flow Rate Stability, Corrected for Temperature, Model 808, No. 2

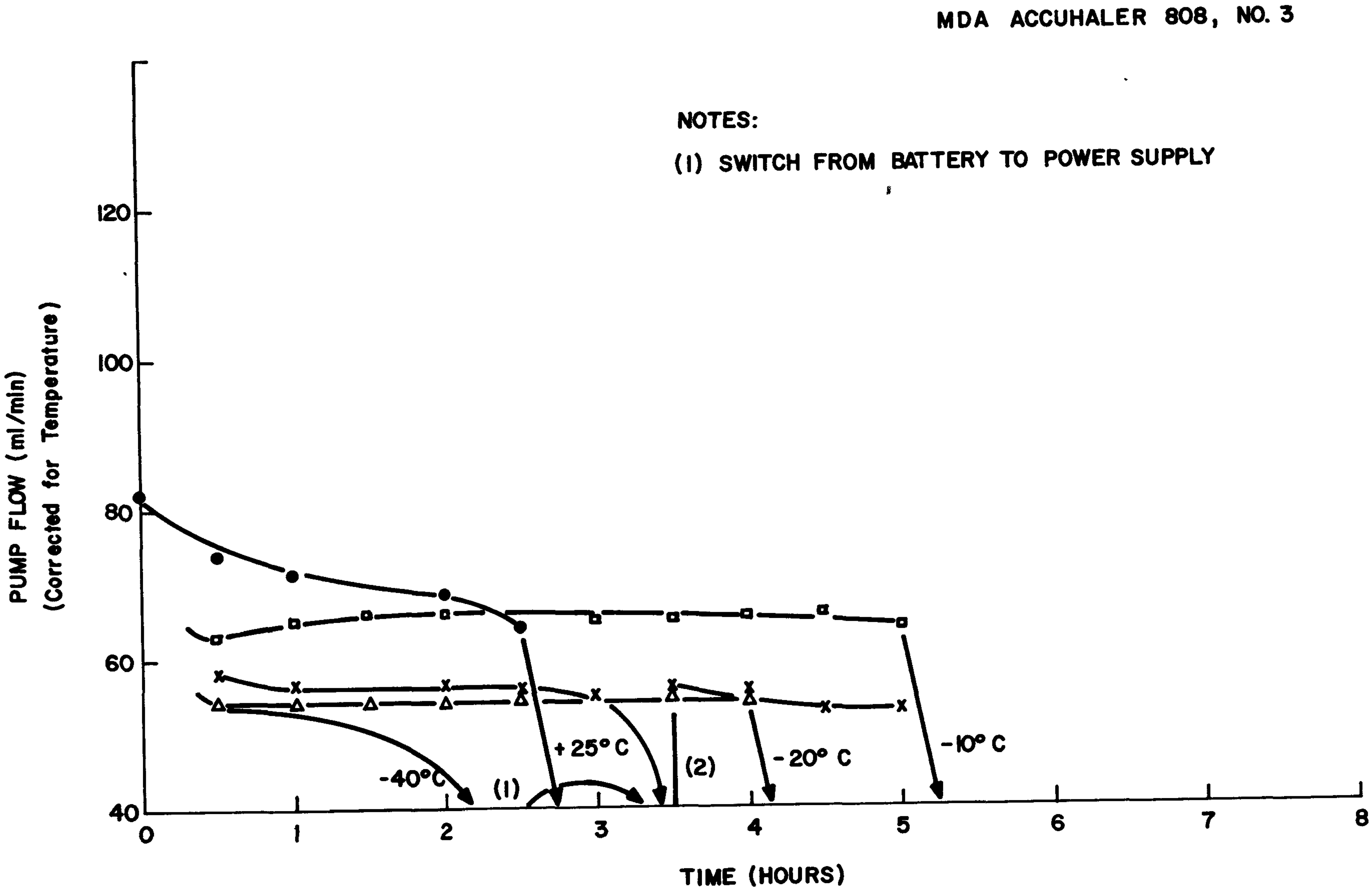

Figure 64 Flow Rate Stability, Corrected for Temperature, Model 808, No. 3

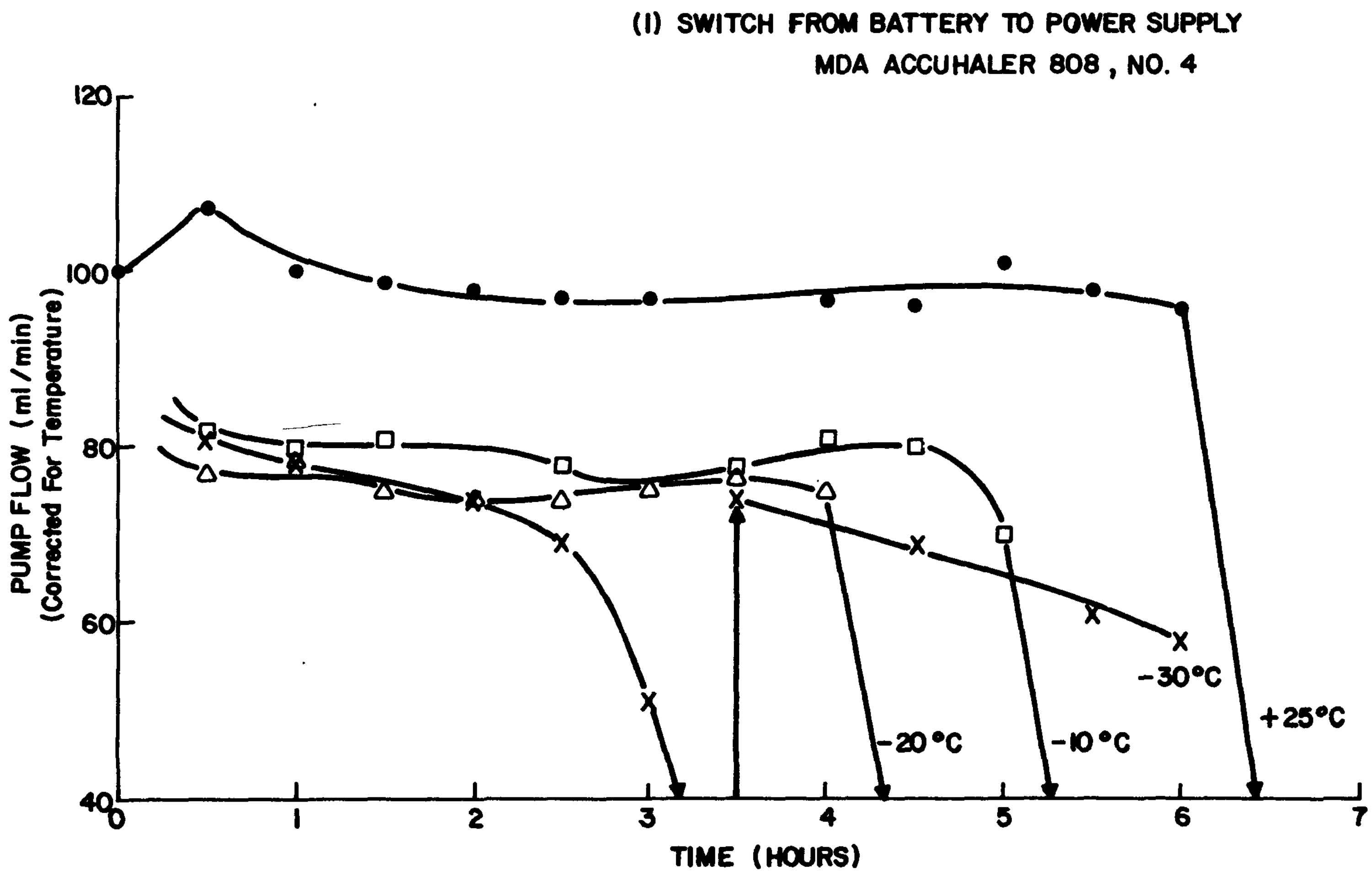

Figure 65 Flow Rate Stability, Corrected for Temperature, Model 808, No. 4

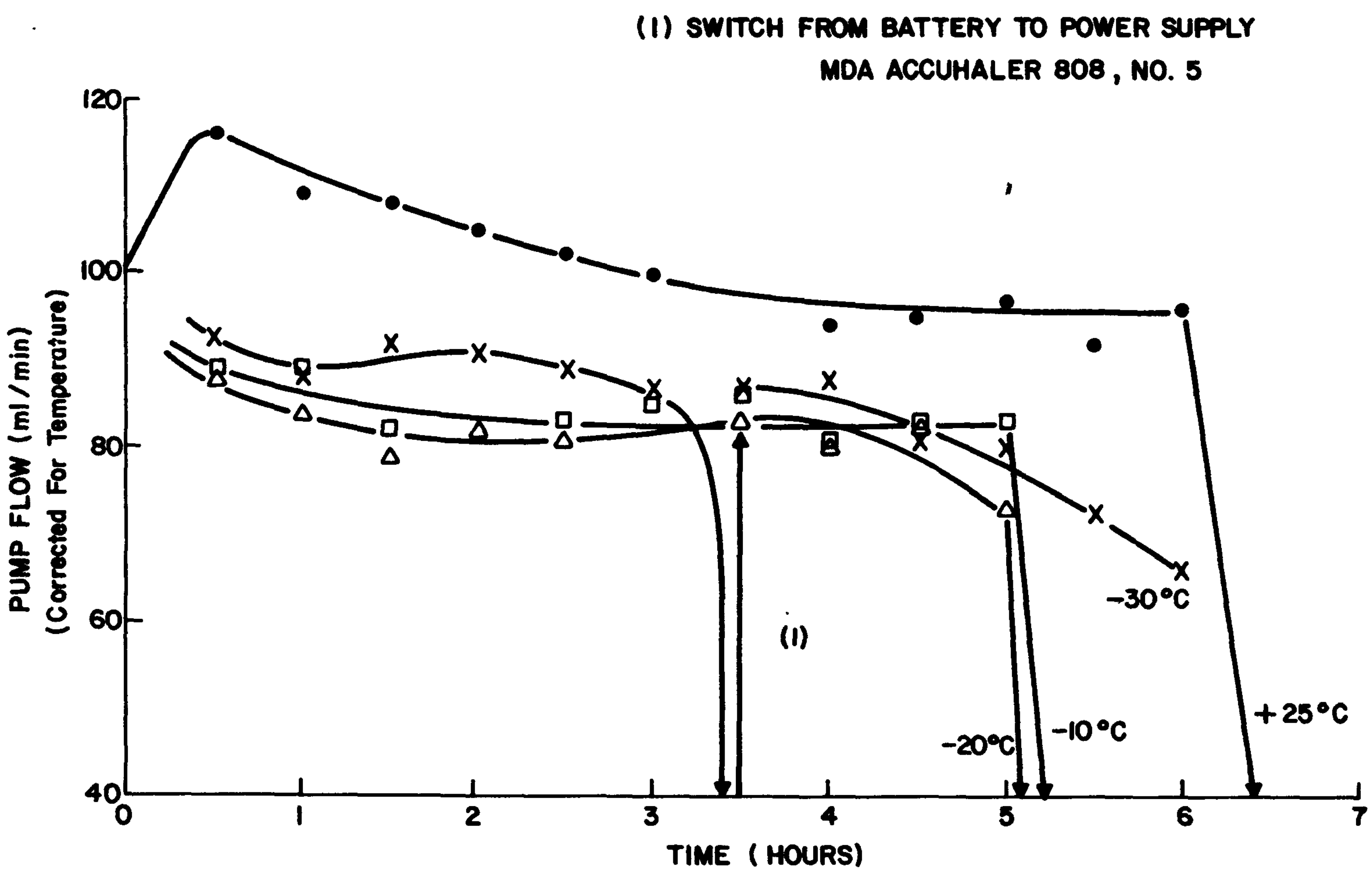

Figure 66 Flow Rate Stability, Corrected for Temperature, Model 808, No. 5

Flow Rate/Pressure Drop Characteristics--
In lieu of measuring the flow rate/pressure drop characteristics of the cycling Model 808's, the characteristics of two of the limiting orifices were measured at +23° and -20°C. The 23°C data are shown in Figure 67, and the -20°C data doesn't differ significantly. These orifices are not critical; the pump doesn't have that capacity. Nor does the orifice operate at a given point on a curve, but cycles about an average value.

Reliability of Calibration over Temperature--
The 1.5 hour data points from the flow rate stability experiments are plotted for the five Model 808 pumps in Figure 68. There is considerable variance between these pumps, and it would be somewhat arbitrary to state a calibration reliability figure. A curve is drawn through the data descriptive of Unit No. 2, and it shows a linear decrease in the flow rate (measured at room temperature) with decreasing temperature, and decreases by about 15 percent between 25° and -40°C. If the data from Unit No. 3, which tended to have low flow rates, is neglected, the calibration stability over the temperature range is reasonable.

Continuously Sample Cold Air--
