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Feasibility Evaluation of a Reusable Contaminant Filter Canister for Use as an Oxygen Breathing Apparatus Trainer

Final Report

By

Arthur K. Colling, Jr.

Prepared Under Contract N61339-83-C-0029

By

Hamilton Standard
Division of United Technologies Corporation
Windsor Locks, Connecticut 06096

For

Department of the Navy
Naval Training Equipment Center
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ABSTRACT

A reusable training canister, OBAT, is being developed for use with the Navy Oxygen Breathing Apparatus, OBA, during training exercises within the controlled environment of the 19F1 Fire Fighter Trainer. Unlike the closed system of the standard OBA, the open OBA system in the 19F1 trainer application requires both gaseous contaminant and particulate removal. The gaseous contaminants of concern are carbon monoxide, carbon dioxide, propane, and nitrogen dioxide. The particulates to be removed are butylated triphenal phosphate used as simulated smoke and sodium bicarbonate used as a simulated dry powder extinguishant. A feasibility model filter canister was designed and built for use in verification testing of the entire OBAT concept. The canister was tested against various levels of the gaseous contaminants at the anticipated extremes of temperature and humidity. The particulate filters were tested under training conditions in the 19F1 Fire Fighter Trainer. Additionally, the total system, OBA and OBAT, was tested for air flow resistance, and the temperature transient in the facemask was measured with the system operating at various high ambient temperatures.

FOREWARD

This report has been prepared by Hamilton Standard, Division of United Technologies Corporation, for the Department of the Navy, Naval Training Equipment Center, in accordance with Contract N61339-83-C-0029, Feasibility Evaluation of a Reusable Contaminant Filter Canister for use as an Oxygen Breathing Apparatus Trainer. The report covers work accomplished during the program between 1 January 1983 and 14 October 1983.

Appreciation is expressed to Mr. Edmund Swiatosz and Mr. Rocco Sciascia of the Naval Training Equipment Center for their guidance.

This program was conducted under the direction of Mr. John S. Lovell, Program Manager, and Mr. Arthur K. Colling, Jr., Program Engineer, with the assistance of Dr. Philip Birbara, Technical Consultant, Mr. Arthur Davenport and Mr. Todd Lewis, Design Engineering, and Mr. Douglas Snowdon, Test Engineer.

Statement A is correct for report per Form 50 card per Mr. Douglas Palosaari, NTEC/Code N423

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SUMMARY

A development program was conducted to prove the feasibility of a cost effective, filter-type reusable canister, OBAT, for use with the standard oxygen breathing apparatus, OBA, in the controlled environment of the Navy Device 19F1 Advanced Fire Fighter Trainer. The OBA, in conjunction with the OBAT, operates as a lung-powered open system unlike the standard OBA, which is a closed system with its expendable oxygen liberating canister. In the 19F1 trainer application, the open system requires that acceptable oxygen levels be present and provides both gaseous and particulate contaminant removal. Preliminary phase tests were conducted to investigate two critical issues: the performance of Hamilton Standard's carbon monoxide oxidation catalyst under the expected range of temperature and humidity conditions and the air flow resistance of the entire system, OBA and OBAT. Based on the successful results of these tests and analyses of other system components, a design for a feasibility model canister was also completed during the preliminary phase. The remainder of the development program involved building and demonstrating the performance of the feasibility model canister assembly.

A plexiglas breadboard canister, which closely reflected the cross-sectional area and flow characteristics of the OBAT design, was constructed for the preliminary phase tests. The breadboard canister was loaded with a layer of 3M Company filtrete particulate filter, a 0.168 lbm (76 gm) bed of activated charcoal, and a 0.293 lbm (133 gm) bed of 10 percent platinum-on-alumina carbon monoxide oxidation catalyst. The catalyst tests were run for a range of gas inlet temperatures from 30°F (-1.1°C) to 140°F (60°C) and for relative humidities from approximately 30 percent to near 100 percent at each temperature. Carbon monoxide concentrations tested correspond to the steady state and transient levels measured in the 19F1 trainer during simulated bilge fires. The steady state level tested was 700 ppm for a 20 minute duration, and the transient level tested was 6000 ppm for a 2 minute duration. The flow rate used for tests was approximately 3.0 ft^3/min (85 l/min), which corresponds to the peak inspiration flow during breathing at a high metabolic rate. Air flow resistance tests were conducted on all of the canister components and on an OBA without a canister installed to obtain an estimate of the total system pressure drop.

During the preliminary tests, the CO catalyst performed well for all conditions. Complete conversion of CO to CO_2 was achieved for all steady state tests. Complete conversion was also achieved for all transient tests at high temperatures for both high and low relative humidity conditions. During low temperature and high relative humidity transient tests, the breadboard canister outlet CO concentration typically increased to approximately 40 ppm after 2 minutes. This is well within the 200 ppm limit for the 2 minute transient conditions. During low temperature and low relative humidity, 25 to 30 percent, transient tests, outlet CO concentration exceeded 200 ppm after about 1.75 minutes. However, when relative humidity at this 30°F (-1.1°C) temperature was raised to 35 percent, the 2 minute test was completed prior to exceeding the 200 ppm outlet CO concentration. Also, when 30°F (-1.1°C) flow at less than 30 percent relative humidity was pulsed, 2 seconds on at 3.89 ft^3/min (110.2 l/min) and 2 seconds off, outlet CO concentration reached only 5 ppm after 3 minutes. Since this type of test more accurately reflected

actual canister usage, the catalyst bed showed acceptable performance at all required conditions. Preliminary phase air flow resistance tests demonstrated a total system pressure drop of 1.94 inches (49.28 mm) of water at a flow of 3.0 ft^3/min (85 l/min). The results of the preliminary tests were reviewed by Mr. Christopher Coffey, Supervisory Chemist for the National Institute for Occupational Safety and Health (NIOSH). A copy of his letter discussing this review is provided in Appendix A.

Four feasibility model canisters were built, one for use in program testing and three for delivery to the Naval Training Equipment Center for evaluation. Additionally, a set of replacement internal hardware was built for each of the delivery canisters. Each feasibility model canister has three internal beds contained within their own individual cans. These cans have a kidney-shaped cross-section to conform to the standard OBA canister's shape. The first bed has a layer of Kimre Incorporated polypropylene mist eliminator, a layer of 3M Company filtrete particulate filter material, 0.110 lbm. (50 gm) of activated charcoal, and retaining screens. This bed acts as a particulate filter and reduces hydrocarbon contaminant concentrations. Additionally, testing showed that the activated charcoal is an affective adsorbent of NO_2 when normal moisture levels are present. The second bed contains 0.366 lbm. (166 gm) of 10 percent platinum-on-alumina CO oxidation catalyst and retaining screens. The final bed contains 1.256 lbm. (570 gm) of sodasorb absorbent material with filtrete antidusting filters and retaining screens. A bypass is provided around this bed, so that only 30 percent of the total flow passes through the bed. This bed reduces CO_2 and NO_2 concentrations. The inlet mechanism on the canister is designed to simulate the activation of a standard OBA canister. Prior to activation, it provides a higher than normal air flow resistance, which is typical during use of a standard OBA canister.

An extensive series of tests was conducted to provide a successful performance demonstration of the feasibility model canister. Tests included measurement of the system's air flow resistance, performance verification against gaseous and particulate contaminants, measurement of the OBA facemask temperature transients at high ambient temperatures, operational checks of the firing mechanism simulator, checks for dusting, settling, and channeling in the canister's beds, and a catalyst life test.

The air flow resistance test verified that the total system, OBA with feasibility model canister installed, air flow resistance is less than 3.0 inches (76.2 mm) of water at 3.0 ft^3/min (85 l/min). The pressure drop at this condition was 2.76 inches (70.1 mm) of water. This is greater than the pressure loss measured during the preliminary tests due to the increased percentage of flow through the sodasorb bed and the smaller granule size resulting in denser packing of the sodasorb.

Gaseous contaminant tests verified the feasibility canister's performance against carbon monoxide, carbon dioxide, nitrogen dioxide, and propane at levels measured in the trainer and at temperature and humidity extremes anticipated in the trainer. As in the preliminary tests, the carbon monoxide catalyst converted essentially all of the carbon monoxide to carbon dioxide at all conditions tested. Carbon dioxide levels are reduced in the OBAT canister by absorption in sodasorb, which is an expendable. Two ranges of sodasorb granule sizes and two grades of sodasorb were tested. The best performance was achieved with 8 to 14 mesh, high performance grade sodasorb. Over the range of temperature and relative humidity conditions tested, approximately 25 to 45 weight percent carbon dioxide loading was demonstrated. The highest loadings were achieved at high temperature and high humidity conditions.

Based on these results, a canister will be usable for a week of typical training before sodasorb replacement is necessary. The indicator in the sodasorb provided a distinct color change when the absorptive capacity was exhausted. In regard to nitrogen dioxide, a literature search revealed that it comprises less than 1 percent of nitrous oxides produced by combustion of gaseous hydrocarbons. Thus, based on the peak measured levels of nitrous oxides in the 19F1 trainer during bilge fires of approximately 17 ppm, the levels of nitrogen dioxide should be less than 1 ppm. A nitrogen dioxide concentration of 5 ppm was used during the gaseous contaminant tests, and it was completely removed by the combination of full flow through the activated charcoal and 30 percent flow through the sodasorb. Activated charcoal for hydrocarbon adsorption was relatively ineffective against propane. However, since peak propane levels in the trainer are less than the eight-hour permissible exposure limit, this is not a problem for the OBAT canister concept. Based on the overall performance during the tests and upon inspection of the canister between tests, dusting, settling, and channeling were not present.

Two candidate particulate filter systems were tested in the 19F1 Fire Fighter Trainer in Norfolk, Virginia. This provided the most realistic challenge of both the simulated smoke and simulated dry powder extinguishant. The two filter systems differed only in the method of filtering the dry powder particles. One system utilized 400 mesh stainless steel screen, and the other used Kimre Incoporporated polypropylene mist eliminator filter media. Both systems demonstrated greater than 99.7 percent filtering efficiency, but the system with the 400 mesh screen clogged quickly. Thus, the system with the mist eliminator was selected for the feasibility canister.

High temperature transient tests were conducted to insure that an open system filter-type canister will not result in excessive facemask temperatures if an individual is exposed to an extreme temperature for a short period. Test results showed that the plexiglas viewing window in the facemask melts before temperature at the mouthpiece reaches 140°F (60°C) at extreme ambient temperatures.

To verify the physical integrity of the firing mechanism simulator, it was successfully operated through 100 cycles for each of the feasibility canisters.

Endurance tests on the carbon monoxide catalyst were conducted after the gaseous contaminant tests to accumulate 250 hours. No measurable degradation of the catalyst's performance was detected.

Based on the program's results, the feasibility of a filter-type oxygen breathing apparatus training canister has been proven. The OBAT canister can be used with an unmodified oxygen breathing apparatus and provides protection for an individual against the gaseous and particulate contaminants present in the 19F1 Fire Fighter Trainer. Based on a minimum catalyst life of 250 hours and lives for sodasorb, charcoal, and filter media expendables of 25 hours, the OBAT canister will provide a cost effective alternative to the use of expendable OBA canisters for the 19F series Fire Fighter Trainer application.

INTRODUCTION

A reusable, cost effective training canister, OBAT, is being developed for use with the Navy Oxygen Breathing Apparatus, OBA, during training exercises within the controlled environment of the 19F1 Fire Fighter Trainer. The OBA, in conjunction with the OBAT canister, operates as a lung powered open system unlike the standard OBA, which is a closed system with its expendable oxygen liberating canister. In the 19F1 trainer application, the open system requires that acceptable oxygen levels be present and provides both gaseous and particulate contaminant removal. The undesirable gases originate in the combustion process at the propane burners utilized for simulating shipboard fires. These are carbon monoxide, carbon dioxide, oxides of nitrogen and hydrocarbons. The particulates are sodium bicarbonate from the training extinguishing agent and butylated triphenyl phosphate from the training smoke used to simulate a shipboard fire environment.

At the start of the development program, two areas were considered critical to the successful design of a reusable training canister; the performance of the platinum-on-alumina CO oxidation catalyst at the anticipated temperature and humidity extremes, and the air flow resistance during inspiration through the training canister and OBA. A preliminary phase test program was conducted addressing these two concerns.

Based on the favorable results of these CO catalyst tests and air flow resistance tests, a design of a feasibility model canister was completed. The feasibility canister design includes a particulate filter to remove the solid matter from the artificial smoke and sodium bicarbonate extinguishant, an activated charcoal layer to reduce hydrocarbon concentrations, a catalyst bed to convert CO to CO_2, and a sorbent bed to reduce the concentrations of CO_2 and NO_2. Additionally, the training canister with the OBA provides a complete simulation of the standard OBA with respect to donning, activation, and usage.

A feasibility test phase was conducted to demonstrate the performance of the feasibility model canister. The feasibility tests included an air flow resistance test, performance tests against various concentrations of CO, CO_2, NO_2, and propane at anticipated temperature and humidity extremes, particulate filter tests, OBA mask inlet temperature transient tests, firing mechanism simulation tests, checks for dusting, settling, and channeling, and a CO catalyst 250-hour life test.

OBJECTIVES

The Feasibility Evaluation of a Reusable Contaminant Filter Canister for use as an Oxygen Breathing Apparatus Trainer program was divided into three phases, the Preliminary Test Phase, the Feasibility Model Canister Design Phase, and the Feasibility Test Phase.

The primary objectives of the Preliminary Test Phase were to evaluate the CO oxidation catalyst performance and to establish the total system, OBA and OBAT, air flow resistance. Specific goals of the CO catalyst tests are listed below:

- Verify the catalyst's performance at the extremes of temperature and relative humidity anticipated in the 19F1 Fire Fighter Trainer.
- Verify the catalyst's performance at the steady state and transient CO concentrations anticipated in the 19F1 Fire Fighter Trainer.
- Generate design data for the CO catalyst bed in the feasibility model canister.

The primary objective of the Feasibility Model Canister Design Phase was to utilize the test data and analyses from the proposal effort and the Preliminary Test Phase to perform a detailed design of a feasibility model canister for use in the subsequent program tests.

The primary objective of the Feasibility Test Phase was to evaluate the performance of the feasibility model canister. Specific goals of the tests are listed below:

- Measure the airflow resistance for the total system, OBA and OBAT.
- Verify the canister's performance against gaseous contaminants including carbon monoxide, carbon dioxide, nitrogen dioxide, and propane at concentrations and temperature and humidity extremes anticipated in the 19F1 Fire Fighter Trainer.
- Verify the particulate filter system's performance against the simulated smoke and simulated dry powder extinguishant at concentrations typical of the 19F1 Fire Fighter Trainer.
- Measure the temperature transient in the OBA facemask with the OBA and OBAT subjected to various ambient temperatures up to 1000°F (537.8°C).
- Verify that the feasibilty model canister's firing mechanism provides an accurate simulation of the initiation of a standard OBA canister.
- Verify that no dusting, settling, or channeling problems occur within the beds of the OBAT canister.
- Verify the carbon monoxide catalyst's performance over a life of at least 250 hours.

- Generate data on the OBAT canister's expendables, including sodasorb, activated charcoal, and the particulate filter media, to allow projecting the replacement intervals of these materials under actual 19F1 Fire Fighter Trainer conditions. This data is valuable for determining the cost effectiveness of the OBAT concept for the 19F1 Fire Fighter Trainer application.

RESULTS AND CONCLUSIONS

1. A reusable, filter-type training canister for use with the Navy Oxygen Breathing Apparatus during training exercises within the controlled environment of the 19F1 Fire Fighter Trainer, which contains sufficient breathable oxygen, has been proven to be a viable concept.

2. The feasibility model canister performed well during the feasibility tests, and it will provide an excellent basis for a production design.

3. The expendables in the OBAT canister are sodasorb for carbon dioxide absorption, activated charcoal for hydrocarbon adsorption, and the particulate filters. Under 19F1 trainer conditions, the most limiting expendable is sodasorb, which will have a minimum life of one week, based on 25 usage hours per week.

4. The total system, OBA and OBAT canister, air flow resistance at peak inhalation flow conditions of 3.0 ft^3/min (85 l/min) is 2.76 inches (70.1 mm) of water.

5. A 0.331 lbm (150 gm) bed of 10 percent platinum-on-alumina CO oxidation catalyst provides excellent performance for the CO concentrations measured during bilge fire simulations in the 19F1 Fire Fighter Trainer.

6. No measurable performance degradation was detected during the 250-hour carbon monoxide catalyst life test.

7. The particulate filter system selected consists of a layer of Kimre Incorporated polypropylene mist eliminator and a layer of 3M Company filtrete filter media. These filters, along with the activated charcoal bed, provide a filtering efficiency of greater than 99.7 percent against the simulated smoke and dry powder extinguishant.

8. The thermal mass of the OBAT canister and OBA protects an individual from breathing high temperature air during short duration exposures to extreme temperature conditions.

9. The OBAT canister's firing mechanism provides an accurate simulation of the activation of a standard OBA canister.

RECOMMENDATIONS

1. Prototype oxygen breathing apparatus training canisters should be designed and built for evaluation in the 19F1 Fire Fighter Trainer in Norfolk, Virginia.

2. A test stand to test the prototype OBAT canisters after refurbishment should be designed and built.

3. Further development testing on the carbon monoxide catalyst should be conducted to optimize the catalyst in regard to cost. Cost reduction may be possible if testing reveals that catalyst with less precious metal content provides satisfactory performance.