After the conclusion of other testing, the Model 808's were operated on six separate days at -20°C. The pump would operate from 4 to 6 hours with the 100 ml/min orifice, and for more than 8 hours with smaller orifices. These pumps operate satisfactorily at -20°C; the battery is the principal limiting factor. At lower flow rates, the stability and the time of operation on a single battery charge will increase.

There is no evidence of damage or degradation due to operations at -20°C, other than the diminished capacity of Ni-Cd batteries at low temperatures, and it is believed that the Model 808 can operate at a low temperature for a long period of time.

Ease of Recalibration--
The only flow control option available on the Model 808 is the optional limiting orifice that attaches to the pump. Several "sets" of orifices are available and these are easily changed.

Battery Performance--
The Model 808's operate from two size AA Ni-Cd cells, each with a rated capacity of 500 mA-hrs. At high flow rates, i.e., at 100 ml/min, the battery is a principal performance limiting factor. A distinctive feature of this system is the periodic operation of a drive motor which operates a cam. The battery pack operates the motor to cycle the cam which, in turn, opens the battery circuit until the next cycle. Thus, the battery is open circuited for a time after each cycle. The battery life is dependent upon the rate at which this cycle is repeated, i.e., the flow rate. The pumps performance is relatively independent of the battery as long as the battery can cycle the cam. When it can no longer cycle the cam, the system simply stops. Between -20°C and +25°C, the Model 808's can operate for about 5 to 7 hours at 100 ml/min. At lower flow rates, it can operate beyond an 8-hour period.

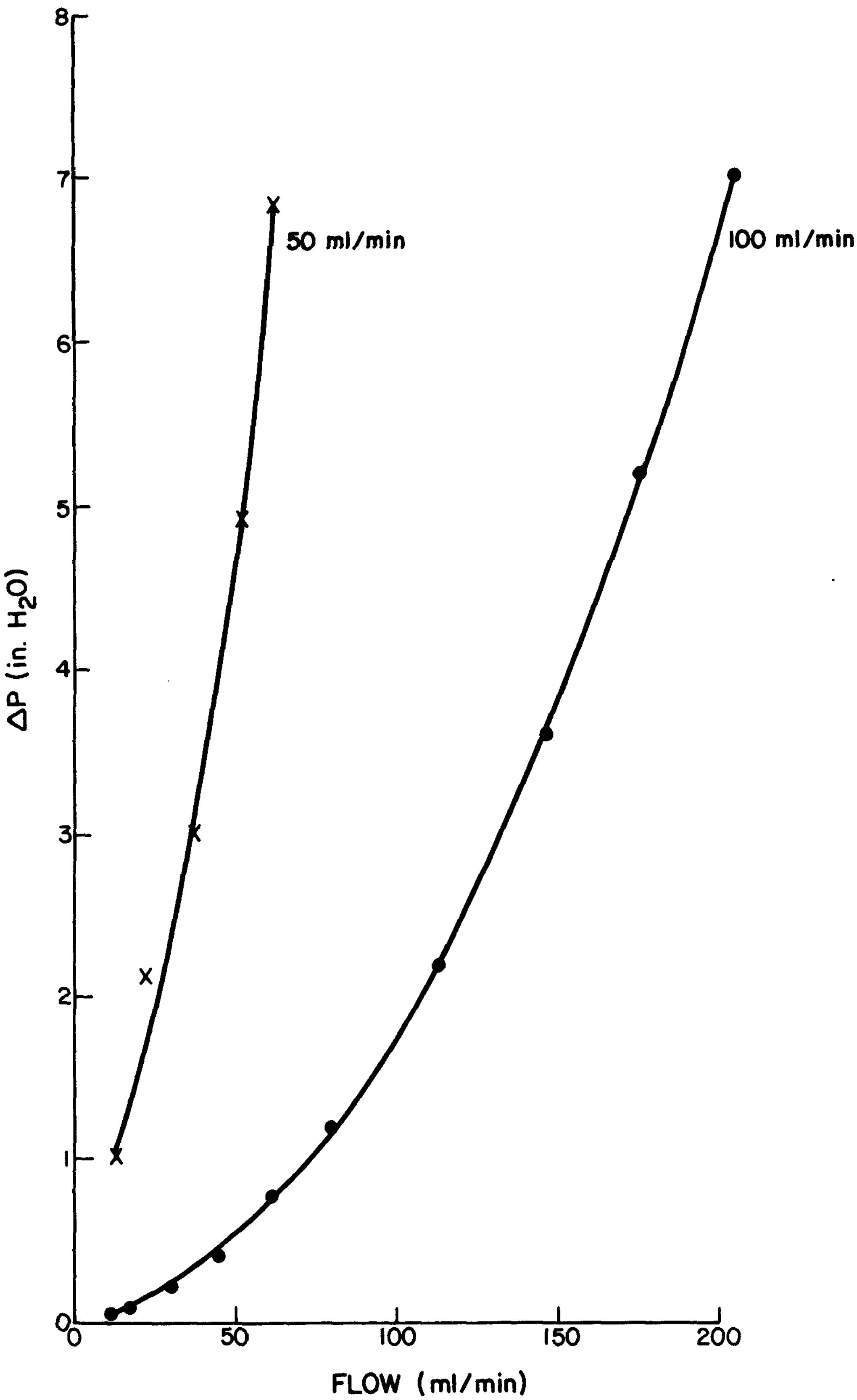

Figure 67 Characteristics of Two Model 808 Limiting Orifices

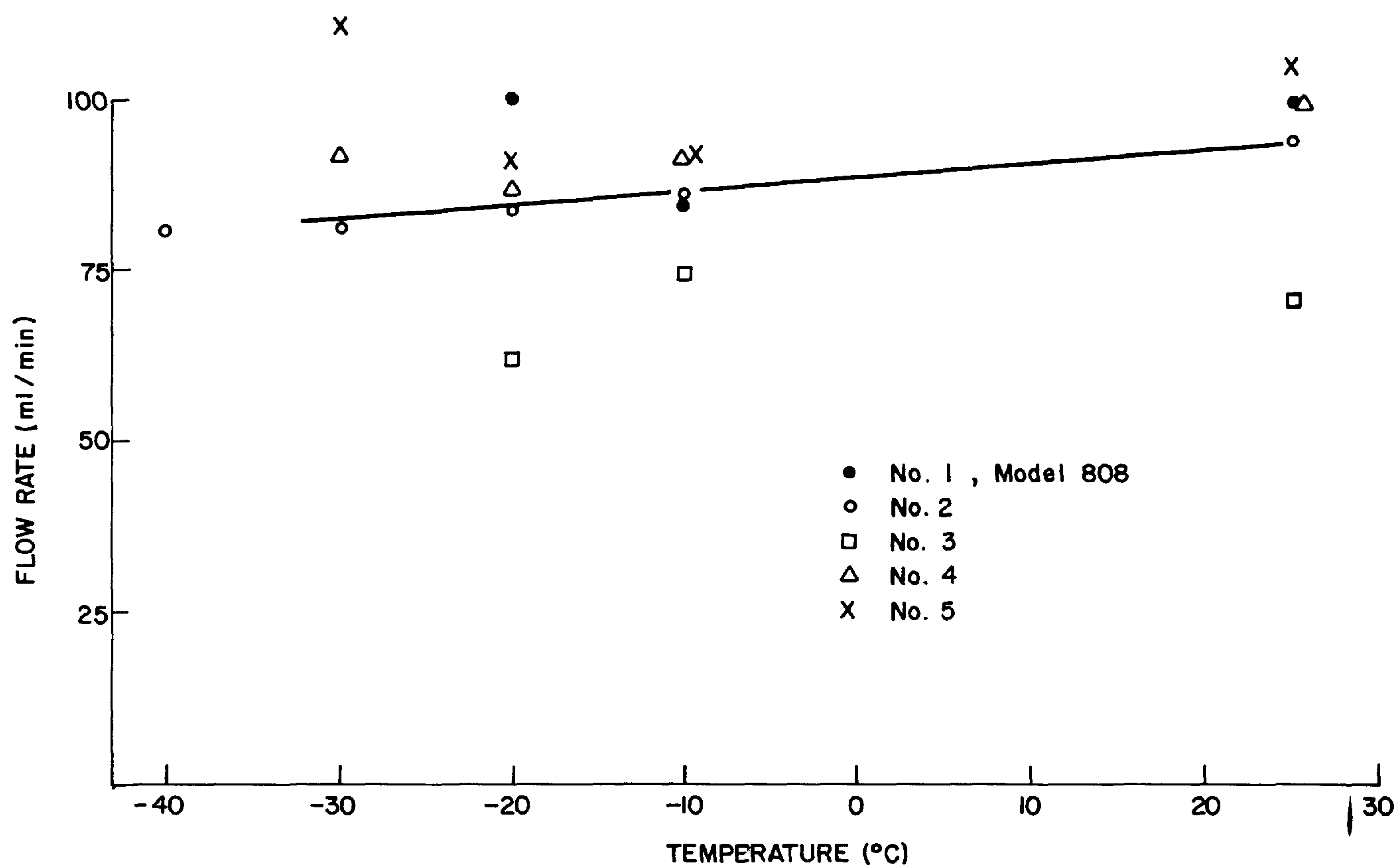

Figure 68 Flow Rate Calibration as a Function of Temperatures, Model 808

Diaphragm Reliability, Bearing Design, and Lubricants--
There is no evidence of failure or performance degradation that can be attributed to either the diaphragm, bearings, or lubricants of the Model 808. It is likely that diaphragm stiffness and cycle-life will change with temperature, and the bearings and lubricants are also likely to become stiff and tend to load the motor at low temperatures. These characteristics were not explicitly evaluated.

Case Ruggedness--
There is no evidence of damage or degradation to the case or other pump components as a result of the exposures encountered during these evaluations.

Spectrex Model PAS-1000

The Model PAS-1000 is a motorless, diaphragm-type pump driven by an oscillator and coil at a relatively high frequency. Figure 69 is a photograph showing two of these units. The wires evident in the photograph were added to facilitate testing with a power supply other than the pump's batteries. A maximum flow rate for the PAS-1000 was observed to be less than 800 ml/min. The flow rate stability tests were run at 200 ml/min at 1.5 in. of H_2O, and the flow rate/pressure drop characteristics were measured with the flow rate set at 200 ml/min at 1.5 in. of H_2O and also set to a maxmimum.

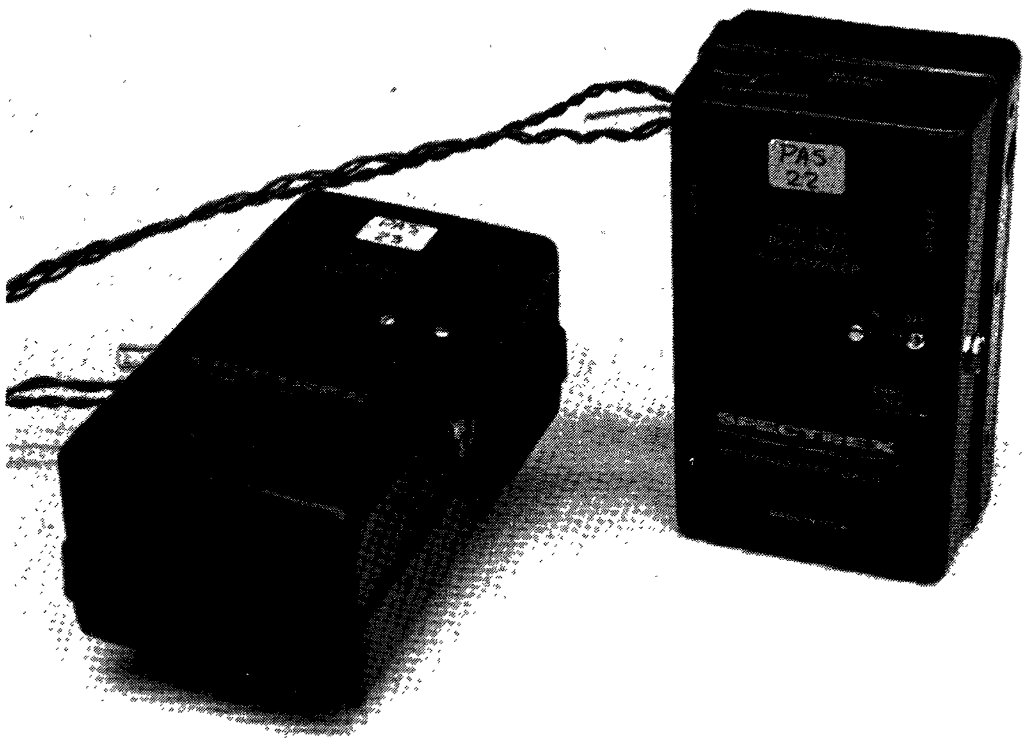

Figure 69 Photograph of the Spectrex PAS-1000

One of the two units was inoperative when received because of defective, i.e., "cold," solder connections. These were repaired to restore operation. One of the two battery chargers was also defective and would not fully restore the battery pack. Subsequent to this discovery, the two battery packs were charged from the same charger.

Flow Rate Stability with Time--
The flow rate stability of the two PAS-1000's is illustrated in Figures 70 and 71. Test conditions were an initial flow rate of 200 ml/min across 1.5 in. of H_2O at room temperature. As illustrated, the 26°C data increased over the 8-hour period. (It may be significant that the chamber (room) temperature also increased over that period from an initial 20° to about 26°C.) Unit No. 2 stopped operating after 6.5 hours at 25°C. Battery pack voltage and current were not being monitored at the time, but subsequent data suggests that this failure to operate was not a battery pack problem.

At 0° and -10°C, the flow rate on Unit No. 1 changed significantly while operating from the battery pack. No explanation is offered for the increase near the end of the day. The test temperatures remained constant and the battery voltage continued a normal decay. (The terminal voltage decayed from 1.3 to 1.09 V/cell at 0°C, and from 1.32 to 1.04 V/cell at -10°C. over the test period.) The Unit No. 2 flow rates also decayed very quickly at 0° and -10°C. At 0°C, a power supply was substituted for the battery pack after 1.5 hrs. when the battery pack voltage was 1.19 V/cell. At -10°C, a substitution was made after one hour when the battery voltage was 1.2 V/cell. In neither instance was a significant increase in flow rate achieved. It can be stated that the rapid decay in flow rate was arrested when the power supply was used. This could suggest that the flow rate was extremely sensitive to power supply voltages. However, the experiments with Unit No. 1 indicate that it is not. Flow rate variations with power supply voltages were not measured. At -30°C, neither unit would pump air. (The test apparatus could indicate flows of less than 5 ml/min.)

Flow rate stability tests were also run at -22°C. For Unit No. 1, the coolant source failed and the test temperature rose to 0°C over a 1.5 hour period. The pump flow rate also increased over this period. When the coolant source was restored and the temperature reduced again to -22°C, the flow rate decayed to about 71 ml/min, i.e., except for the perturbation with temperature, the flow rate was somewhat like the 0° and -10°C performances. Unit No. 2 dropped to a flow rate of less than 10 ml/min after 2 hrs.

Flow Rate/Pressure Drop Characteristics--
The flow rate/pressure drop characteristics of the PAS-1000's are shown in the curves of Figures 72 and 73 for Units 1 and 2, respectively. These data show the PAS-1000 flow rates to be very sensitive to both temperature and the pressure drop across the pump. These data were acquired after the pumps were adjusted for 210 ml/min at 1.5 in. of H_2O at 25°C, except for the 25°C data with the flow control set to a maximum. These latter data were acquired because the PAS-1000 was advertised as a 1ℓ /min pump.