DESCRIPTION

Preliminary Phase Test System

The test setup for the preliminary phase tests was located in Hamilton Standard's Environmental and Space Systems Advanced Engineering Laboratory. A photograph of the test rig is given in Figure 1, and it is shown schematically in Figure 2. The rig provided the capability of supplying the test article with a controlled gas flow, preconditioned to the desired temperature and relative humidity. Instrumentation, as listed in Table 1, allowed accurate monitoring of test conditions including flowrate, temperature, pressure, dew point, and carbon monoxide concentration.

Conditions for a specific test, except CO concentration, were established using the dry nitrogen supply to the test rig. This allowed stabilizing gas temperature and relative humidity prior to switching to the certified premixed gas supply of CO in air. Gas flow rate for either nitrogen or the premixed CO in air was controlled by adjusting pressure regulators (PR1) or (PR2), respectively. The primary flow measurement was obtained from venturi (V1) in conjunction with manometer (M1). Backup flow measurement was provided by flowmeters (FM1) for nitrogen or (FM2) for the CO in air mixture. Gas temperature was controlled by four tube-in-tube heat exchangers. Heating or cooling was supplied to the heat exchangers by two constant temperature baths, each supplying two of the heat exchangers. Additionally, cooling or heating was provided as required from one of the constant temperature baths to the hygrometer sensor. This was necessary to be able to read the extremely low and high dew points required by the test specification. Humidification of the gas stream was accomplished by directing part of the flow through a humidifier. A sample of the recombined flow was passed through the hygrometer sensor. While test conditions were being established, the gas flow could be directed through the test article or could be bypassed around the test article through valve (14). The gas flow could be sampled for CO concentration either upstream or downstream of the test article. The CO analyzer was calibration checked with certified calibration gas each day prior to testing. Manometer (M2) provided a differential pressure reading across the test article.

Breadboard Test Canister

The breadboard canister for the preliminary phase tests is shown in Figure 3. It was designed to accurately reflect the shape and size of the standard OBA canister. Also, the inlet and outlet tubes were sized and positioned similarly to the anticipated design of the feasibility model canister.

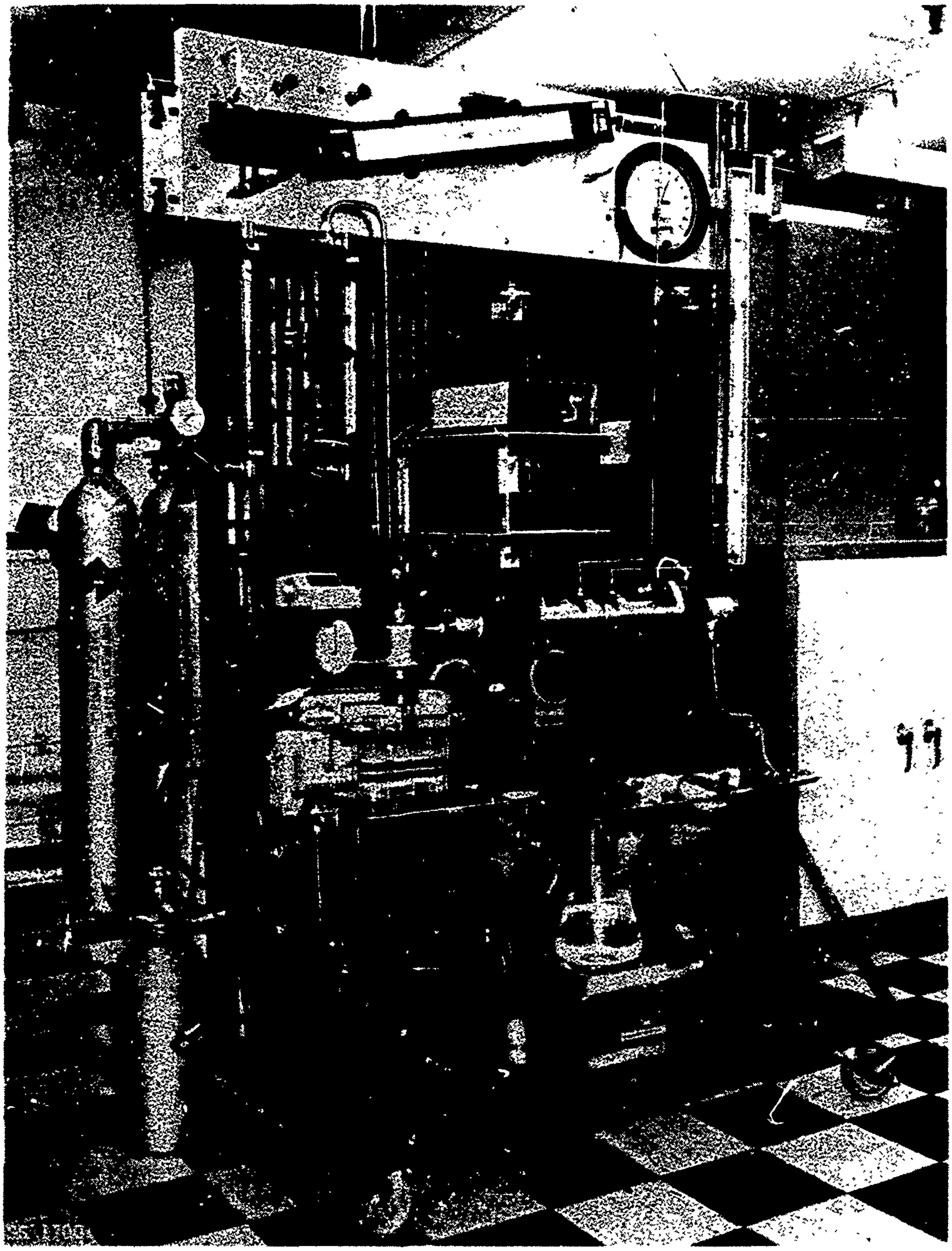


FIGURE 1

PRELIMINARY PHASE TEST RIG

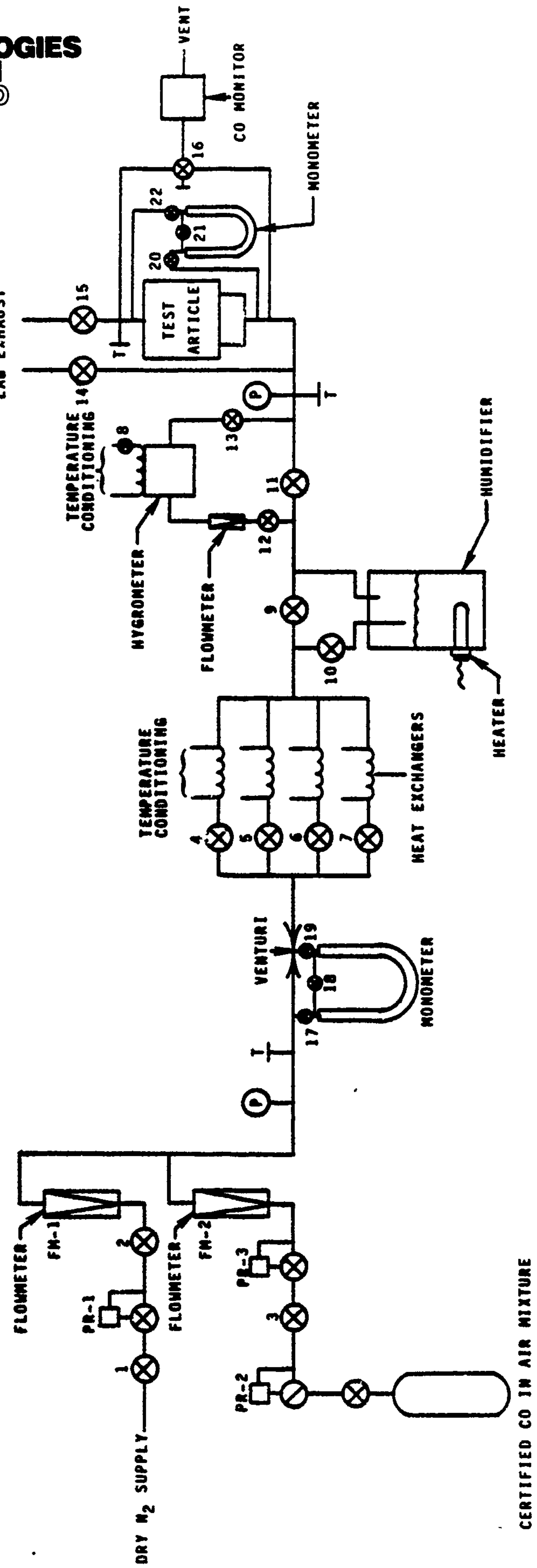


FIGURE 2
PRELIMINARY PHASE TEST RIG SCHEMATIC

TABLE 1

INSTRUMENTATION LIST

PRELIMINARY PHASE TEST SYSTEM

Parameter	Units	Instrument	Range
Total Dry Flow	ft^3/min	Venturi/Manometer	0 to 5 CFM
N_2 Flow	ft^3/min	Flow Meter	0 to 3.5 CFM
Certified Gas Mixture Flow	ft^3/min	Flow Meter	0 to 3.5 CFM
Venturi Inlet Pressure	psia	Gage	0 to 30 psia
Canister Inlet Pressure	psia	Gage	0 to 30 psia
Temperature Venturi Inlet Canister Inlet Canister Outlet Tubing Wall (2)	°F	Type T Thermocouples with Doric Readout	-382 to 752°F
Canister Inlet Dew Point	°C	General Eastern Optical Hygrometer	-35 to 70°C
Canister Inlet and Outlet CO Conc.	ppm	Ecolyzer 2000 Series Energetics Science	0 to 250 ppm
Canister Differential Pressure	inches of water	Manometer	0 to 4 inches of water

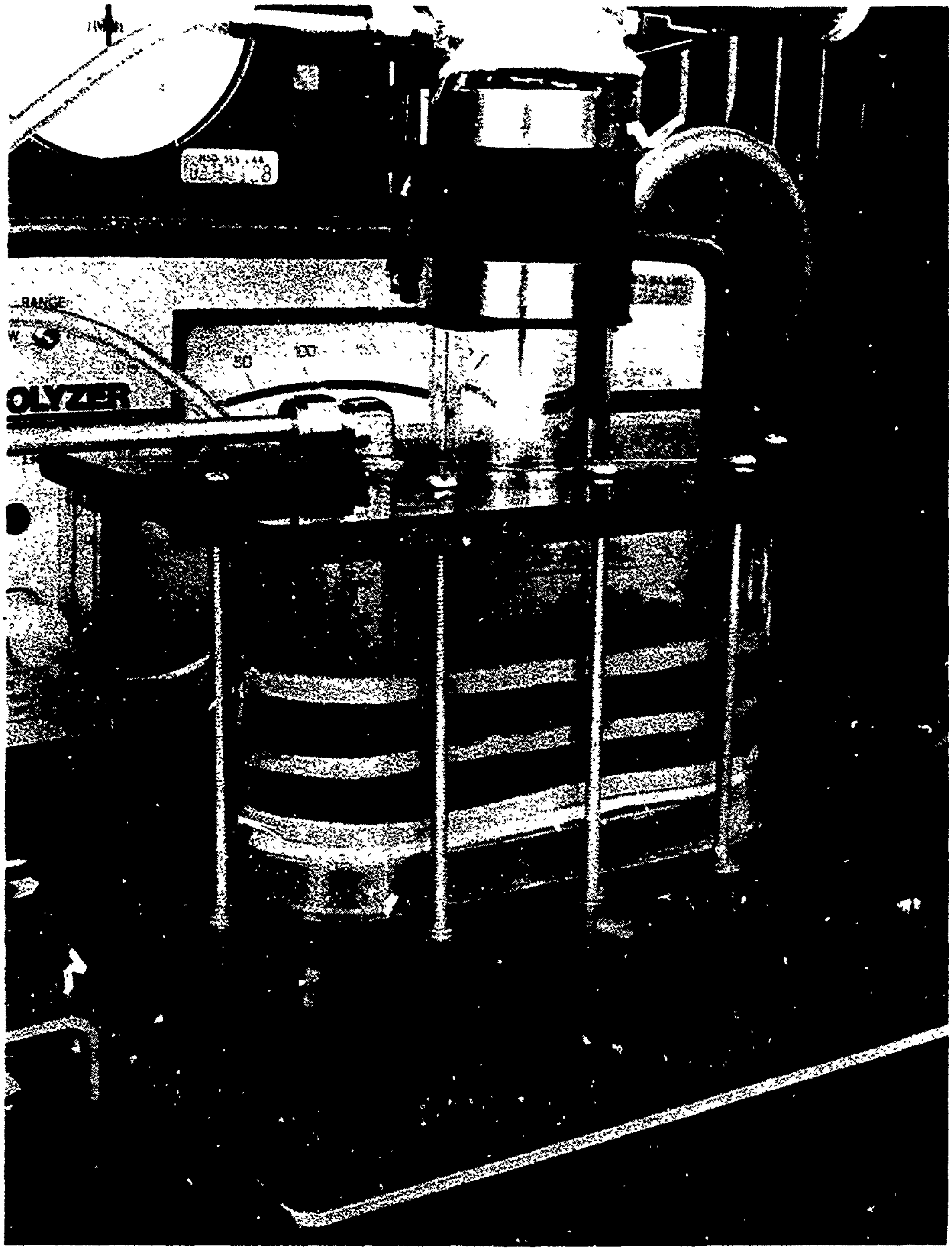


FIGURE 3

BREADBOARD TEST CANISTER

The breadboard canister was constructed from 0.25 inch (6.35 mm) thick plexiglas. The canister's sides were made from flat sheets, and the semicircular edge pieces were made by cutting a 2 inch (50.8 mm) inside diameter tube into halves logitudinally. After machining their edges to provide smooth surfaces, the pieces were glued together to form the main body of the canister. The inlet and outlet end plates were rectangular in shape and were oversized compared to the cross-sectional area of the canister body. This allowed the long retaining screws to be located externally to prevent interference with the catalyst bed. The inlet, bottom, end plate was glued to the canister body. The outlet, top, end plate was removable to allow loading the canister. A rubber gasket, glued to the outlet end plate provided a tight seal with the canister body. The outlet plate was drilled and fitted with a 1.5 inch (38.1 mm) inside diameter outlet tube. The inlet plate was drilled and fitted with two 1.0 inch (25.4 mm) inside diameter inlet tubes.

Preliminary Phase Test Beds

The activated charcoal and carbon monoxide oxidation catalyst beds used during the Preliminary Test Phase can be seen in Figure 3. Their arrangement is shown schematically in Figure 4. A 0.25 inch (6.35 mm) plexiglas spacer at the inlet of the activated charcoal bed helped to provide even flow distribution. Referring to Figure 4, the test bed components from inlet to outlet were a 40 mesh stainless steel retaining screen, a 100 mesh stainless steel screen for coarse filtration, a 0.25 inch (6.35 mm) layer of polypropylene filter material, a 40 mesh stainless steel retaining screen, a 0.168 lbm (76 gm) bed of activated charcoal, a 40 mesh stainless steel retaining screen, a 0.293 lbm (133 gm) bed of 10 percent platinum-on-alumina CO oxidation catalyst, and a 40 mesh stainless steel retaining screen. The screens were held in place by adhesive backed, closed-cell foam strips attached to the inside of the canister.

The filter material used was 3M Company Filtrete Brand Type G particulate filtering media. This is a polypropylene material formed into a fibrous blanket. The Type G-0130 filtrete used has a weight of approximately 0.0614 lbm/ft^2 (300 gm/m^2) for the standard 0.25 inch (6.35 mm) thickness.

The activated charcoal bed consisted of 0.168 lbm (76 gm) of Barnebey Cheney Company type CR2762, 8-14 mesh, coconut shell, activated charcoal. The charcoal was washed with pure water to remove dust and was dryed in a vacuum oven prior to loading the canister.

The carbon monoxide oxidation catalyst bed consisted of 0.293 lbm (133 gm) of 10 percent platinum on 14 to 18 mesh alumina granules. With a cross-sectional area of 11.9 inches^2 (7677 mm^2) and a depth of 0.75 inch (19.05 mm) the space velocity was 35,000 hour^{-1}, and the residence time was 0.103 second at a gas flow of 3.0 ft^3/min (85 l/min).