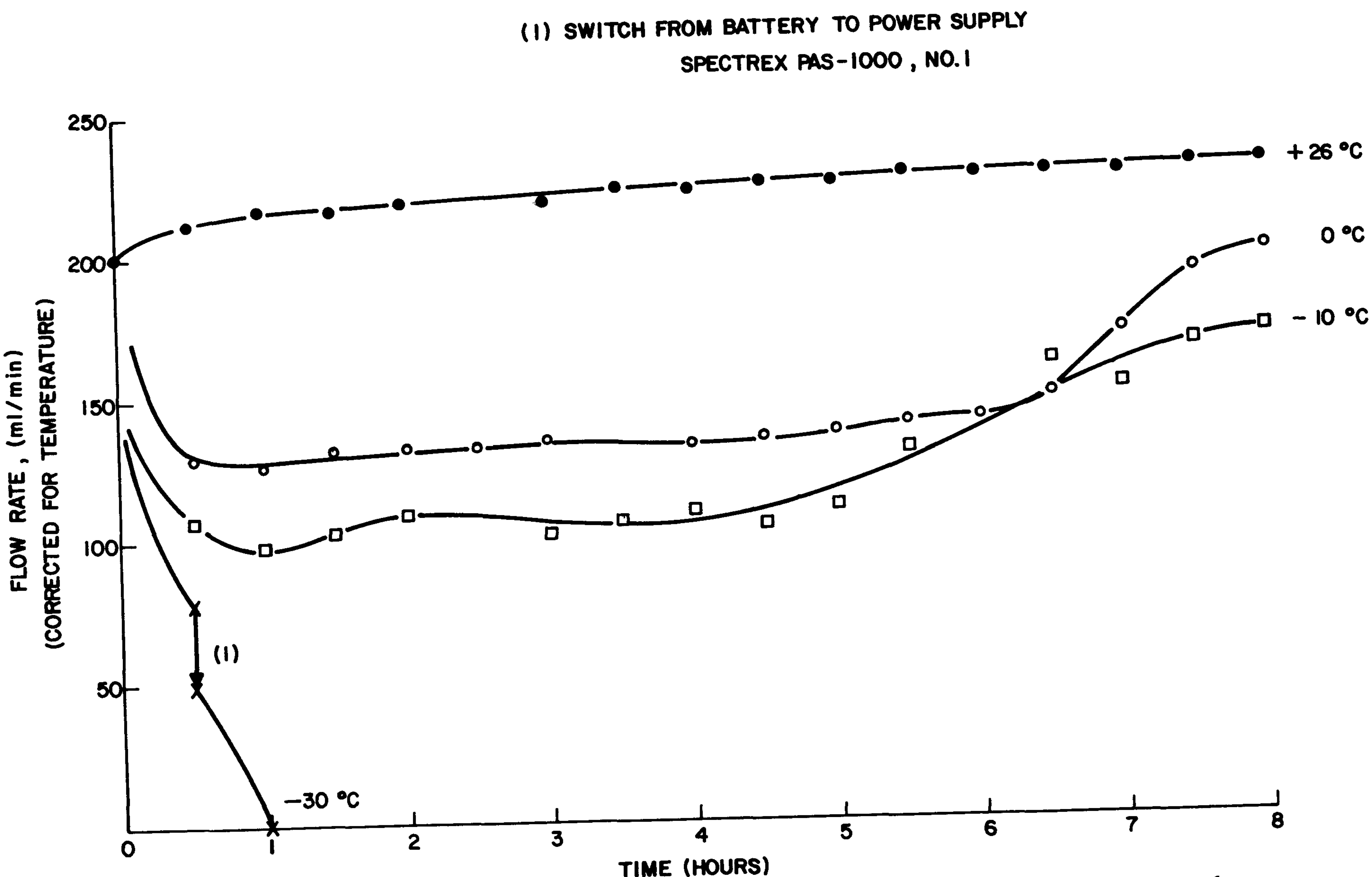

Figure 70 Flow Rate Stability, Corrected for Temperature, Model PAS-1000, No. 1

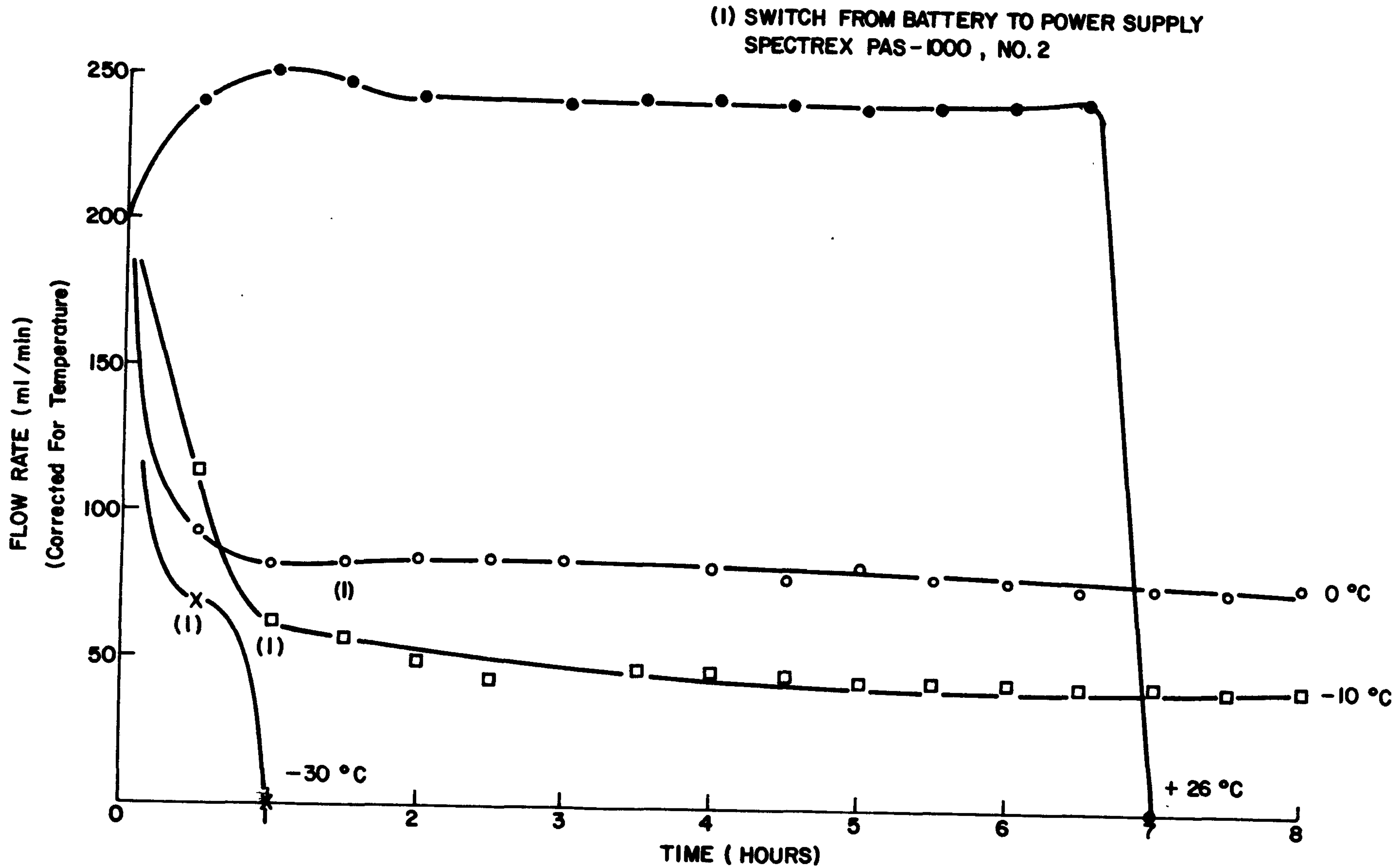

Figure 71 Flow Rate Stability, Corrected for Temperature, Model PAS-100, No. 2

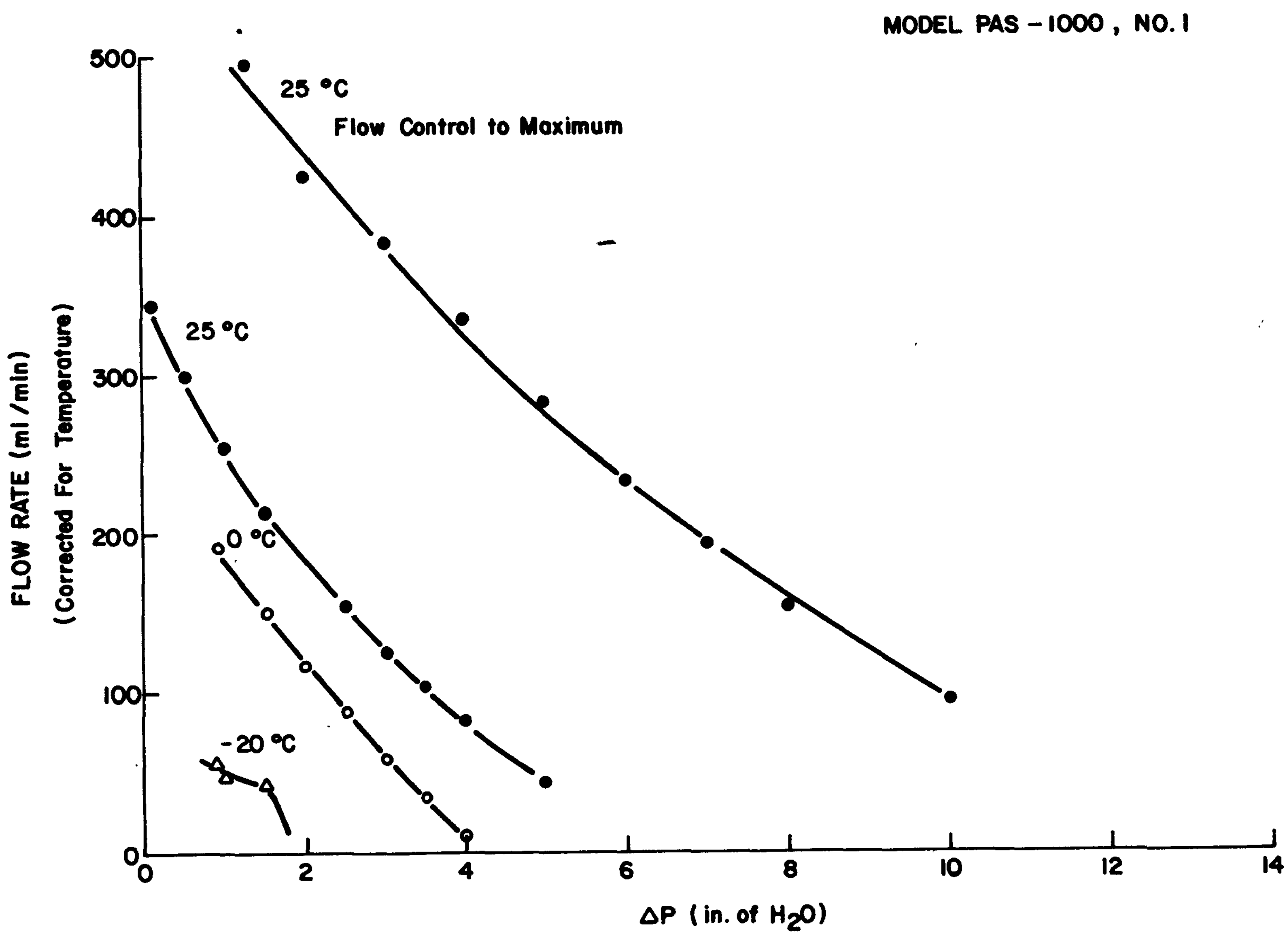

Figure 72 Flow Rate Versus Differential Pressure, Model PAS-1000, No. 1

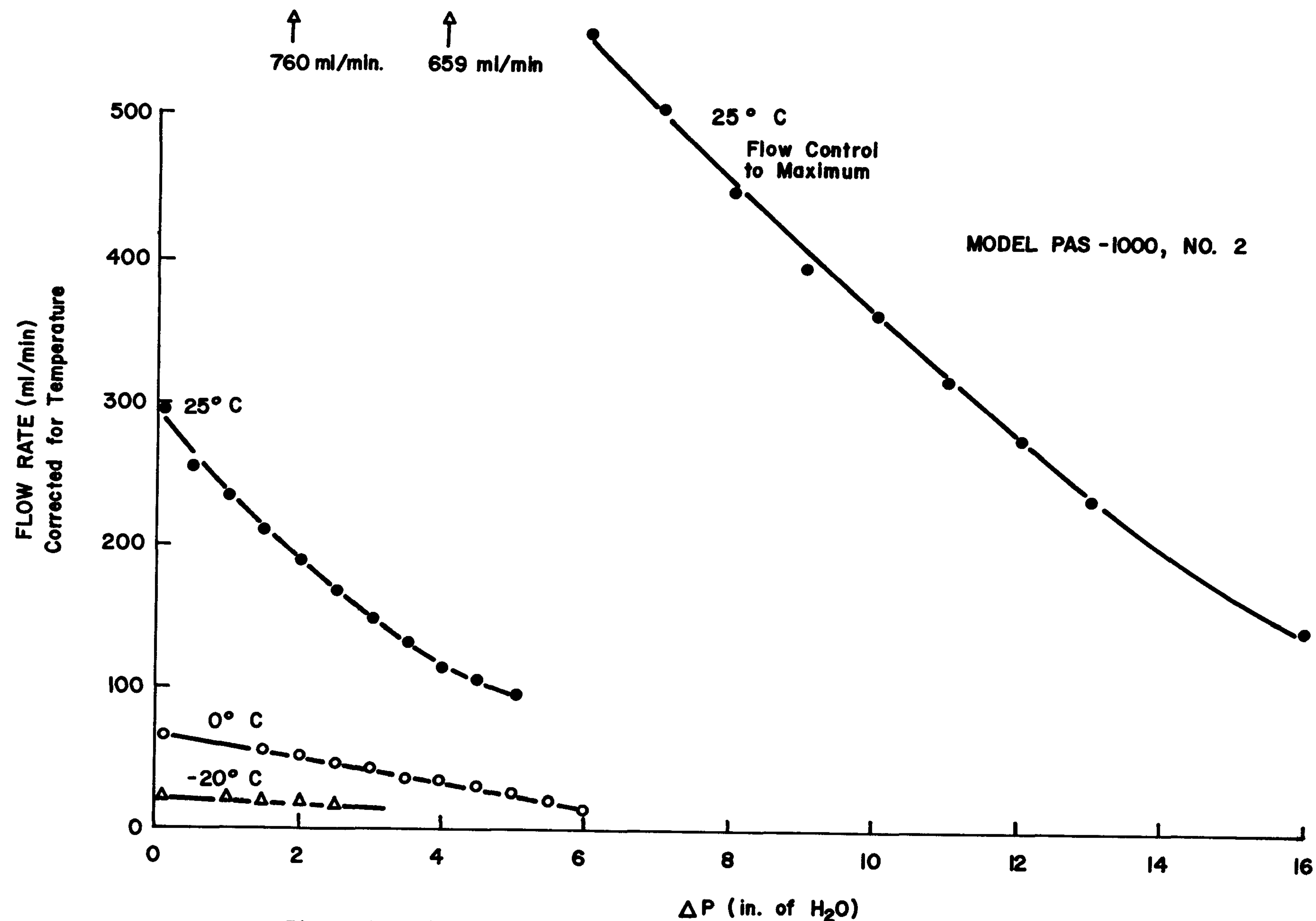

Figure 73 Flow Rate Versus Differential Pressure, Model PAS-1000, No. 2

Reliability of Calibration over Temperature--
After 1.5 hours of operation, the measured flow rates of Unit No. 1 were 217 ml/min at 25°C, 142 ml/min at 0°C, and 115 ml/min at -10°C. Thus, the calibration had decreased by 35 percent at 0°C and by 47 percent at -10°C.

Ease of Recalibration--
Calibration adjustments on the Model PAS-1000 are easily made with a multiple-turns potentiometer. There is no flow indicator on the unit, so these adjustments are not routine field adjustments. The calibration does vary with time and temperature.

Battery Performance--
The PAS-1000's are powered by 7, size C Ni-Cd batteries. There is no evidence to suggest that the pumps' performances were negatively influenced by battery degradation. Terminal voltages were high when power supply substitutions were made, and improved performances did not result from these substitutions.

Diaphragm Reliability--
There is no evidence that the diaphragm was damaged or degraded as a result of the testing and exposures encountered during these evaluations.

Bearing Design and Lubricants--
The oscillator/coil design of the PAS-1000 eliminates the usual motor and pump bearings. The oscillator/coil construction should reduce relative motion between components to a minimum and reduce low temperature problems associated with bearings and lubricants.

Case Ruggedness--
There was no case or component damage or degradation evident as a result of these tests and exposures.

Sipin Model SP-1

A single Model SP-1 available for evaluation had a minor binding problem that may have influenced some of the experimental results. A second unit was received as a replacement but not in time to be tested. Figure 74 is a photograph of the Model SP-1.

Flow Rate Stability with Time--
The Model SP-1 flow rate was measured at several test temperatures with the flow control set to a maximum, i.e., approximately 240 ml/min, and a pressure differential of 1.5 in. of H_2O. Figure 75 shows the measured flow rates, corrected for the difference between the test temperature and measurement (room) temperature, as a function of time at 25°, 0°, and -20°C. Flow rates computed from the pump's counter is essentially the same as the measured and corrected flow rate plotted, and a separate curve is not drawn.

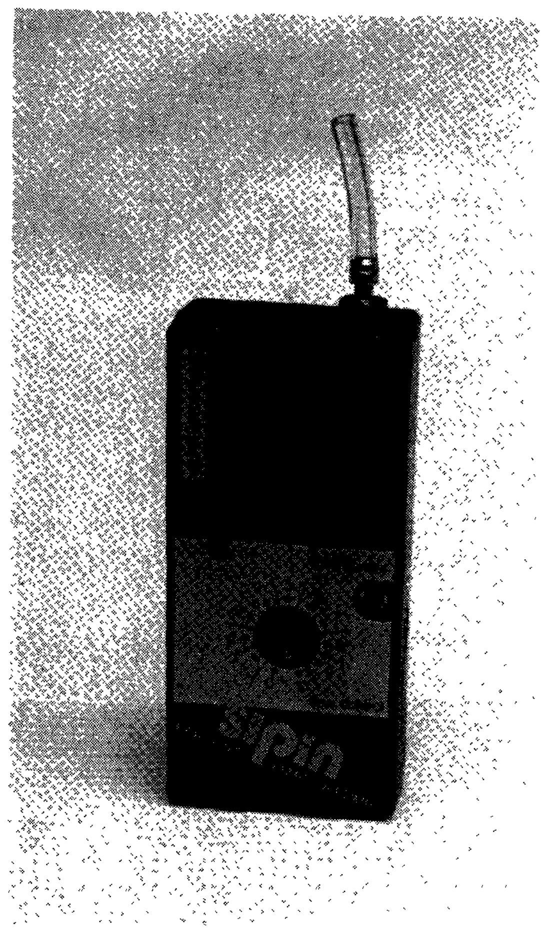

Figure 74 Photograph of the Sipin Model SP-1

At 25°C, the flow rate remained stable over the 8-hour period. The failure to operate after 5 hours at 0°C is thought to be due to a binding problem evident at the pump-counter interface. This problem, clearly evident at times, was not always evident. It is difficult to estimate what influence it had on other performances. At -20°C, the measured flow rate had the unusual characteristic illustrated. The flow rate computed from the pumps counter does not have the same anomaly. Except for the anomaly, the measured and corrected flow rates and the flow rates computed from the counter compare very closely. The Model SP-1 did not operate long at -30°C, probably because of the effect of temperature on a Hg reference cell used in the electronics.