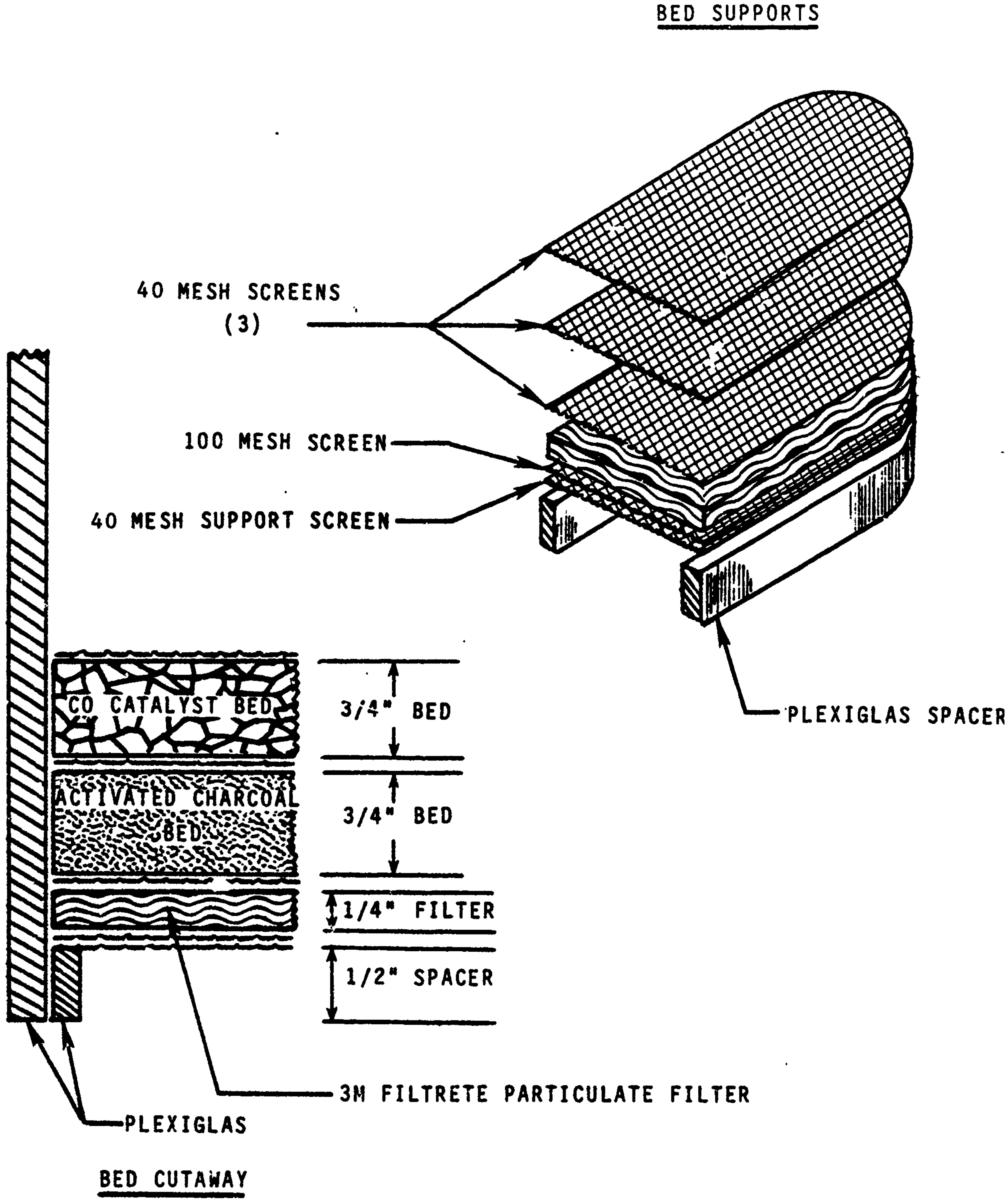


FIGURE 4

BREADBOARD TEST CANISTER SCHEMATIC

Breadboard Canister Flow Distribution Test

Prior to the start of preliminary phase testing, the flow distribution through the breadboard canister was tested. The canister was loaded as described above for the preliminary phase tests, except the CO catalyst was replaced by indicating silica gel dessicant. As room air was drawn through the bed, the uniform color change in the dessicant indicated even flow distribution through the canister. The clear plexiglas construction of the canister allowed easy viewing of the dessicant.

Feasibility Test Systems

The feasibility tests consisted of eighteen separate tests, designated F1 to F18. Due to the signficant differences in the various test requirements, three separate test systems were used. The air flow resistance test, F1, the gaseous contaminant tests, F2 to F13, the dusting settling/channeling test, F17, and the carbon monoxide catalyst life test, F18, were conducted in Hamilton Standard's Environmental and Space Systems Advanced Engineering Laboratory. The test setup utilized during the preliminary phase tests was upgraded to provide control and monitoring of additional gaseous contaminants. The particulate tests, F14, were conducted within the 19F1 Fire Fighter Trainer in Norfolk, Virginia. The OBA mask inlet temperature transient tests, F15, were conducted utilizing a large heat treating oven in Hamilton Standard's manufacturing facilities.

A photograph of the test system utilized for tests F1 to F13, F17 and F18 is given in Figure 5, and the system is shown schematically in Figure 6. The rig provided the capability of supplying the test article with a controlled gas flow, preconditioned to the desired temperature and relative humidity. Instrumentation, as listed in Table 2, provided accurate monitoring of test conditions including flowrate, temperature, pressure, dew point, and gaseous contaminant concentrations, including carbon monoxide, carbon dioxide, nitrogen dioxide, and propane.

Temperature and humidity conditions for a specific test were established prior to adding contaminants to the air stream. During this period, the air flow was bypassed around the test article through valve (14). Air flow rate was controlled by adjusting pressure regulator (PR1). The primary flow measurement was obtained from venturi (V1) in conjunction with manometer (M1). Backup flow measurement was provided by flowmeter (FM1). Gas temperature was controlled by four tube-in-tube heat exchangers. Heating or cooling was supplied to the heat exchangers by two constant temperature baths, each supplying two of the heat exchangers. Additionally, cooling or heating was provided as required from one of the constant temperature baths to the hygrometer sensor. This was necessary to be able to read the extremely low and high dew points required by the test specification. Humidification of the gas stream was accomplished by directing part of the flow through a humidifier. A sample of the recombined flow was passed through the hygrometer sensor. Once

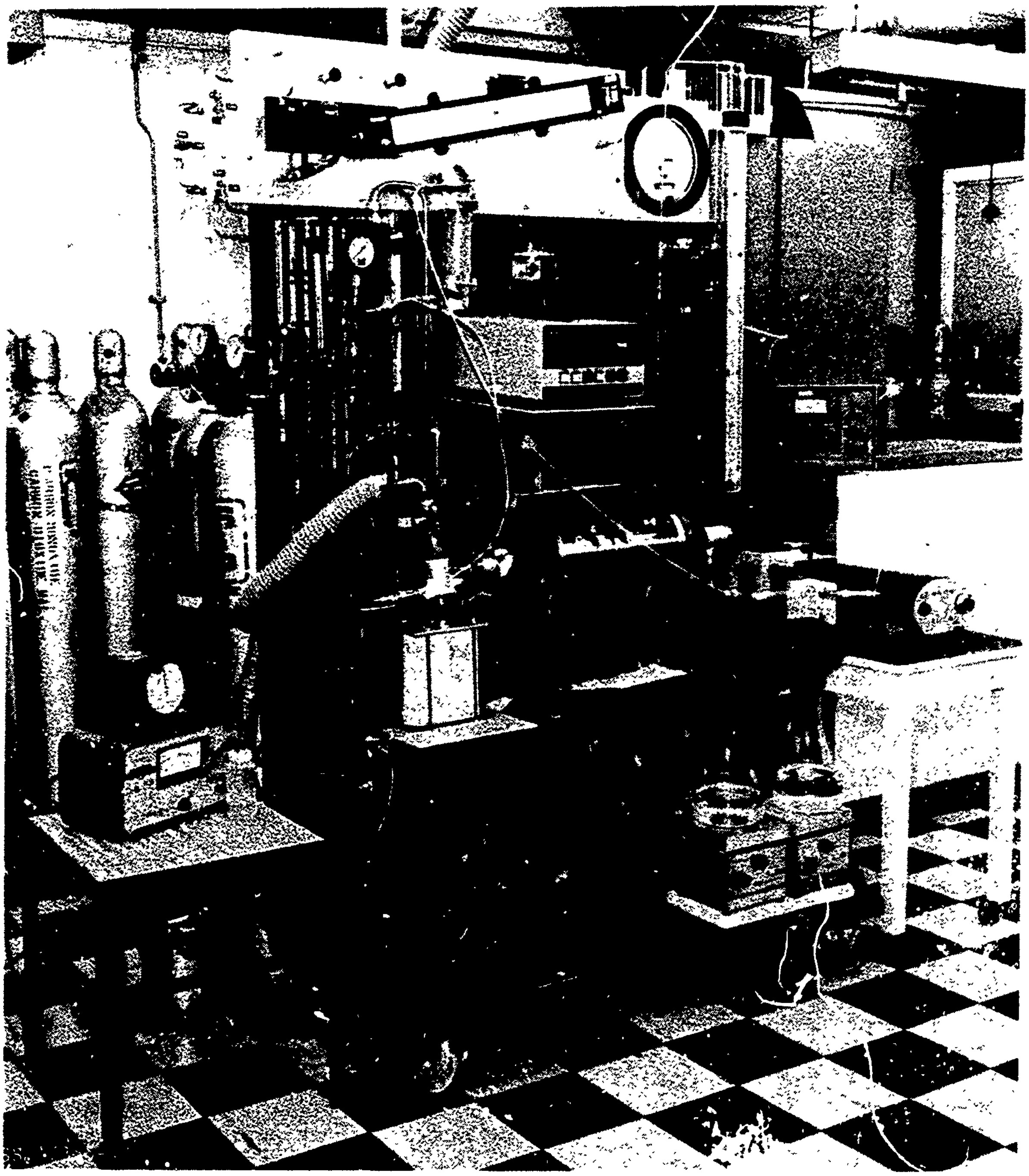


FIGURE 5

FEASIBILITY GASEOUS CONTAMINANT TEST RIG

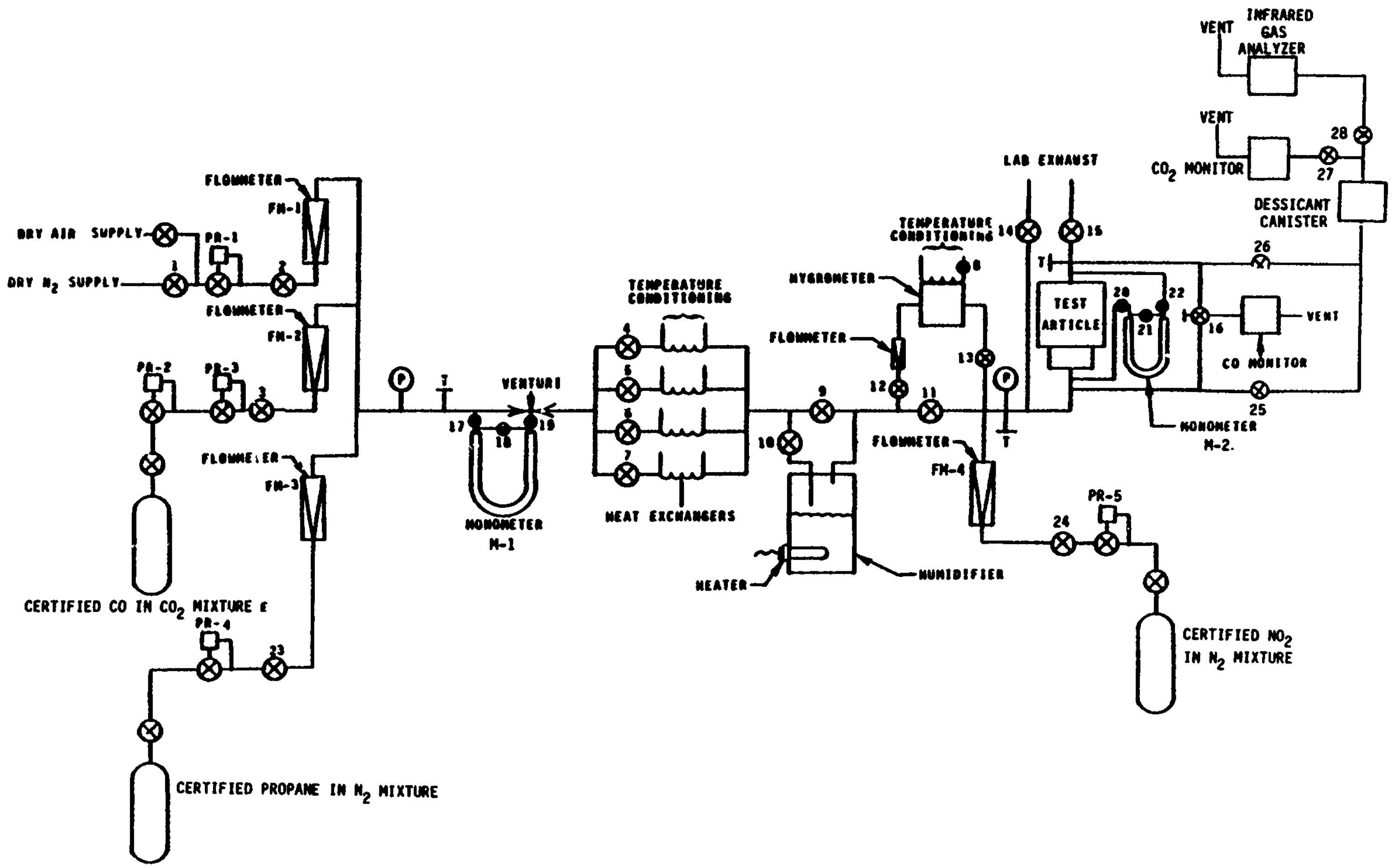


FIGURE 6

FEASIBILITY GASEOUS CONTAMINANT TEST RIG SCHEMATIC

TABLE 2

INSTRUMENTATION LIST

FEASIBILITY TEST SYSTEM

Parameter	Units	Instrument	Range
Total Dry Flow	ft^3/min	Venturi/Manometer	0 to 5 CFM
Air Flow	ft^3/min	Flow Meter	0 to 3.5 CFM
Certified Gas Mixture Flow	ft^3/min	Flow Meter	
CO in CO_2 Propane in N_2 NO_2 in N_2			0 to 0.06 CFM 0 to 0.065 CFM 0 to 0.15 CFM
Venturi Inlet Pressure	psia	Gage	0 to 30 psia
Canister Inlet Pressure	psia	Gage	0 to 30 psia
Temperature Venturi Inlet Canister Inlet Canister Outlet Tubing Wall (2)	°F	Type T Thermocouples with Doric Readout	-382 to 752°F
Canister Inlet Dew Point	°F	General Eastern Optical Hygrometer	-35 to 180°F
Canister Inlet and Outlet CO Conc.	ppm	Ecolyzer 2000 Series Energetics Science	0 to 250 ppm
Canister Differential Pressure	inches of water	Manometer	0 to 4 inches of water
Canister Inlet and Outlet CO_2 Conc.	% of CO_2	Infrared Industries Model 705-341 CO_2 Analyzer	0 to 3.67%
Canister Inlet and Outlet Propane Conc.	ppm	Foxboro Analytical Miran-1A CVF Gas Analyzer	0 to 1000 ppm

the required temperature and dew point were established, the appropriate concentrations of contaminant gases were metered into the air stream. Carbon monoxide and carbon dioxide concentrations were controlled by adjusting metering valve 3, and their flow rate was measured by flowmeter FM2. Since all of the required test conditions included only two ratios of carbon monoxide to carbon dioxide, only two different mixtures of these gases were needed to provide the desired concentrations. The propane concentration was controlled by adjusting metering valve (23) and its flow rate was measured by flowmeter (FM3). The nitrogen dioxide concentration was controlled by adjusting metering valve (24), and its flow rate was measured by flowmeter (FM4). The nitrogen dioxide was added to the air flow downstream of the humidifier, since nitrogen dioxide is soluable in water. The concentrations of the contaminant gases were checked prior to the start of a test by sampling at the test article inlet. Once all conditions including temperature, humidity level, and contaminant gas concentrations were established, a test was started by opening valve (15) and shutting valve (14). The carbon monoxide and carbon dioxide concentrations in the air flow leaving the test article were monitored continuously during each test. Outlet propane and nitrogen dioxide concentrations were monitored periodically. The gas analyzers were calibration checked prior to each test. Manometer (M2) provided a differential pressure reading across the test article.

The test system for the particulate tests, F14, is shown schematically in Figure 7. The system was designed to be portable and two identical systems were assembled in the 19F1 Fire Fighter Trainer in Norfolk, Virginia. This allowed testing two candidate particulate filter systems simultaneously. Performing the particulate tests in the trainer provided the most accurate and practical method of determining the particulate filter systems' performance. The breadboard canisters from the preliminary test phase were utilized as the test articles for particulate filter testing. The canisters with their particulate filter systems are shown schematically in Figures 8 and 9. Each test system had its own air pump, throttle valve and flowmeter, which allowed drawing a fixed air flow through the test articles. To evaluate the filter systems' performance, 0.45 micron Gelman metricel filters were positioned near each canister and inside each canister downstream of the canister's particulate filters. A constant flow of 0.071 ft^3/min. (2.0 l/min.) was drawn through each Gelman filter by a Gilian model HFS 113 sample pump. These positive displacement pumps were flow calibrated prior to the tests and provide a constant flow over a significant range of differential pressure. The Gelman metricel filters used during the tests were weighed prior to and after the tests by Environmental Health Laboratory of Hartford, Connecticut. Thus, a comparison between the weight changes of the Gelman filters exposed to ambient particulate levels and the Gelman filters downstream of the test article filter systems provided a measurement of the filter systems' performance. Also, the differential pressure across each filter system was measured.