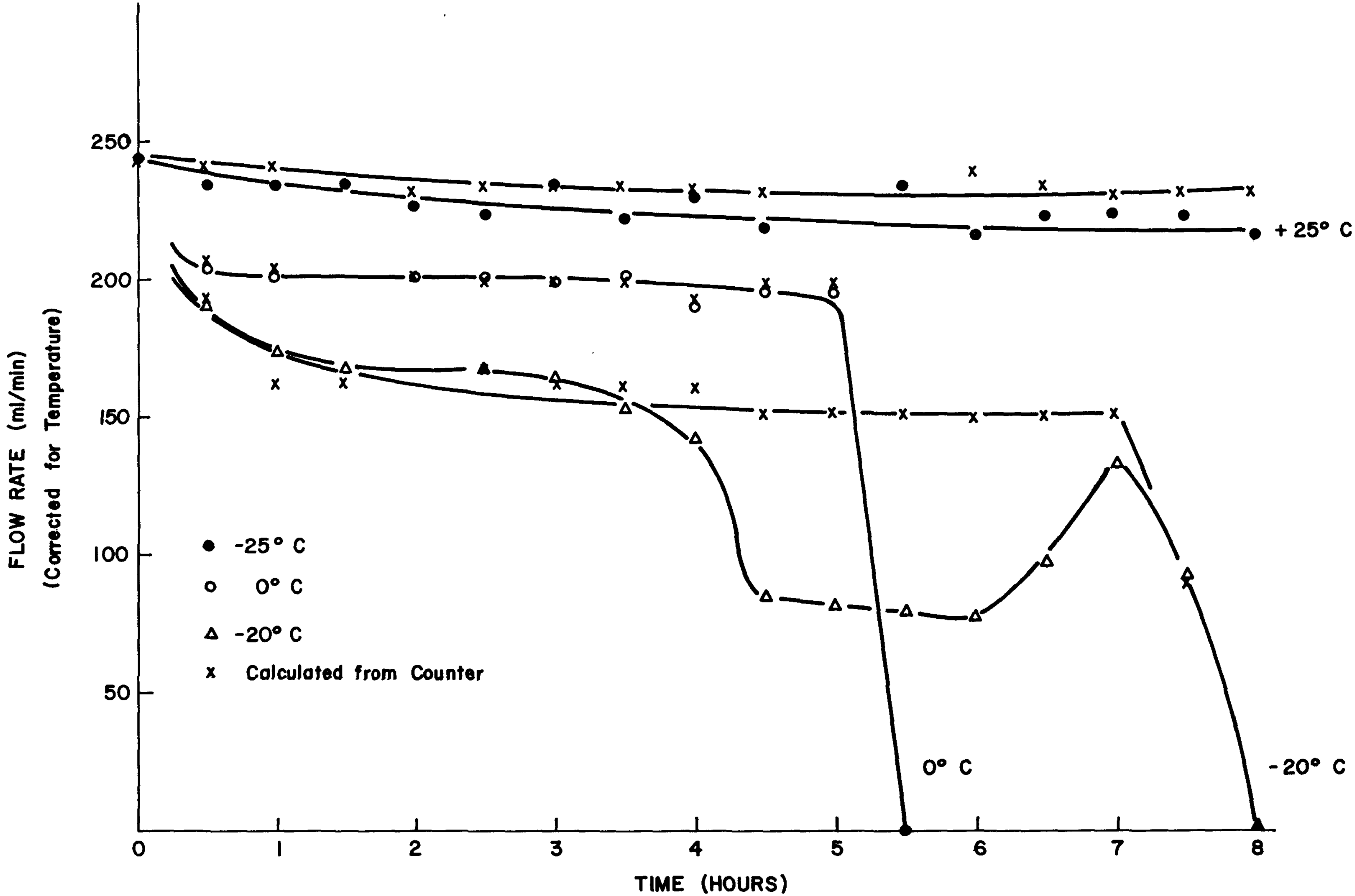

Figure 75 Flow Rate Stability, Corrected for Temperature, Model SP-1

Flow Rate/Pressure Drop Characteristics--
The flow rate/pressure differential characterisitics of the Model SP-1 are included in Figure 76. The values plotted are corrected to correspond to the measurement (room) temperature. The flow rates vary linearly with pressure differential. (At all test temperatures, and the measured flow rates would appear much more uniform.)

Reliability of Calibration over Temperature--
The measured 1.5 hour data points from the flow rate stability data show the flow rate to decrease from the 25°C value by 7 and 17 percent at 0°C and -20°C, respectively.

Continuously Sample Cold Air--
The Model SP-1 was operated at -10°C on several days after the completion of other testing. Its performance, influenced by the binding problem described earlier, was somewhat erratic, i.e., it's period of operation varied significantly from day to day.

Ease of Recalibration--
The flow rate of the Model SP-1 is easily adjusted with a screwdriver adjustment control. Reference numbers are on the control, and these could be used to facilitate field adjustments. However, there is no indication of flow rate other than the counter.

Diaphragm Reliability, Bearing Design, and Lubricants--
The diaphragms, bearings, and lubricants were not explicitly evaluated. There is no evidence of diaphragm or bearing degradation or failure. The binding discussed earlier in this section occurred in a slotted fitting interfacing the pump and counter and not in a motor or pump bearing.

Case Ruggedness--
There is no evidence of case or component damage as a result of the low temperature exposures encountered during these evaluations.

SUMMARY

All of the personal sampling pumps evaluated are sensitive to temperature changes between 25°C and -50°C. There is considerable variance in the sensitivity of the different models evaluated, and some variance within a single model. All of the pumps evaluated are useful sampling instruments at 0°C, and none are functional at -50°C. (Pumps which perform poorly at 25°C also perform poorly at 0°C.) Between these extremes, the different models are effected differently by temperature. From among these pumps, the industrial hygienest can select a pump suitable for most any application to a low temperature of -20°C. At lower temperatures, his options are severely limited.

None of the pumps tested were useful at -50°C. The Ni-Cd batteries used in these personal sampling pumps are not useful at this low temperature. (We do not know of any other battery system, primary or secondary, that is superior to the Ni-Cd system for this application.) If a suitable power source were

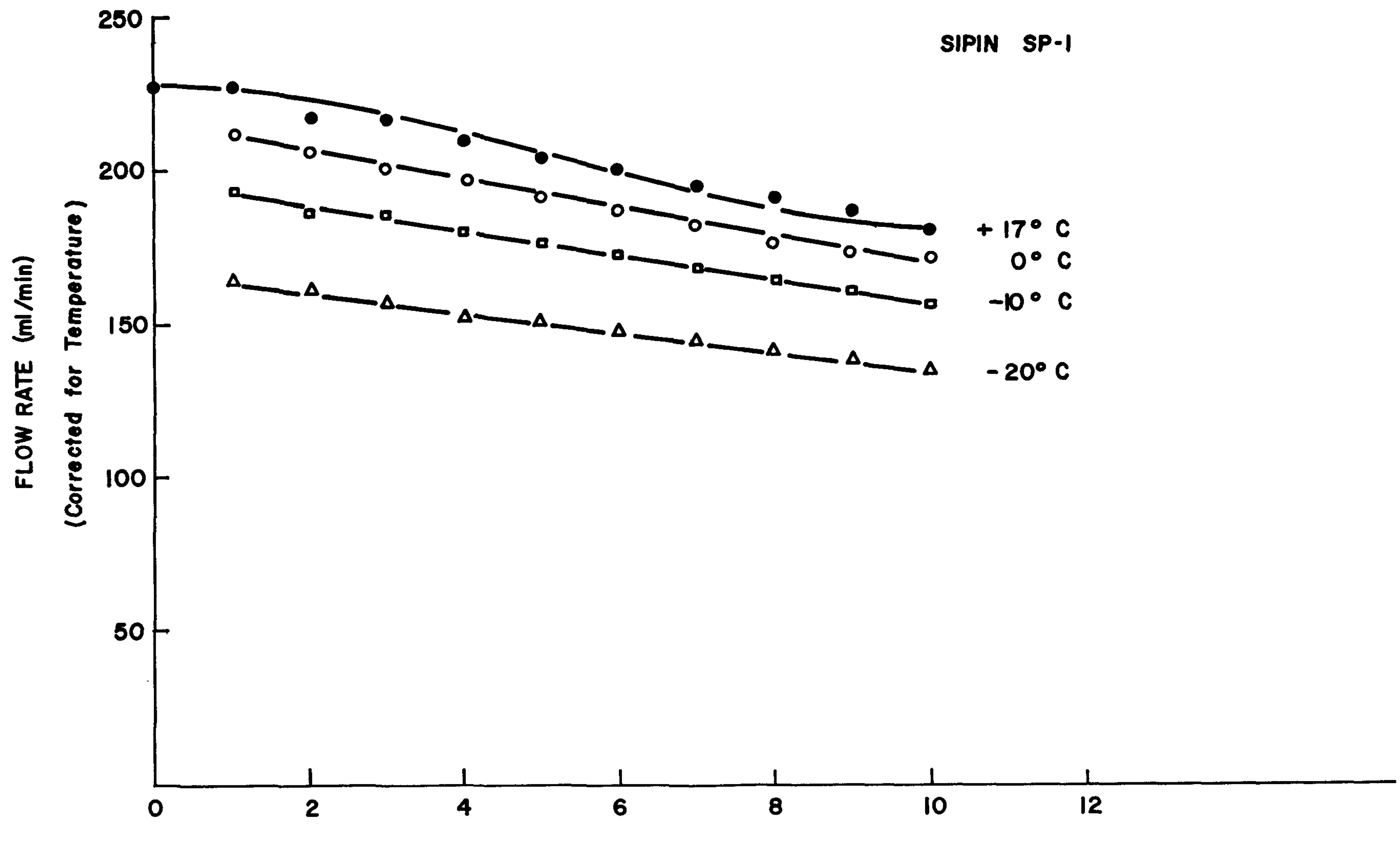

Figure 76 Flow Rate Versus Differential Pressure, Model SP-1

available, the pumps themselves would not be suitable. None would operate reliably and most would not operate at all.