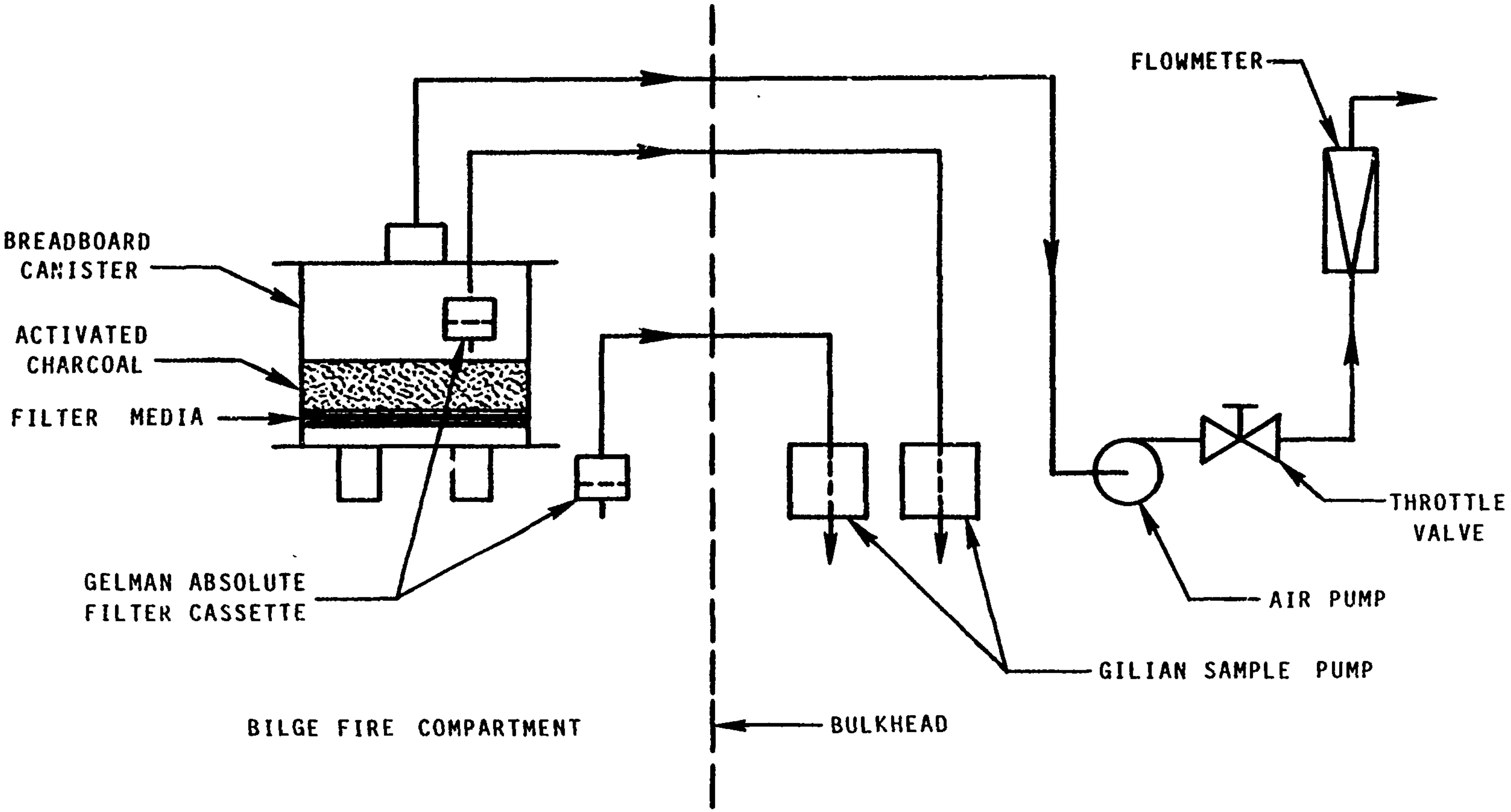


FIGURE 7

PARTICULATE FILTER TEST SYSTEM SCHEMATIC

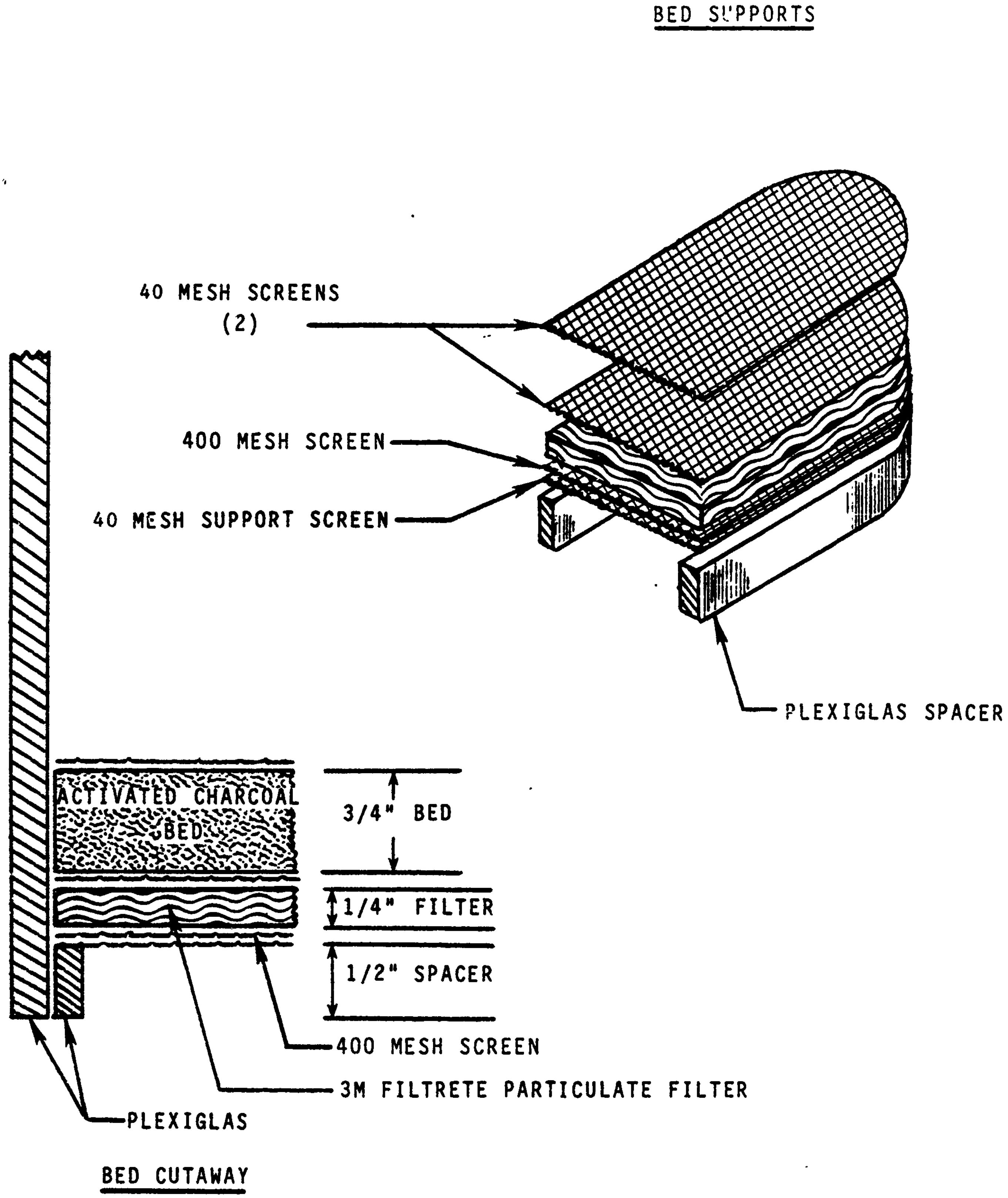
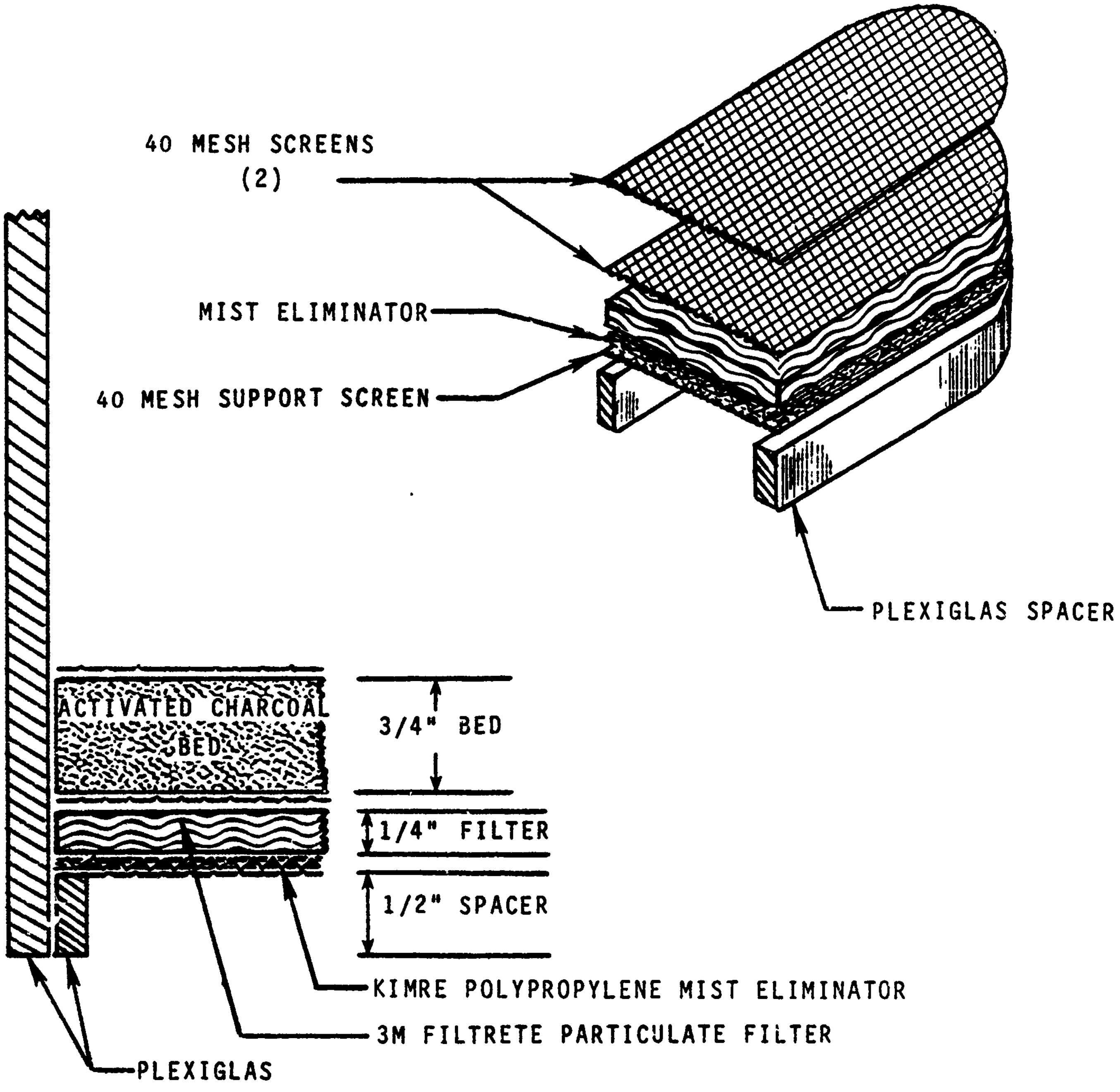


FIGURE 8

PARTICULATE TEST CANISTER SCHEMATIC

FILTER SYSTEM #1

BED SUPPORTS



BED CUTAWAY

FIGURE 9

PARTICULATE TEST CANISTER SCHEMATIC
FILTER SYSTEM #2

The two particulate filter systems were tested in the breadboard canisters, used in the preliminary tests and shown in Figure 3. The breadboard canisters were constructed of plexiglas, and the details of their construction were described previously. Each filter system contained a 0.154 lbm. (70 gm.) bed of 8 to 14 mesh activated charcoal and a 0.25 inch (6.35 mm.) layer of 3M type G0130 filtrete brand filter media. This filtrete layer provided the filtration of the 0.5 to 2 micron butylated triphenol phosphate simulated smoke. One filter system had a 400 mesh stainless steel screen for filtering the coarse sodium bicarbonate simulated dry powder extinguishant. The alternate system had a layer of Kimre Incorporated polypropylene mist eliminator style 4/96 filter media instead of the 400 mesh screen. Both filter systems were retained by inlet and outlet 40 mesh stainless steel screens.

The OBA mask inlet temperature transient test, F15, was conducted utilizing a heat treating oven in Hamilton Standard's manufacturing facilities. Photographs of the test system are shown in Figures 10 and 11. The sliding door on the oven and the quick-disconnect on the tube leading to the pump allowed the mannequin and OBA to be rapidly positioned in the preheated oven prior to the start of each test. The three thermocouples for monitoring canister and face mask temperatures could also be quickly connected. Thus, a test could be started before the mannequin and OBA had been heated significantly above ambient temperature. Figure 10 shows the mannequin and OBA in the oven just prior to closing the oven door. Immediately after the door was shut, the pump and temperature recorder were started. The flow was preset with a throttle valve at 1.0 ft^3/min. (28.3 l/min.) and was monitored with a flowmeter. Temperatures were monitored in the oven, in the activated charcoal bed, at the canister outlet, and in the facemask. When the temperature in the facemask reached about 140°F (60°C), the pump was stopped, the oven door was opened, and the mannequin and OBA were removed. A large fan was used to cool the mannequin and OBA to room temperature after each test. Figure 11 shows the test system outside of the oven including the mannequin and OBA being cooled.

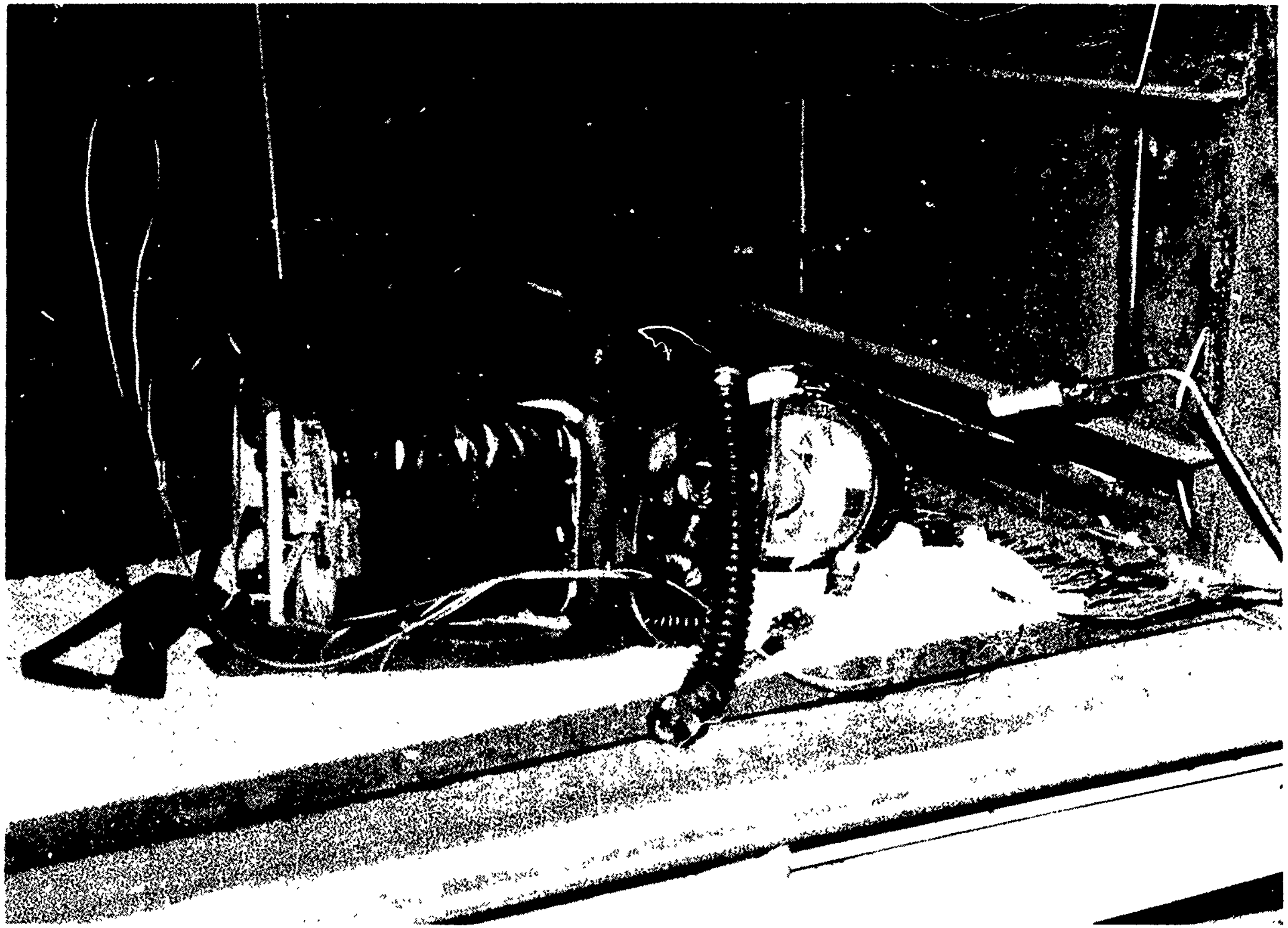


FIGURE 10

HIGH TEMPERATURE TRANSIENT TEST SYSTEM
(MANNEQUIN SHOWN IN OVEN)