At -40°C, the Model P-125 would provide some sampling capability, i.e., a reasonable but somewhat erratic flow rate for a period of 2 to 4 hours. With an adequate power supply, e.g., a larger Ni-Cd battery capacity or a remote battery pack maintained at a higher temperature near the body, the -40°C sampling may be reasonably good.

At -30°C, the Model P-125 can provide a useful sampling capability for about 8 hours on its internal battery pack. (Some selection of battery packs and pumps may be necessary.) The MSA Models G and S are marginally useful for the higher, nominally 2ℓ /min flow rates, and the MDA Model 808 is marginally useful for lower flow rates, i.e., less than 100 ml/min. The Models G and S flow rates will be significantly lower than 2ℓ /min, and they will operate for about 7 to 8 hours. The MDA will have a maximum flow rate of about 50 ml/min and the period of operation will be less than 4 hours.

At -20°C, the MSA Models G and S, the DuPont Model P-125, the Model 808, and the Sipin Model SP-1 will all provide a useful, 8-hour sampling capability. The Models G and S and the P-125 will perform reasonably well as compared to their 25°C capabilities. The Model 808 will be limited by battery capacity if an 8 hour period of operation is desired. The Model SP-1, which may have been limited by an uncharacteristic anomaly, will provide a reasonable pumping capability at -20°C. The Sipin has a Hg reference cell which does limit its performance at lower temperatures.

It is emphasized again that a comparison of the pumps evaluated was not an objective of this effort. The pumps are rated or specified differently by their manufacturers and, consequently, comparison is somewhat unfair. This is especially true of the pumps which were not tested as CMDPSU units. However, in our opinion, there is an obvious quality of construction and room temperature performance about some of these pumps which should be acknowledged. The MSA Models G and S, the MSA Model C-200, and the DuPont P-125 perform well at room temperature and give an impression of quality construction. (The C-200, however, should not be considered for application below 0°C because of the Hg reference cell.) This is not to say that the other pumps are not adequately constructed and some advantages cited for each. The SP-1, for example, is well constructed, and the simplicity of the system can be advantageous. The Model 808 has a different operating mechanism which could have some advantages. It should, for example, be relatively insensitive to battery status until the pump fails to operate at all. The Model 2392-PS is similar in many respects to the Models G and S. It is lighter, has a smaller battery pack, and performs well for 8 hours at room temperature. The Model PAS-1000 is significantly different from any of the other pumps. It does not contain a conventional motor driven pump, but operates a diaphragm pump in a small displacement/high frequency mode. There are some inherent advantages to such a system at low temperatures. However, in the present model, the pump is very sensitive to pressure differential and the high frequency sound can be somewhat objectionable.

RECOMMENDATIONS

We concluded that the personal sampling pumps evaluated were not designed for use in sub-zero environments. Instead, they were designed and optimized for use in temperatures near 25°C. We conclude further that, in response to the solicitation for pumps for this evaluation, the standard models were submitted without significant changes to optimize these units for low temperatures because of insufficient time and incentive. Consequently, standards based upon the results of these evaluations will tend to be premature and somewhat pessimistic. Standards recommended in a subsequent section should be considered as preliminary, subsequent to further investigations and developments.

INVESTIGATIONS

The Working Environment In Cold Climates

The Alaskan environment has been adequately defined in this report, and the interested reader can find a more detailed description in the references cited. What is needed is a definitive description of the Alaskan working environment. It is doubtful that personnel work in -50°C temperatures, for example. Moreover, at low temperatures, their options for adjusting pump flows or observing operations will be significantly limited. In a cold environment, a useful mode of operation for a personal sampling pump would be to protect the unit by wearing it underneath the outer clothing. As a minimum, the pump could be configured so that the batteries could be worn near the body and thus maintained at a warmer temperature.

It is recommended that the working environment encountered in the Arctic Area be investigated, along with various options regarding the use of personal sampling pumps in such an environment. These investigations would involve placing a knowledgable observer in that environment for several weeks at select periods to evaluate the environment and further test the use of personal sampling pumps. Selected pumps, configured for optional use practices, would be worn and monitored in the working environment. A small, portable, controlled environment instrument package could be configured to monitor the pump's performances. These investigations would enhance the development of reasonable standards pertinent to the use practices and performances of personal sampling pumps in cold environments, and it is recommended that they be conducted. As a part of these investigations, the influence of the cold, dense air on the distribution of contaminants and its significance in terms of toxicity and detector tube responses should also be considered.

Battery Investigations

There is a dearth of information pertaining to the characteristics of Ni-Cd batteries at low temperatures. Since these batteries are the best choice for operating personal sampling pumps and other portable apparatus, it is reasonable to investigate their characteristics between room temperature and -50°C.

It is recommended that a compliment of commercially available Ni-Cd batteries in all of the standard sizes be tested to rate their performances as a function of temperature and discharge rate as compared to their performances at 25°C and ten-hour discharge rate. Ideal maintenance practices should be followed. It is further recommended that the cycle life of a complement of Ni-Cd cells be measured at the ten-hour discharge rate as a function of temperature. The capacity of the cells under test should be derated to correspond to the capacity at the test temperature as determined in the preceding investigations.

Sampling Devices

These investigations have not addressed the issue of the effect of temperature on the various sampling devices which are used with personal sampling pumps. The sampling devices are an integral part of the system, and it is recommended that these be characterized at low temperatures in a subsequent study.

DEVELOPMENTS

There is much that can be done to enhance the performance of personal sampling pumps at low temperatures. A thoughtful selection of materials, components, and lubricants with low temperature performance as an objective is an obvious initial step. It may also be advantageous to configure the pump differently, e.g., such that the battery pack is separate and can be selected to provide different capacities. Subsequent to the investigations prepared in the preceding section, it is recommended that NIOSH sponsor the development of a pump optimized for use in the working environment encountered in cold climates. This environment would be defined as a result of the recommended investigations.

The recommended development effort is not envisioned as an extensive undertaking, and the manufacturers of promising pumps may undertake the project on their own resources if a use environment and a potential market is defined.

In either event, the resultant pumps would have to be reevaluated with the defined environment as a test condition. If a suitable pump did not evolve, further development efforts would need to be considered. The results of the evaluations described herein suggest that personal sampling pumps suitable for use in -30°C environments can be obtained with a little effort. (The Model P-125 may be suitable now with selected batteries.)

RECOMMENDED USE TECHNIQUES

For the personal sampling pumps evaluated, it is recommended that they not be used at temperatures lower than tabulated below:

Pump	Low Temperature Limit (°C)
MSA Model G	-20
MSA Model S	-20
RAC Model 2392-PS	0
MSA Model C-200	0
Du Pont Model P-125	-30
MDA Model 808	-20
Spectrex Model PAS-1000	0
Sipin Model SP-1	-10

It is further recommended that each pump be calibrated for the desired flow at the use temperature. To the extent that the pump's environment can be moderated (by wearing under clothing, for example) it should be done. However, the moderated environment needs to be defined. It is conceivable that the working environment need not be moderated for some of the pumps evaluated.

The manufacturers use and application instructions should be considered as a guide and followed to the extent possible. The user should be mindful that these instructions assume near room temperature conditions. In the interpretation of sampling results, the effects of a more dense air sample should be considered. The effect of air density on contaminant levels and detector responses has not been considered herein.

The battery pack should be used with care regardless of temperature. Recharging should be carried out with the charger supplied by the manufacturer according to instructions and at room temperature. In lieu of this option, the batteries should be charged at a constant C/10 rate for about 15 hours, or at a C/20 rate for much longer periods. (C is the ampere-hour rating of the battery.) The battery should not be recharged unless a significant portion of its capacity has been dissipated, e.g., C/3 ampere-hours.

STANDARDS RECOMMENDED BY RTI

The standards recommended below are an adaptation of the CMDPSU standards in 30 CFR 74 to personal sampling pumps for use in cold environments [Ref. 1]. These standards reflect the needs of OSHA and industry for pumps suitable for sub-zero industrial hygiene surveys as reflected in 30 CFR 74 and the performances observed in the pumps evaluated. These recommended standards are arranged in a numbered paragraph format to conform to the format usually found in the Federal Register. A statement of rationale is included in those instances where it is considered helpful. With reference to 30 CFR 74, references to the sampling devices have been deleted. There is an obvious need to evaluate the performances and responses of sampling devices and detectors in low temperatures, but these were not objectives of this evaluation program.

1. Purpose
The regulations in this part set forth the requirements for approval of personal sampling pumps designed for use in sub-zero environments.

2. Sampler unit
The personal sampling pumps shall consist of a pump unit adaptable to a sampling head assembly and, if rechargeable batteries are used in the pump unit, a battery charger.

3. Specifications of the personal sampling pump
(a) Pump unit--(1) Dimensions. The overall dimensions of the pump, hose connections and valve or switch covers shall not exceed 8 inches in height, 6 inches in width and 4 inches in thickness.

(2) Weight. The pump unit shall not weigh more than 4 pounds.
(3) Construction. The case and all components of the pump unit shall be of sufficiently durable construction to endure the wear of use in sub-zero environments to -30°C. (Rationale: The pumps evaluated did not perform acceptably at temperatures below -30°C. Thus, durability at -30°C is a suitable objective.)
(4) Exhaust. The pump shall exhaust into the pump case, maintaining a slight positive pressure which will reduce the entry of foreign materials into the pump case. (Rationale: This requirement, repeated here from 30 CFR 74, does eliminate positive pressure applications such as filling gas bags. However, it seems as important a consideration in an environment of blowing snow as in a coal-dust environment. Moreover, the emphasis in these tests was personal sampling.)
(5) Flow rate adjustment. The pump unit shall be equipped with a convenient means of flow rate adjustment. To prevent accidental adjustment, the flow rate adjuster shall be inside the pump case or recessed in the pump case and shall require the use of an adjusting tool. (Rationale: This requirement is intended to be less restrictive than the similar requirement in 30 CFR 74. All pumps will not have a flow rate indicator. However, all pumps shall provide a means of adjusting flow rates either in the field or in a laboratory.)

(6) Battery. The power supply for the pump shall be a suitable battery pack located in the pump case or in a separate case which attaches to the pump case by a permissible electrical connection.

(7) Pulsation. When a pump's flow rate is 1.0 ℓ/min or greater, the irregularity in flow rate due to pulsation shall have a fundamental frequency of not less than 20 Hz. This requirement shall not apply when the flow rate is less than 1.0 ℓ/min.

(8) Belt clips. The pump unit shall be provided with convenient means of securing the pump to a wearer's clothing.

(9) Recharging connection. A suitable connection shall be provided so that the battery may be recharged without removing the battery from the pump case or from the battery case if a separate battery case is used.

(10) Flow rate indicator. Pumps specified by their manufacturers for flow rates greater than 1 /min at room temperature shall have a flow rate indicator as an integral part of the pump unit and the flow rate indicator shall be calibrated within +/- 5 percent for flow rates between 1 and 2 l/min and temperatures between 40° and -20°C. The manufacturer shall provide temperature and pressure operation ranges and correction factors. Pumps specified by the manufacturers for flow rates less than 1 l/min at room temperature shall provide for an indication of the total volume of air pumped, or an indication that the pump has failed to maintain a selected flow rate over the sampling period. In these instances, the manufacturer shall also provide temperature and pressure operation ranges and correction factors. The specified flow rates shall correspond to a specified maximum pressure differential.

(11) Flow rate range. There is a need for a wide range of sampling flow rates. Manufacturers of pumps approved under this part shall specify a range of flow rates that can be maintained for 4- and 8-hour periods at specified pressures by the pump, and the pump flow rate shall be adjustable over this range.

(12) Flow rate consistency. The 8-hour flow rate shall remain within +/- 15 percent of a specified value over an 8-hour period and over a temperature range of 40° to -20°C. (Rationale: The better pumps evaluated conformed to this requirement.)

(13) Duration of operation. Pumps approved under this part shall be specified for either 4 or 8 hours of operation at the specified flow rate and pressure differential across the pump in the temperature range of 40° to -20°C.

(14) Battery charger. The battery charger shall be operated from a 117 volt, 60 Hz power line. It shall be provided with a cord and polarized connector so that it may be connected to the charge socket on the pump or battery case. The battery charger shall be fused, shall have a grounded power plug, and shall not be susceptible to damage by being operated without a battery on charge. The battery charger shall be capable of operating at either a 16- or 64-hour charge rate. It shall be capable of fully charging the battery in the pump unit in the stated times and shall not overcharge a discharged battery in 16 hours when operating at 16-hour charge rate or in 88 hours when operating at the 64-hour charge rate.

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APPENDIX

TABLE 1A

COMPANIES RECEIVING REQUESTS FOR LITERATURE DESCRIPTIVE OF PERSONAL SAMPLING PUMPS

Company
Air Sampling Division, OR
The American Society of Safety Engineers, Inc., IL
Anatole J. Sipin Company, NY
Anderson 2000, Inc., GA
Bacharach Instrument Company, PA
Bendix Corporation, MD
The Canadian Society of Safety Engineers, Inc., Ontario
Century Systems Corporation, KS
CSE Corporation, PA
Denver Equipment Division, CO
Devco Engineering, Inc., NJ
E. I. du Pont de Nemours & Company, DE
Edmont Wilson Company, OH
Industrial Products Company, PA
Industrial Safety Equipment Association, Inc., VA
Joy Manufacturing Company, CA
Lefco Engineering, CA
Matheson Gas Products, NJ
Microchemical Specialties Company, CA
Mine Safety Appliances Company, PA
Quality Control Equipment Company, IA
Research Appliance Company, PA
Safety Equipment Distributors, Inc., VA
SKC, Incorporated, PA
Spectrex Company, CA
Staplex Company, NY
Thermo Systems, Inc., MN
Weather Measure Corporation, CA
Willson Products Division, PA

RESEARCH TRIANGLE INSTITUTE
POST OFFICE BOX 12194
RESEARCH TRIANGLE PARK, NORTH CAROLINA 27709

SYSTEMS AND MEASUREMENTS DIVISION

Gentlemen:

The Research Triangle Institute (RTI), under contract to the National Institute for Occupational Safety and Health (NIOSH), is planning an evaluation of personal sampling pumps suitable for use in cold, sub-zero environs such as the Alaskan oil fields. Pumps such as the Coal Mine Dust Personal Sampler Units (30 CFR 74) and Detector Tube Units (42 CFR 84) are especially of interest for the planned evaluation. Other pumps and prototypes which are suitable for use in low temperature environs will also be solicited.

The evaluation program will be conducted under NIOSH Contract No. 210-76-0124. The NIOSH Project Officer is Mr. Charles S. McCammon, DPSE-MRD, Robert A. Taft Laboratories, 4676 Columbia Parkway, Cincinnati, Ohio 45226, Telephone (513) 684-2591. The Project Director at RTI is Dr. Richard Whisnant, and the Project Leader is Mr. Carl D. Parker.

Manufacturers of personal sampling pumps are urged to participate in this evaluation program. We are initially seeking to determine the availability of personal sampling pumps by requesting brochures, specifications, and other descriptive information. Pumps will be selected for evaluation from the information received. Subsequent correspondence will include additional information relative to the evaluation program and request specific pumps for evaluation. We will appreciate receiving this information as soon as possible and no later than July 12, 1976. It should be sent to the attention of the undersigned.

Your response to this request for descriptive literature and your cooperation with the planned evaluation program will be appreciated. If you desire additional information, please call the undersigned at (919) 549-8311.

Very truly yours,

Carl D. Parker
Systems & Measurements Division

CP/smk

(919) 549-8311 FROM RALEIGH, DURHAM AND CHAPEL HILL

RESEARCH TRIANGLE INSTITUTE
POST OFFICE BOX 12194
RESEARCH TRIANGLE PARK, NORTH CAROLINA 27709

SYSTEMS AND MEASUREMENTS DIVISION

Gentlemen:

We appreciate your prompt response to our recent request for information descriptive of available personal sampling pumps. We have reviewed the information received and concluded that your Models are suitable for the purposes of the evaluation program. The purpose of this letter is to provide you with additional information about the planned program and to request your further participation.

The Research Triangle Institute is conducting this evaluation under contract to the National Institute for Occupational Safety and Health (NIOSH). The NIOSH Contract No. is 210-76-0124 and the Project Officer is Mr. Charles McCammon, Robert A. Taft Laboratories, 4676 Columbia Parkway, Cincinnati, Ohio 45226, (513) 684-2591. The Project Director at RTI is Dr. Richard A. Whisnant and the Project Leader is Mr. Carl D. Parker.

With the development of United States energy resources in sub-zero environs, such as in Alaska, there is an increasing need for information relative to the current air sampling instrumentation and methodology available for industrial hygiene investigations in sub-zero weather. In field use, cold temperatures may alter the response of such air sampling instruments as personal sampling pumps. Some basic problems associated with the operation of air sampling instruments in sub-zero environs are, for example, greases and oils freezing, bearings freezing up, piston units freezing and sticking, pump diaphragms becoming brittle, valves sticking, and decreased battery efficiency. Since it is necessary to use personal sampling pumps for field industrial hygiene surveys including compliance work by OSHA, data must be obtained to establish the reliability and operating characteristics of personal sampling pumps in these sub-zero environs.

The temperature range of interest will be from room 21°C to a lower limit of -50°C. It is not necessary for a pump to be functional to the lower limit to be of interest. Further, since battery deficiency will limit the low temperature operation of most pumps to a much higher temperature than -50°C, some experimental evaluations will be completed using a laboratory power supply rather than batteries.

(919) 549-8311 FROM RALEIGH, DURHAM AND CHAPEL HILL

If you have explicit recommendations to enhance the operation of your pump at low temperatures, please call them to our attention. If the pumps evaluated differ in any way from those obtained with a routine purchase order, it is essential that these differences be called to our attention.

We are requesting that five (5) units of your Models be sent to us for evaluation at your earliest convenience, and no later than September 20, 1976. These should be shipped to RTI to the attention of Mr. Carl D. Parker. Shipment may be made C.O.D. (include insurance). RTI will return the pumps F.O.B. your plant (with full insurance coverage).

The following points are also relevant to the evaluation program and are called to your attention:

1. Pumps submitted for evaluation must be accompanied by a statement excluding RTI and NIOSH from responsibility for damages which might occur during the evaluation program. Necessary accessories should also be included. A complete operational manual featuring operating instructions, flow diagrams, and circuit diagrams, for example, are required for the evaluation program and should be included. Material routinely supplied to purchasers of the instrument should be clearly identified.

2. Based upon the results of the evaluation program, RTI will recommend to NIOSH a set of performance standards and quality control standards applicable to personal sampling pumps for use in sub-zero environs. Participants will have an opportunity to comment on these recommendations.

3. Each participant is entitled to see the results of the evaluation of his pump only. Results of tests on other pumps will be kept confidential until governmental publication of test results.

4. The results of the preliminary evaluation released to the participant by RTI may not be used for advertising purposes or as a claim of endorsement by NIOSH. Any publication resulting from these evaluations can, of course, be referenced.

Your prompt reply to this invitation and your cooperation in this evaluation program will be greatly appreciated. If you desire additional information, please call the undersigned at (919) 549-8311 or Mr. C. McCammon at (513) 684-2591.

Very truly yours,

Carl D. Parker
Project Leader

CDP/js

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