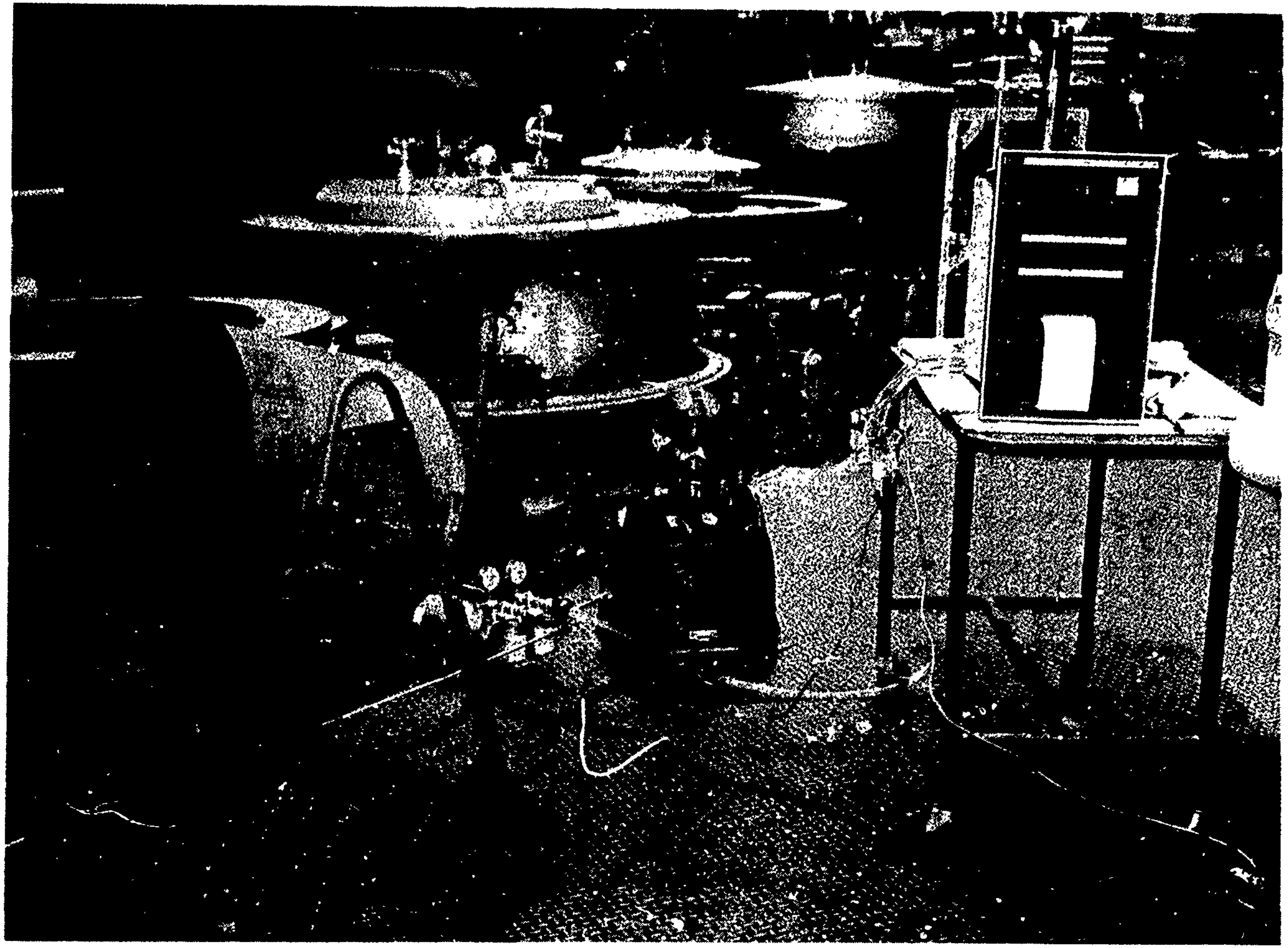


FIGURE 11

HIGH TEMPERATURE TRANSIENT TEST SYSTEM

(MANNEQUIN BEING COOLED BETWEEN TESTS; AIR PUMP AND TEMPERATURE MONITOR)

Feasibility Model Canister Design

To provide the ability to test the entire OBA training canister concept, a feasibility model canister was designed and built. All feasibility tests, except for the particulate filter tests, were conducted utilizing a feasibility model canister. The assembly of the feasibility canister is shown in Figure 12 and pictures of the canister and its components are provided in Figures 13 and 14. The components are packaged within the shell of a standard OBA canister. This gives the training canister the same size and shape as the standard canister and provides the same mating interface with the OBA. The components added to the standard canister shell include the bottom cover assembly, the particulate filter and activated charcoal container, the CO catalyst container, the CO_2 and NO_2 sorbent container, and the exhalation tube.

Feasibility Canister Components

The bottom cover assembly is shown in Figure 15. It retains the beds within the canister and provides accurate simulation of the activation of a standard OBA canister. The chlorate candle cover from the standard canister is used as the cover for the training canister's activation mechanism. Activation is achieved by pulling the cover away from the canister, which removes a cotter pin. Prior to activation, the inlet ports are covered by the slide plate which provides the high air flow resistance characteristic of the standard OBA prior to canister activation. Upon activation, the slide plate is pulled by a spring, and the inlet ports are uncovered to reduce the system's peak pressure drop to less than 3 inches (76.2 mm) of water. Prior to the next use of the training canister, the slide plate can be moved to its preactivation position and held there by reinstalling the cotter pin attached to the mechanism's cover.

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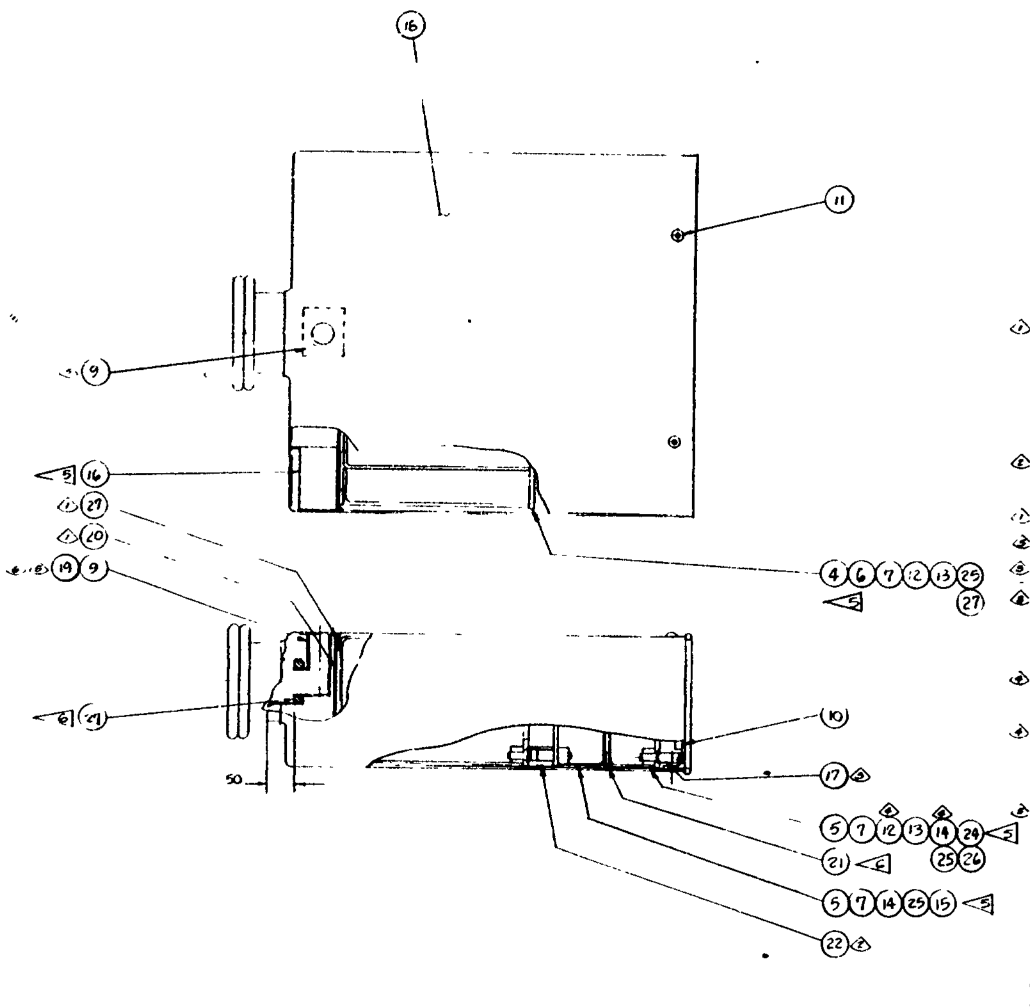


REVISIONS

DWG NO.	ZONE	LTR	DESCRIPTION	DATE	APPROVED
		A	1 ADDED F/N 20 PLATE BASE - AND F/N 27 GASKET 2 MOVED F/N 22, GASKET, TO LOCATION SHOWN. 3 ADDED F/N 17, SPACER, ON BOTTOM OF CHARCOAL CAN. 4 F/N 12 QTY ON ASSY-102 WAS 6 ADDED QTY 6 OF F/N 14 ON ASSY-102 5 BRAZED ASSY OF F/N 7 & 9 TO F/N 18 WAS FORMERLY RIVETED. 6 MITER JOINT 90°EL CONSTRUCTION OF F/N 19 WAS FORMERLY TEE JOINT	12-13 83	

	-102	-101	-100	SVSK 106962-1	FIND NO	PART NUMBER	PART NAME	REMARKS
1				A/R	27	SVSK 106962-210	GASKET	◁3 3/16" THICK
	A/R			A/R	26	TYPE G0130	FILTER	◁2 1/4" THICK POLYPROPYLENE BLANKET 300 gm/m²
	AR	AR	A/R	AR	25	SVSK 106962-209	SCREEN	40 x 40 MESH 300 SERIES S.S. WIRE CLOTH
	A/R				24	SVSK 106962-208	FILTER	◁1 POLYPROPYLENE MIST ELIMINATOR STYLE 4/96
				1	23	SVSK 106962-207	CAP, TUBE	3/8" COPPER TUBE CAP
2				A/R	22	SVSK 106962-206	GASKET	◁3 3/8" THICK
				AR	21	SVSK106962-205	GASKET	◁3 1/16" THICK
1				1	20	SVSK106962-202	PLATE, BASE	◁4
6				A/R	19	SVSK 106962-204	TUBE	3/8" COPPER TUBE
5				1	18	SVSK 106962-203	CANISTER	MODIFY AS SHOWN
3	4				17	SVSK106959-8	SPACER	
				2	16	SVSK 106962-201	SPACER	◁4
		6			15	SVSK 106959-7	SPACER	
4	9	6			14	92196A197	SCREW, SOC HD CAP	◁1 8-32 x 75 LONG
	A/R		A/R		13	TYPE G-0110	FILTER	◁2 1/8" THICK POLYPROPYLENE BLANKET 100 gm/m²
4	2		6		12	NAS 560CK20	SCREW, FLAT HEAD	8-32 x 41 LONG
				4	11	91255A106	SCREW, BUTTON HEAD	◁1 4 40 x 25 LONG
				1	10	SVSK 106961-1	COVER BOTTOM, ASSY	
5				1	9	SVSK 106962-211	FLANGE	MADE FROM COPPER FLASHING
				1	8	MS 24665-155	PIN, COTTER	1" LONG
	1	1	1		7	SVSK 106926-1	COVER	
			1		6	SVSK 106943-1	PLATE, SEPARATOR	
	1	1			5	SVSK 106925-2	CANISTER	
			1		4	SVSK 106925-1	CANISTER	
	X			1	3	SVSK 106962-102	CANISTER CHARCOAL	
		X		1	2	SVSK106962-101	CANISTER, CATALYST	
			X	1	1	SVSK 106962-100	CANISTER, SODASORB	

QUANTITY PER ASSEMBLY — ASSY NO

◁7 OBTAINABLE FROM KIMRE INC PERRENE, FLA. 33157

◁6 BOND USING EC1300 PER HS1265 CODE II A1-2

◁5 VERY LIGHTLY ABRADE BOND AREAS W/ 200 GRIT SANDPAPER BOND SCREENS TO F/N'S 4, 5 & 7 BOND F/N 6 TO F/N 4 BOND F/N 16 TO F/N 18 ALL BONDING PER SVHS 9122

◁4 MATERIAL: ALUMINUM AA3003 H18

◁3 MATERIAL NEOPRENE PER MIL-R-6130C TYPE II, GRADE A, CONDITION SOFT

◁2 OBTAINABLE FROM 3M CO / OCCUPATIONAL HEALTH & SAFETY PRODUCTS DIV ST PAUL, MN 55144

◁1 OBTAINABLE FROM McMASTER-CARR SUPPLY CO. CHICAGO, ILL 60680.

SVSK 106962 1 A

SVSK 106962 1

SVSK 106962 1 A

UNLESS OTHERWISE SPECIFIED

UNITED TECHNOLOGIES — HAMILTON STANDARD DIVISION

NEXT ASSY | USED ON | APPLICATION

CONTRACT NUMBER

DWG RELEASE | LEVEL

OBAT CANISTER

SIZE	FSCM NO	DRAWING NO
J	73030	SVSK 106962

SCALE | WEIGHT ~ LB | SHEET 1 OF 1

FIGURE 12

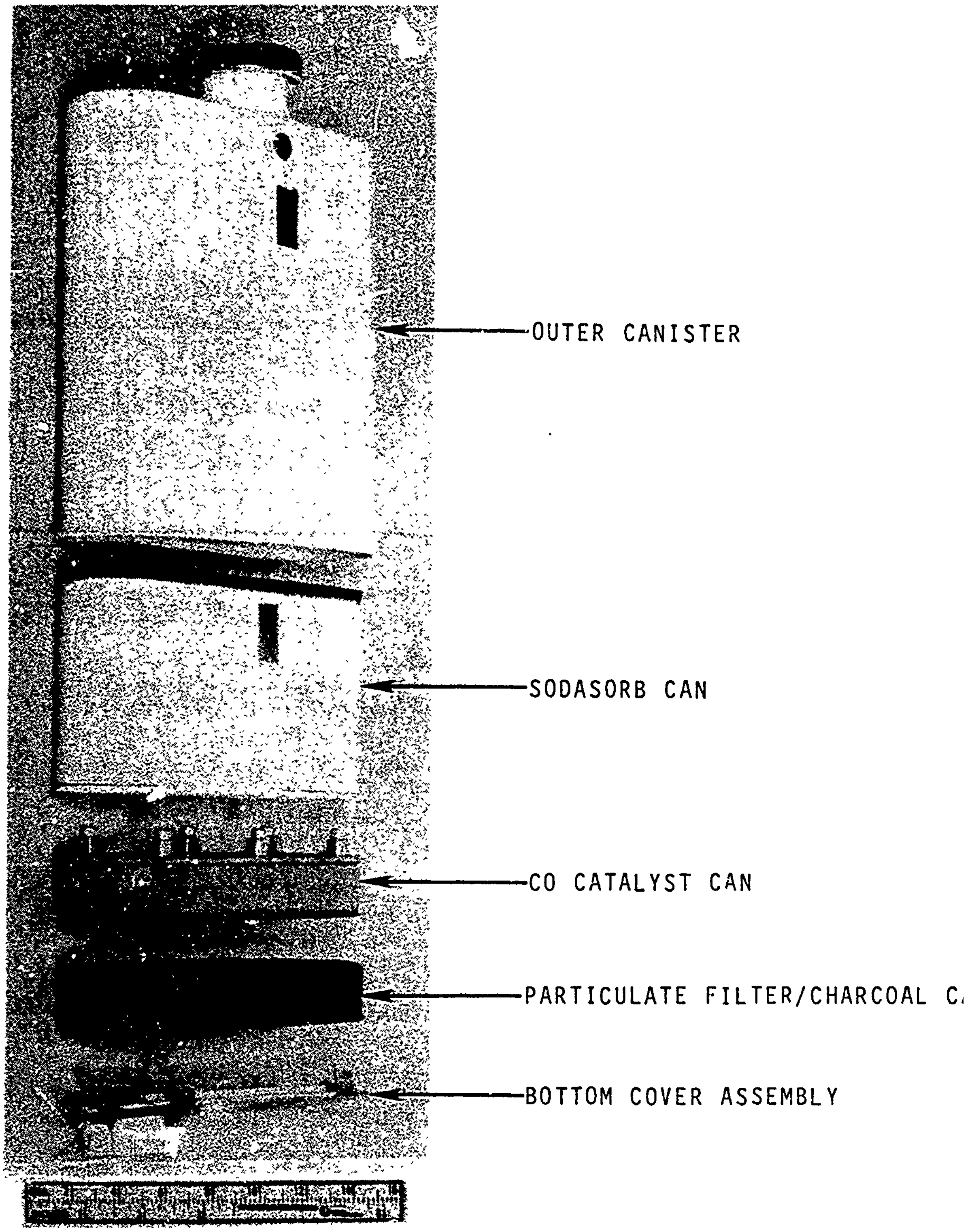


FIGURE 13

FEASIBILITY CANISTER (EXPLODED VIEW)

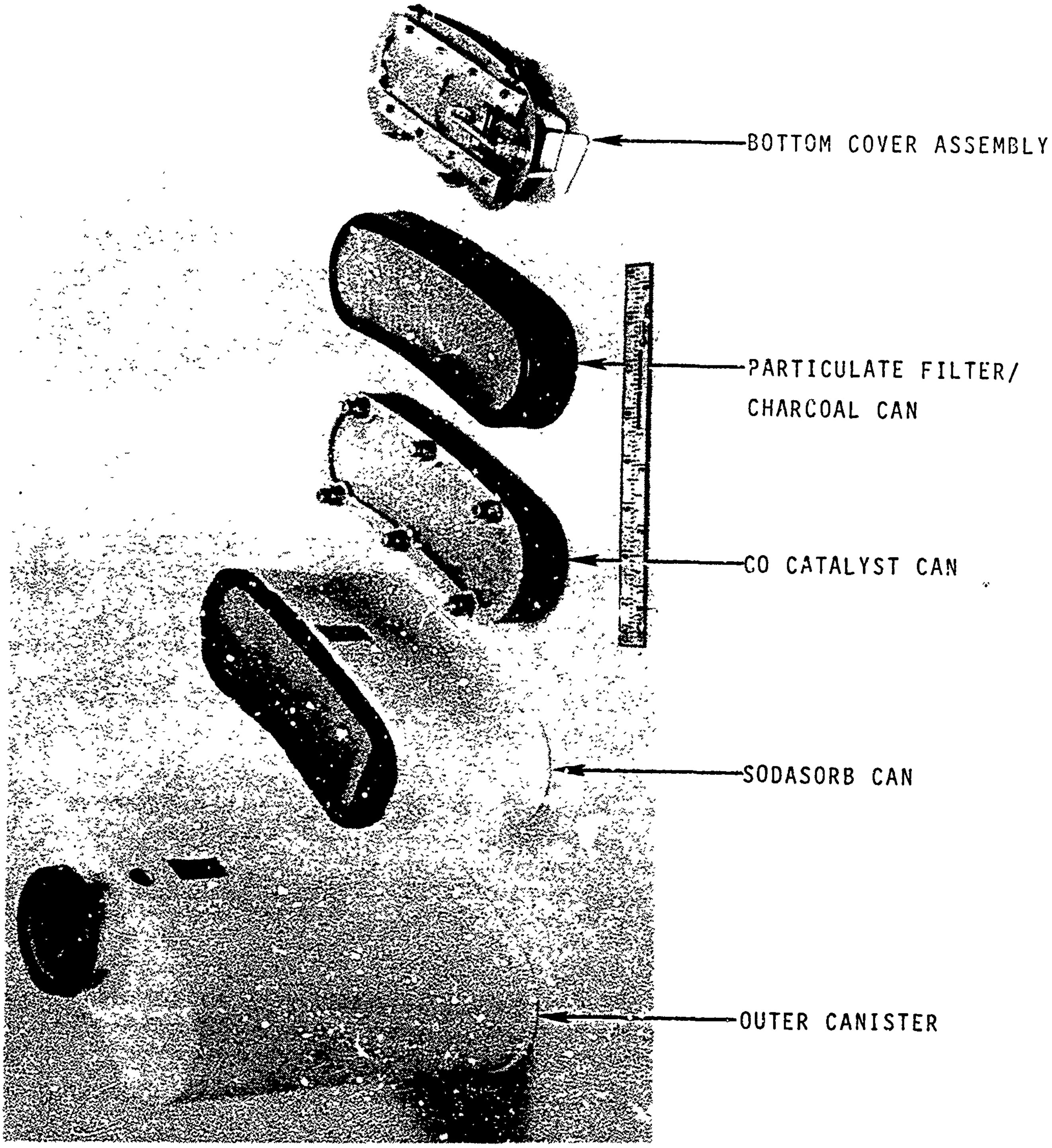
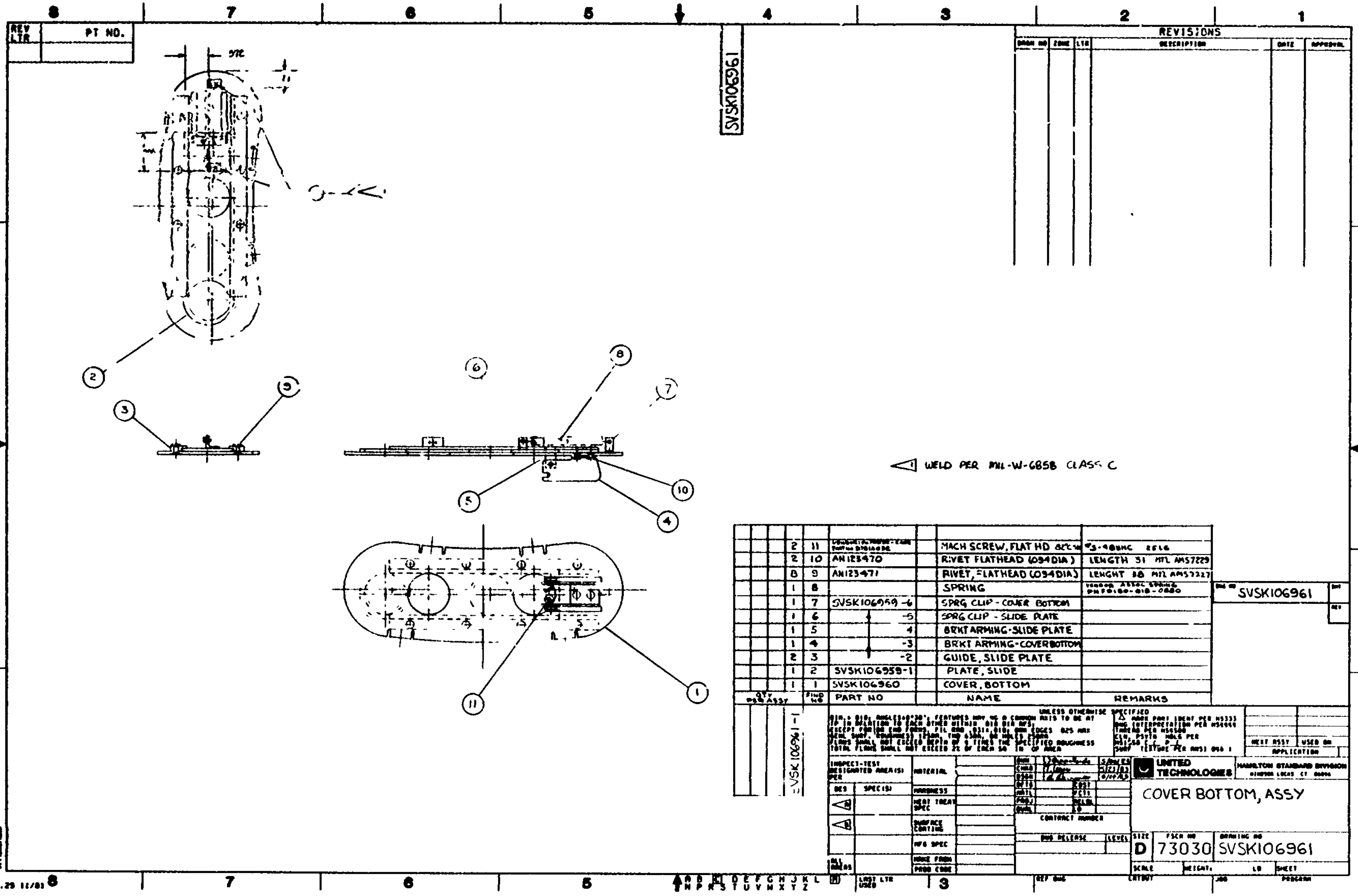


FIGURE 14
FEASIBLITY CANISTER COMPONENTS



QTY PER ASSY	FIND NO	PART NO	NAME	REMARKS
2	11	[illegible]	MACH SCREW, FLAT HD 82°CSK	#5-40UNC 2F16
2	10	AN123470	RIVET FLATHEAD (.094 DIA)	LENGTH .31 MTL AMS7229
8	9	AN123471	RIVET, FLATHEAD (.094 DIA)	LENGHT .38 MTL AMS7227
1	8		SPRING	VENDOR ASSOC SPRING PN F0180-018-0880
1	7	SVSK106959-6	SPRG CLIP - COVER BOTTOM	
1	6	-5	SPRG CLIP - SLIDE PLATE	
1	5	-4	BRKT ARMING-SLIDE PLATE	
1	4	-3	BRKT ARMING-COVER BOTTOM	
2	3	-2	GUIDE, SLIDE PLATE	
1	2	SVSK106959-1	PLATE, SLIDE	
1	1	SVSK106960	COVER, BOTTOM	

FIGURE 15

The three beds, charcoal, catalyst and sorbent, in the canister are each packaged in their own aluminum cans, shown in Figure 16. The cans are color-coded for identification. The particulate filter and charcoal can is black, the carbon monoxide catalyst can is grey, and the sodasorb can is white. The three cans have a common cross-sectional shape, which closely conforms to the inside shape of the standard OBA canister. This arrangement allows optimal utilization of the available volume and provides for easy replacement of individual bed materials. The cans' covers, shown in Figure 17, are easily removable. The individual cans are loaded into the canister from the bottom and are retained by the bottom cover assembly. Neoprene gaskets between the cans prevent air from bypassing the beds. The CO catalyst bed size is based on the preliminary phase test results. The activated charcoal and CO_2/NO_2 absorbent bed sizes are based on analyses discussed in Hamilton Standard's technical proposal, HSPC 82T13 of 15 October 1982, titled "Development of a Reusable Type Training Canister for use with Navy Oxygen Breathing Apparatus (OBA) Type A-4". These beds were tested during the canister's feasibility tests as discussed in this report.

The bottom can in the canister contains the particulate filter and activated charcoal bed. The particulate filter consists of a layer of Kimre Incorporated polypropylene mist eliminator style 4/96 filter media for the larger sodium bicarbonate particles and a 0.25 inch (6.35 mm) layer of 3M filtrete brand filter media, type G-0130, for the 0.5 to 2.0 micron size artificial smoke particles. The activated charcoal bed has approximately 0.110 lbm (50 gm) of Barneby Cheney type MI, 12 to 20 mesh, coconut shell activated charcoal, primarily for the adsorption of hydrocarbon contaminants. The activated charcoal was also found to be an effective adsorption of NO_2. A layer of filtrete type G-0110 filter media is placed on the outlet of the charcoal to act as a dust filter. The particulate filters and charcoal bed are retained in the can by a 10 mesh screen on the inlet side and a 40 mesh screen on the outlet side. The 10 mesh inlet retaining screen was selected to prevent clogging due to sodium bicarbonate dry powder extinguishant.

The middle can in the training canister holds the carbon monoxide oxidation catalyst, which is 10 percent platinum on 14 to 18 mesh alumina subtrate. The bed is 0.75 inch (19.05 mm) deep and contains approximately 0.368 lbm (165 gm) of catalyst. The catalyst is retained by 40 mesh screens on the inlet and outlet.

The upper can in the training canister contains the CO_2 and NO_2 absorbent chemical. The absorbent material is 8 to 14 mesh, high performance sodasorb, manufactured by W.R. Grace and Company. Sodasorb is a mixture of hydrated lime, $Ca(OH)_2$, sodium hydroxide, NaOH, and potassium hydroxide, KOH. The bed contains approximately 1.257 lbm (570 gm) of absorbent retained between 40 mesh screens. Layers of type G-0110 filtrete at the inlet and outlet provide

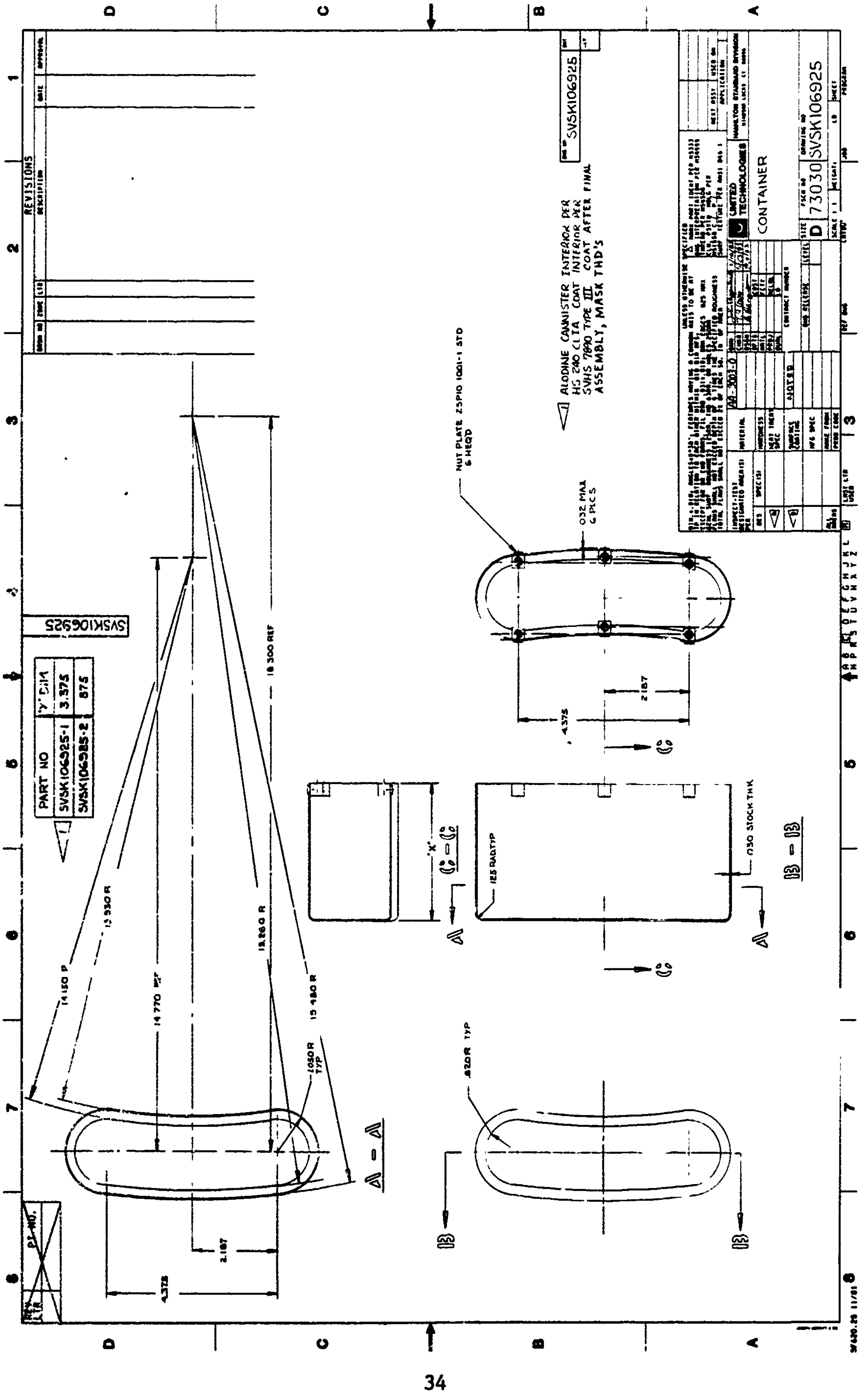

REVISIONS
SVSK106925
PART NO
'Y' DIM
SVSK106925-1
3.375
SVSK106925-2
.875
NUT PLATE Z5P10 1001-1 STD 6 REQD
.032 MAX 6 PLCS
ALODINE CANNISTER INTERIOR PER HS 240 CL TA COAT INTERIOR PER SVHS 7890 TYPE III COAT AFTER FINAL ASSEMBLY, MASK THD'S
18.300 REF
14.770 REF
14.150 R
15.930 R
18.260 R
19.480 R
1.050 R TYP
.820 R TYP
4.375
2.187
.125 RAD TYP
.030 STOCK THK
'X'
A - A
B - B
C - C
CONTAINER
D
73030
SVSK106925
UNITED TECHNOLOGIES
HAMILTON STANDARD DIVISION

FIGURE 16

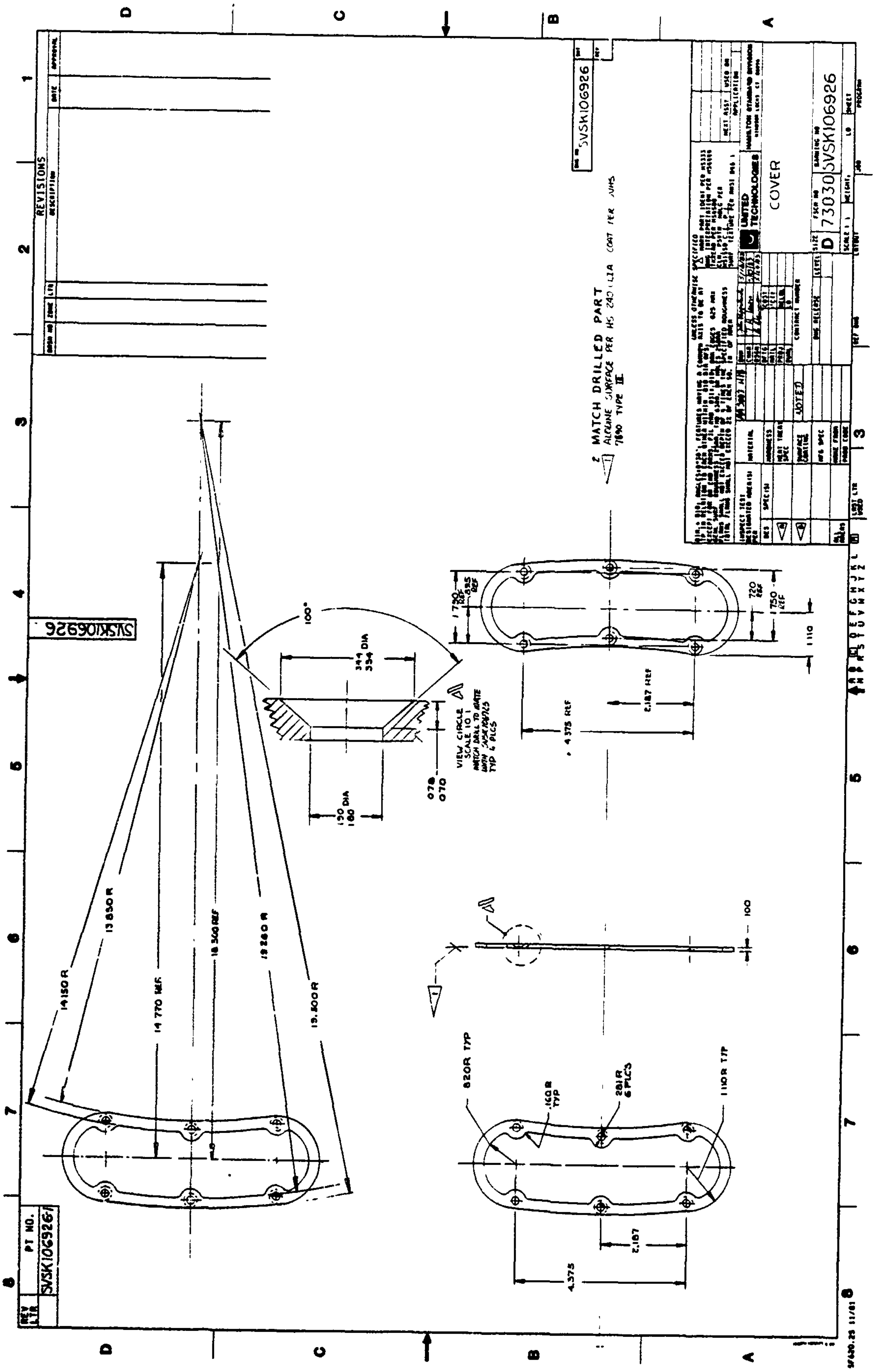

REVISIONS
SVSK106926
PT NO.
SVSK106926-1
MATCH DRILLED PART
ALKANE SURFACE PER HS 240 ...
100°
VIEW CIRCLE SCALE 10:1
COVER
UNITED TECHNOLOGIES
D
73030
SVSK106926
4.375 REF
2.187 REF
4.375
2.187
14150 R
13850 R
14 770 REF
18 560 REF
19280 R
19.800 R
820R TYP
.160R TYP
281R 6 PLCS
110R TYP
1.750
1.750 REF
1.110
.720
.100
.078
.070
A
B
C
D
1
2
3
4
5
6
7
8

FIGURE 17

dust filters. The sodasorb bed has a partition on one end to form a bypass flow channel which is sized so that only approximately 30 percent of the flow passes through the absorbent. This arrangement results in extending the bed life while still reducing CO_2 and NO_2 concentrations within acceptable limits. With 30 percent of the flow through the sodasrob bed, the maximum average CO_2 concentration of 1.24 percent is reduced below the time weight average limit of 1.0% for CO_2. Although it was initially intended to pass only 20 percent of the flow through the CO_2 absorbent, 30 percent was selected to provide a conservative performance margin. The sodasorb used in the canister is indicator type, containing ethyl violet which changes in color from white to purple as its powers of absorption are exhausted. A viewing window is provided in the side of the canister adjacent to the end of the sodasorb bed to allow seeing the color change without disassembling the canister.

The absorption of CO_2, or any acid gas, by sodasorb is a chemical and not a physical process. The action is quite different from adsorption, by activated carbon, for example, where there is physical entrapment of gases. In sodasorb absorption, the CO_2 is chemically converted, the gas first going into solution and forming carbonic acid, which then reacts with the hydroxide to form sodium carbonate, at the same time regenerating the water consumed earlier. The sodium carbonate then reacts with the hydrated lime to form calcium carbonate and regenerate caustic soda and caustic potash.

The chemical neutralization of CO_2 by sodasorb may be expressed by the following equations:

$$\text{(i)}\quad CO_2 + H_2O \rightleftharpoons H_2CO_3$$

$$\text{(ii)}\quad 2H_2CO_3 + 2Na^+ + 2OH^- + 2K^+ + 2OH^- \longrightarrow 2Na^+ + CO_3^{=} + 2K^+ + CO_3^{=} + 4H_2O$$

$$\text{(iii)}\quad Ca(OH)_2 + H_2O \rightleftharpoons Ca^{++} + 2OH^- + H_2O$$

$$\text{(iv)}\quad 2Ca^{++} + 4OH^- + 2Na^+ + CO_3^{=} + 2K^+ + CO_3^{=} \rightleftharpoons 2CaCO_3 + 2Na^+ + 2OH^- + 2K^+ + 2OH^-$$

In (i) the CO_2 dissolves at a rate governed by a number of physical chemical factors. The rate is not proportional to the partial pressure of the CO_2 which is in contact with the film of moisture coating the sodasorb granules, but greater, because some of the CO_2 combines chemically with the water to form carbonic acid. The rate is directly proportional to the rate of removal of dissolved CO_2, or H_2CO_3, from solution, by reaction with hydroxyl ions, reaction (ii). Thus the rapidity of removal of dissolved CO_2 is directly related to the availability of hydroxyl ions. Since the reaction between H^+ and OH^- is instantaneous, forming water, reaction (ii) is extremely rapid, and available OH^- ions are quickly exhausted. Hense equations (iii) and (iv) must supply additional hydroxyl ions to keep the absorption of CO_2 progressing. The latter two reactions are, therefore, rate limiting.

Exhalation flow from the OBA face mask is directed from the exhalation breathing tube to ambient via the canister exhalation tube shown in Figure 12. This arrangement extends the sodasorb bed life by not passing the metabolic CO_2 through the sodasorb bed.

DISCUSSION

Preliminary Test Phase

Background

In the feasibility evaluation of a reusable training canister for use with the Navy OBA during training exercises within the controlled environment of the 19F1 trainer, two critical design issues needed to be addressed at the start of the program: the catalytic CO conversion performance at temperature and humidity extremes and the total system air flow resistance at the peak inspiration flow rate. Additionally, it was necessary to generate design data for the CO conversion catalyst bed for the feasibility model canister.

Inlet CO concentration levels for the preliminary tests were to be consistent with the ambient levels measured during simulated bilge fire conditions in the 19F1 trainer. Bilge fire data was recorded in the Fire Fighter Trainer Environmental Considerations Phase II report of 31 July 1981 by Booz, Allen and Hamilton, Inc.

A summary of this data for carbon monoxide is given in Table 3.

TABLE 3 - BILGE FIRE CONCENTRATION DATA FOR CO

Phase II Run No.	Carbon Monoxide Concentration (%)		
	Transient		Steady State Average
	Maximum	Duration (sec)	
3	0.40	45	0.04
4	0.27	20	0.04
5	0.60	20	0.06
6	0.21	20	0.04
9	0.58	20	0.07
10	0.25	30	0.04
Maximum	0.60	45	0.07
Overall Average			0.05

The use of this data for generating the test specification is compliant with the requirements defined in the Naval Training Equipment Center Requirements Specification N-731-102 of 4 May 1982, as modified by Specification Amendment 0001 of 4 October 1982. From the bilge fire data, the inlet CO concentration to the OBAT for all steady state testing was selected as 0.07 percent CO, 700 ppm, based on the steady state maximum average value. The inlet CO concentration for all transient OBAT testing was selected as 0.6 percent CO, 6000 ppm, based on the transient maximum concentration.

The performance goals for the OBAT canister outlet CO concentration levels are based on the recommended NIOSH limits. The maximum outlet concentration limit applied to the twenty-minute, steady state tests with an inlet CO concentration of 700 ppm is 35 ppm, which corresponds to the NIOSH 10 hour weighted average permissible exposure limit. The maximum outlet concentration limit applied to the twenty-minute, transient tests with an inlet CO concentration of 6000 ppm is 200 ppm, which corresponds to the NIOSH ceiling exposure limit.

Table 4 defines the carbon monoxide catalyst performance test matrix for the Preliminary Phase of the program. A total of 24 tests, 3 at each of the 8 test conditions, were planned to demonstrate acceptable catalyst performance. However, to further investigate performance at certain conditions, a total of 46 tests were conducted. A detailed list of all tests run is provided in the following test results section.

TABLE 4 - CO PERFORMANCE TEST MATRIX FOR PRELIMINARY PHASE TESTING

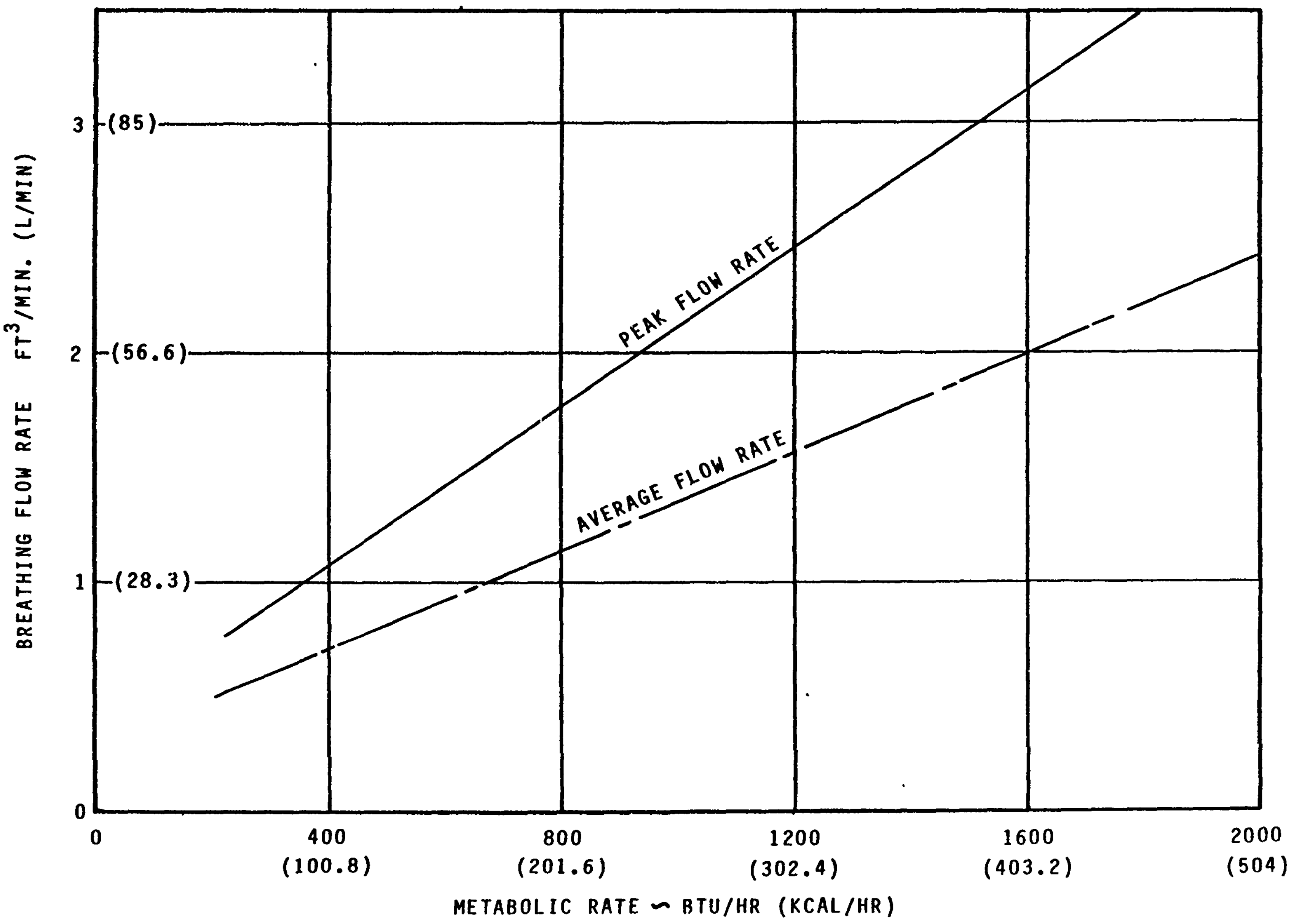
Test No.	Temperature (°F)	Relative Humidity (%)	CO Concentration (PPM)	Test Condition	Test Duration (Min.)	Number of Tests
P1	30	30	700	STEADY STATE	20	3
P2	140					
P3	30	~ 100				
P4	140					
P5	30	30	6000	TRANSIENT	2	3
P6	140					
P7	30	~100				
P8	140					

The air flow rate through the test canister was chosen as 3.0 ft^3/min (85 l/min). This corresponds approximately to the peak inspiration flow rate for an individual at a high metabolic rate, 1510 Btu/hr (380 kcal/hr). Refer to the Figure 18 data, which is based on testing performed by Hamilton Standard in the development of the Space Shuttle Portable Oxygen System under NASA Contract NAS9-15246 and presented in test report TER 3156 of 10 February 1981. The average inspiration rate for this person is about 1.90 ft^3/min (54 l/min), and the total inspiration flow in one minute is 0.95 ft^3 (271). The choice of 3.0 ft^3/min (85 l/min) builds conservatism into the testing, since meeting CO conversion performance at this flow represents a more stringent requirement than the normal cyclic inspiration flow. However, it proves that the peak flow rates experienced during inspiration do not result in breakthrough of the catalyst bed.

Air flow resistance tests, designated test series P9, were conducted to establish the total system air flow resistance. The breadboard test canister, loaded as described earlier and shown in Figure 4, provided the air flow resistance data for the particulate filter, activated charcoal, and CO catalyst. A CO_2 absorbent bed was tested separately in a breadboard canister, and an OBA, without a canister installed, was also tested to establish the OBA pressure loss value. An analytical summation of these pressure losses established the expected air flow resistance for the feasibility model canister mated with an OBA. The performance goal for this test was to verify that the total system air flow resistance is less than 3 inches (76.2 mm) of water at a flow rate of 3.0 ft^3/min (85 l/min).

FIGURE 18

BREATHING FLOW RATE CHARACTERISTIC



TEST RESULTS

Preliminary Test Phase

The carbon monoxide oxidation catalyst tests were run for both steady state and transient CO concentrations with four basic sets of inlet conditions: cold and hot at both low and high relative humidities. The actual inlet conditions and the results for the eight test series, designated tests P1 through P8, are summarized in Table 5 and are discussed separately below. The "flow at venturi" column of Table 5 is the 70°F (21.1°C) dry gas flow through the test rig venturi. The actual flow through the test canister in the adjacent column has been corrected for temperature and moisture content.

Steady State Tests

Test series P1 was run at low temperature and relative humidity for the steady state, approximately 700 ppm, CO concentration. The duration of each test case was about 20 minutes. Three tests were run in this series. The canister outlet CO concentration was 0.0 ppm during this entire series, indicating complete conversion to CO_2.

Test series P2 was run at high temperature and low relative humidity for the steady state CO concentration. Again, three twenty-minute cases were run in this test series, and complete conversion of CO to CO_2 was achieved.

Test series P3 was run at low temperature and high relative humidity for the steady state CO concentration. As in the above series, three cases, each of about twenty-minutes duration, were run; and complete CO conversion was achieved.

Test series P4 was run at high temperature and high relative humidity for the steady state CO concentration. For cases P4-1 to P4-4, test conditions of temperature and humidity were established with the nitrogen flow passing through the canister. Complete CO conversion was demonstrated in case P4-1. However, in cases P4-2 and P4-3, which were performed after case P4-1, a detectable CO concentration was measured in the canister outlet stream. Although the results of these cases were within the 35 ppm limit, further testing at these conditions was conducted to investigate the sudden performance degradation. Case P4-4 showed further performance degradation and was terminated after 12 minutes. During tests P4-2, P4-3 , and P4-4, the peak outlet CO concentration was measured at the start of the tests, and CO conversion performance improved as the test continued. Also, due to nearly four hours of hot, moist, dew point greater than 125°F (51.7°C), nitrogen flow through the canister, free water was visible in the catalyst bed. To determine if this water was restricting CO transport to the catalyst sites, the bed was partially dried with warm, dry nitrogen flow for 1 hour. The subsequent test, case P4-5, was run at high temperature with no moisture added, and complete CO conversion was achieved. For the final test, case P4-6, in this series, the conditions were established with flow bypassing the canister, and the catalyst bed was at room temperature, 78°F (25.6°C) at the start of the test. Complete conversion of CO was achieved.

TABLE 5

PRELIMINARY PHASE CO CATALYST TEST DATA

STEADY STATE TESTS

Test Number	Flow At Venturi (Ft^3/Min)	Flow At Canister (Ft^3/Min)	Test Duration (Min)	Avg. Inlet Temp. (°F)	Avg. Inlet Dew Point (°F)	Avg. Inlet Relative Humidity (%)	Inlet CO Conc. (PPM)	Max. Outlet CO Conc. (PPM)	Avg. Canister Differential Pressure (in. water)	Applicable Notes
P1-1	2.95	2.74	21.0	31.54	5.24	28.50	685	0.0	1.075	
P1-2	2.96	2.74	20.0	30.56	-1.89	20.16	680	0.0	1.071	
P1-3	2.95	2.73	20.0	30.51	4.64	28.45	680	0.0	1.074	
P2-1	2.97	3.57	20.0	139.56	97.21	30.62	656	0.0	1.591	
P2-2	2.97	3.59	22.0	142.60	97.27	28.36	703	0.0	1.690	
P2-3	2.95	3.57	22.0	140.81	99.25	31.60	656	0.0	1.634	
P3-1	2.92	2.75	20.0	36.41	30.80	79.60	672	0.0	1.130	
P3-2	2.92	2.73	21.0	33.11	30.31	81.20	674	0.0	1.063	
P3-3	2.95	2.75	22.0	32.15	26.80	79.28	703	0.0	1.085	
P4-1	2.92	4.17	20.0	157.41	137.80	61.07	656	0.0	1.830	
P4-2	2.95	4.23	20.0	159.84	137.86	57.56	672	1.0	1.918	
P4-3	2.96	3.88	20.0	140.91	125.87	67.16	672	20.0	1.784	1
P4-4	2.98	3.89	12.0	142.23	124.48	62.50	672	155.0	2.024	2
P4-5	2.97	3.46	2.0	143.50	< 0.0	< 10.00	672	0.0	1.380	3
P4-6	2.96	4.13	20.0	150.14	135.55	68.86	707	0.0	1.938	4

TABLE 5 (Cont.)

PRELIMINARY PHASE CO CATALYST TEST DATA

TRANSIENT TESTS

Test Number	Flow At Venturi (Ft^3/Min)	Flow At Canister (Ft^3/Min)	Test Duration (Min)	Avg. Inlet Temp. (°F)	Avg. Inlet Dew Point (°F)	Avg. Inlet Relative Humidity (%)	Inlet CO Conc. (PPM)	Max. Outlet CO Conc. (PPM)	Avg. Canister Differential Pressure (in. water)	Applicable Notes
P5-1	1.54	1.44	3.00	33.75	5.09	25.89	5702	1.5	0.520	
P5-2	1.99	1.85	2.70	32.70	5.60	27.70	5702	250.0	—	5
P5-3	2.18	2.03	2.90	32.34	6.98	30.09	5702	200.0	0.760	6
P5-4	2.93	2.72	1.35	32.25	5.72	28.33	5702	250.0	1.110	7
P5-5	2.97	2.74	1.25	29.15	2.57	27.34	5702	190.0	1.058	8
P5-6	2.98	2.76	1.50	30.90	3.38	26.26	5702	250.0	1.073	9
P5-7	2.97	2.77	1.75	33.20	13.52	39.46	5762	250.0	1.090	10
P5-8	2.97	2.79	2.25	36.83	18.28	42.99	5762	145.0	1.122	11
P5-9	3.14	2.95	1.80	36.55	3.29	21.03	5762	250.0	1.157	12, 13
P5-10	3.14	2.96	2.00	38.50	5.90	22.36	5762	250.0	1.167	12, 14
P5-11	3.14	2.98	2.08	42.50	9.50	22.88	5762	200.0	1.185	12, 15
P5-12	3.14	3.01	2.58	46.10	16.52	28.05	5762	200.0	1.226	12, 16
P5-13	3.10	2.90	3.00	35.20	1.13	19.40	5762	56.0	1.240	17
P5-14	3.10	2.87	3.00	31.47	< -22	0	5762	3.6	1.490	18
P5-15	1.85	1.72	3.00	30.80	7.97	33.75	5702	3.5	—	19
P5-16	2.09	1.94	3.00	32.15	3.02	24.38	5702	5.0	—	20
P5-17	2.94	2.78	2.25	28.10	—	—	5702	180.0	1.052	21
P6-1	2.94	3.52	2.50	139.02	94.60	28.73	5762	0.2	1.657	
P6-2	2.97	3.57	2.00	141.90	95.54	27.[illegible]6	5762	0.0	1.694	
P6-3	3.01	3.64	3.33	142.13	97.40	28.82	5762	0.0	1.733	
P7-1	1.51	1.40	3.00	28.8[illegible]	21.20	70.05	5702	1.0	0.490	
P7-2	1.98	1.85	3.00	33.86	23.36	62.43	5702	11.0	0.703	
P7-3	2.93	2.74	2.50	32.05	30.38	92.53	5702	200.0	1.102	22
P7-4	2.93	2.73	2.50	31.70	31.82	100.00	5702	120.0	1.106	23
P7-5	2.97	2.77	2.50	31.88	31.73	99.33	5702	120.0	1.115	24
P7-6	2.08	1.94	3.00	32.50	31.64	96.43	5702	5.0	—	25
P7-7	2.93	2.85	2.50	51.68	34.52	51.68	5702	200.0	1.164	
P7-8	2.90	2.83	3.00	52.20	48.06	85.61	5702	55.0	1.204	26
P8-1	2.98	4.28	2.50	157.70	138.65	62.09	5762	1.0	1.480	
P8-2	2.93	4.03	2.50	146.93	134.00	71.37	5762	2.5	1.595	
P8-3	2.98	4.18	2.50	153.30	135.86	63.99	5762	0.5	1.568	

TABLE 5 (Cont.)

PRELIMINARY PHASE CO CATALYST TEST NOTES

1. The bed was subjected to high temperature, ~140°F (60°C) and high relative humidity (65-70%) nitrogen flow for 2-3 hours prior to the test.

2. High temperature and high relative humidity flow through the bed was continued between tests P4-3 and P4-4. The bed was probably saturated with moisture, causing the degraded CO performance. CO performance improved as tests P4-3 and P4-4 progressed.

3. The bed was partially dried with warm dry nitrogen flow for approximately 1 hour between tests P4-4 and P4-5. CO performance completely recovered. Flow was dry with no moisture added.

4. Test P4-6 was run with the bed initially at room temperature, 78°F (25.6°C) and dry. Test conditions were established with flow bypassing the bed.

5. Differential pressure across the canister was not recorded. Outlet CO concentration at 2.0 minutes was 80 ppm.

6. Outlet CO concentration at 2.0 minutes was 32 ppm.

7. Outlet CO concentration exceeded 200 ppm at approximately 78 seconds.

8. Outlet CO concentration exceeded 200 ppm at approximately 80 seconds.

9. Outlet CO concentration exceeded 200 ppm at approximately 85 seconds.

10. Outlet CO concentration exceeded 200 ppm at approximately 100 seconds.

11. Outlet CO concentration at 2.0 minutes was 65 ppm.

12. For tests P5-9 to P5-12, the bed was preconditioned with nitrogen at the dew point used during the individual test.

13. Outlet CO concentration exceeded 200 ppm at 105 seconds.

TABLE 5 (Cont.)

PRELIMINARY PHASE CC CATALYST TEST NOTES

14. Outlet CO concentration exceeded 200 ppm at 111 seconds.

15. Outlet CO concentration exceeded 200 ppm at 125 seconds.

16. Outlet CO concentration exceeded 200 ppm at 155 seconds.

17. The bed was subjected to 76°F (24.4°C) air flow at 50 percent relative humidity for six hours prior to the test. The bed was at room temperature, 78°F (25.6°C), at the start of the test.

18. The bed was subjected to [illegible] ft^3/min (42.5 l/min) of moist, 142°F (61.1°C), air flow for 15 minutes prior to the test.

19. Flow was pulsed, 2 seconds on and 2 seconds off, with an average flow while on of 3.43 ft^3/min (97.14 l/min).

20. Flow was pulsed, 2 seconds on and 2 seconds off, with an average flow while on of 3.89 ft^3/min (110.16 l/min).

21. Dew point was not recorded due to instrument problems.

22. Outlet CO concentration at 2.0 minutes was 58 ppm

23. Outlet CO concentration at 2.0 minutes was 40 ppm.

24. Outlet CO concentration at 2.0 minutes was 37 ppm.

25. Flow was pulsed, 2 seconds on and 2 seconds off, with an average flow while on of 3.89 ft^3/min (110.16 l/min).

26. Outlet CO concentration at 2.0 minutes was 13 ppm.

In summary, for all steady state, 700 ppm inlet CO concentration tests, complete conversion of CO to CO_2 was achieved. The degraded performance during some test series P4 cases was due to saturating the catalyst bed, including having condensed water droplets in the bed, which resulted after 3 to 4 hours of nitrogen flow with a dew point in excess of 125°F (51.7°C). This continuous and extended period of extremely moist flow is unrealistic for the 19F1 Fire Fighter Trainer application, and the bed recovered completely when partially dried.

Transient Tests

Since the low temperature and low relative humidity test condition was anticipated to be the most limiting, these tests, series P5, were the first transient cases, 6000 ppm CO concentration, conducted. The first few tests, P5-1 to P5-3, were run at less than the nominal 3.0 ft^3/min (85 l/min) flow. Case P5-1, with 1.44 ft^3/min (40.8 l/min) flow, shows essentially complete CO conversion for its three minute duration. Cases P5-2 and P5-3 were conducted at 1.85 ft^3/min (52.4 l/min) and 2.03 ft^3/min (57.5 l/min), respectively. Although still within the 200 ppm limit, outlet CO concentration rose to 80 and 32 ppm, respectively, at the two-minute point of these tests. During cases P5-4, P5-5, and P5-6, run at flows of approximately 2.75 ft^3/min (77.9 l/min), outlet CO concentration exceeded the 200 ppm limit at about 80 seconds into the tests. These cases, P5-1 to P5-6, were run with the catalyst bed purged with dry nitrogen prior to each test. Thus, little moisture was present on the bed at the start of each run. Since testing had shown that increased moisture improved the catalyst's conversion performance, cases were run at higher inlet dew points to determine the minimum dew point necessary to maintain outlet CO concentration less than 200 ppm for 2 minutes. Cases P5-7 and P5-8 were run at inlet dew points of 13.5°F (-10.3°C) and 18.3°F (-7.6°C), respectively. Carbon monoxide conversion performance is shown in Figure 19 for cases at various inlet dew points and with other conditions being constant. For all of these tests, the bed was preconditioned, with dry nitrogen flow. Extrapolating between the curves shows that an inlet dew point of approximately 15°F (-9.4°C) is required to meet the 200 ppm maximum outlet CO concentration limit for 2 minutes of 3.0 ft^3/min (85 l/min) flow. A more realistic situation is to have the catalyst preconditioned at the dew point to be tested. Cases P5-9 to P5-12 were run using nitrogen flow for moisture preconditioning. Figures 20 and 21 show the CO catalyst's performance for these tests. Extrapolating between the curves of Figure 20 or reading the dew point corresponding to 120 seconds on Figure 21 shows that for a bed preconditioned at the test condition dew point, an inlet dew point of only approximately 8°F (-13.3°C) is required to meet the 200 ppm maximum outlet CO concentration limit for 2 minutes of 3.0 ft^3/min (85 l/min) flow.

FIGURE 19

CO CATALYST PERFORMANCE

LOW TEMPERATURE, TRANSIENT CASES

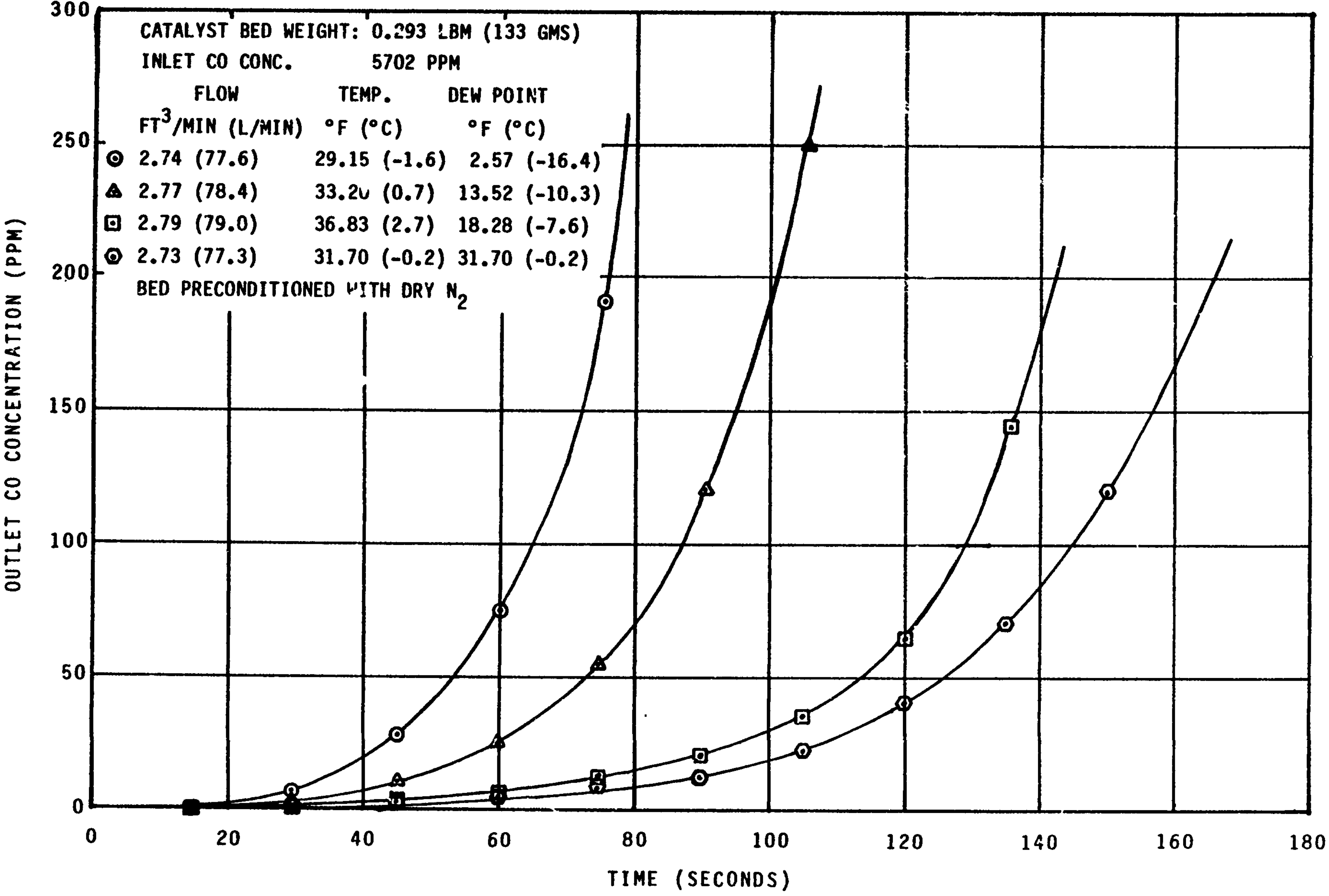


FIGURE 20

CO CATALYST PERFORMANCE

LOW TEMPERATURE, TRANSIENT CASES

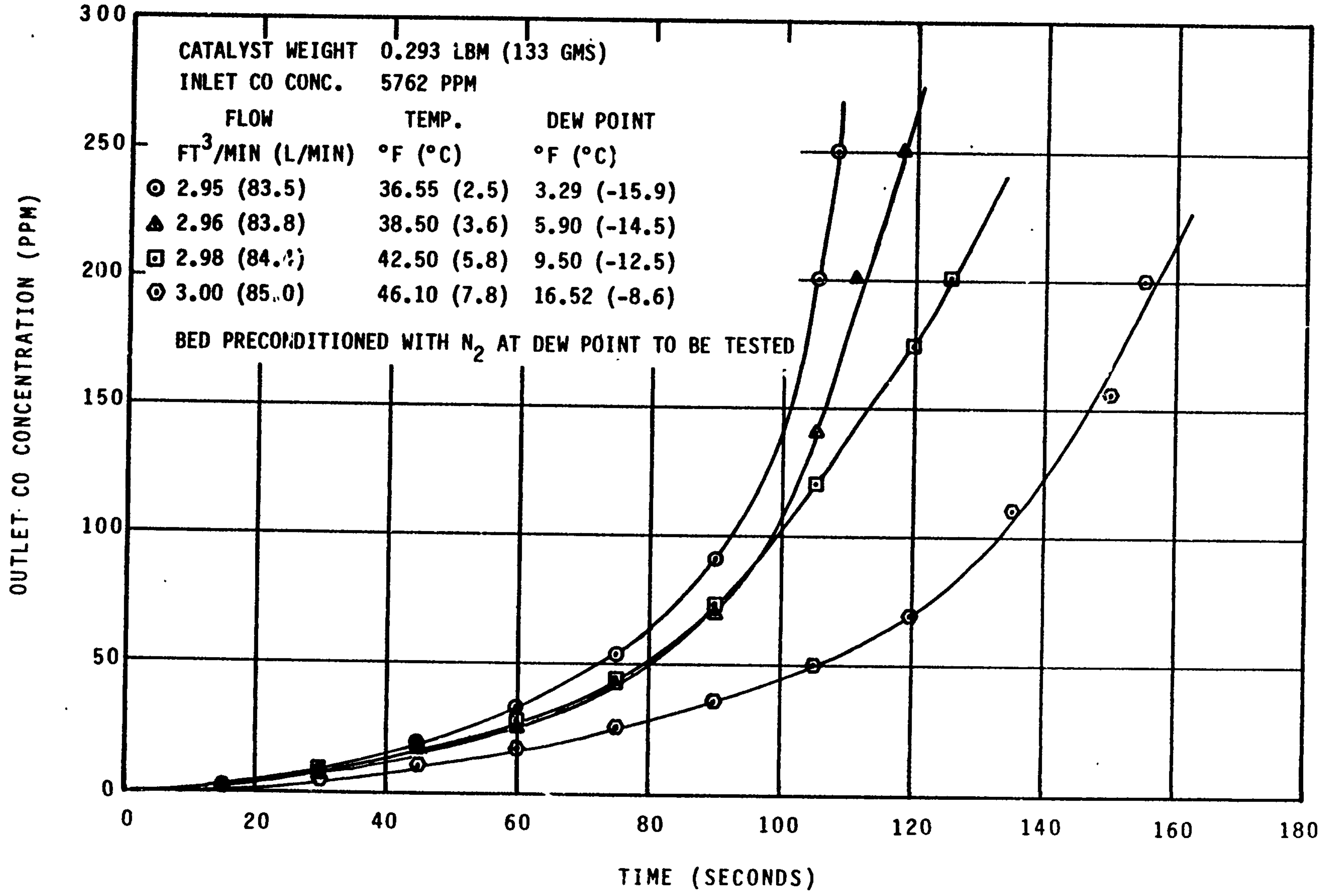
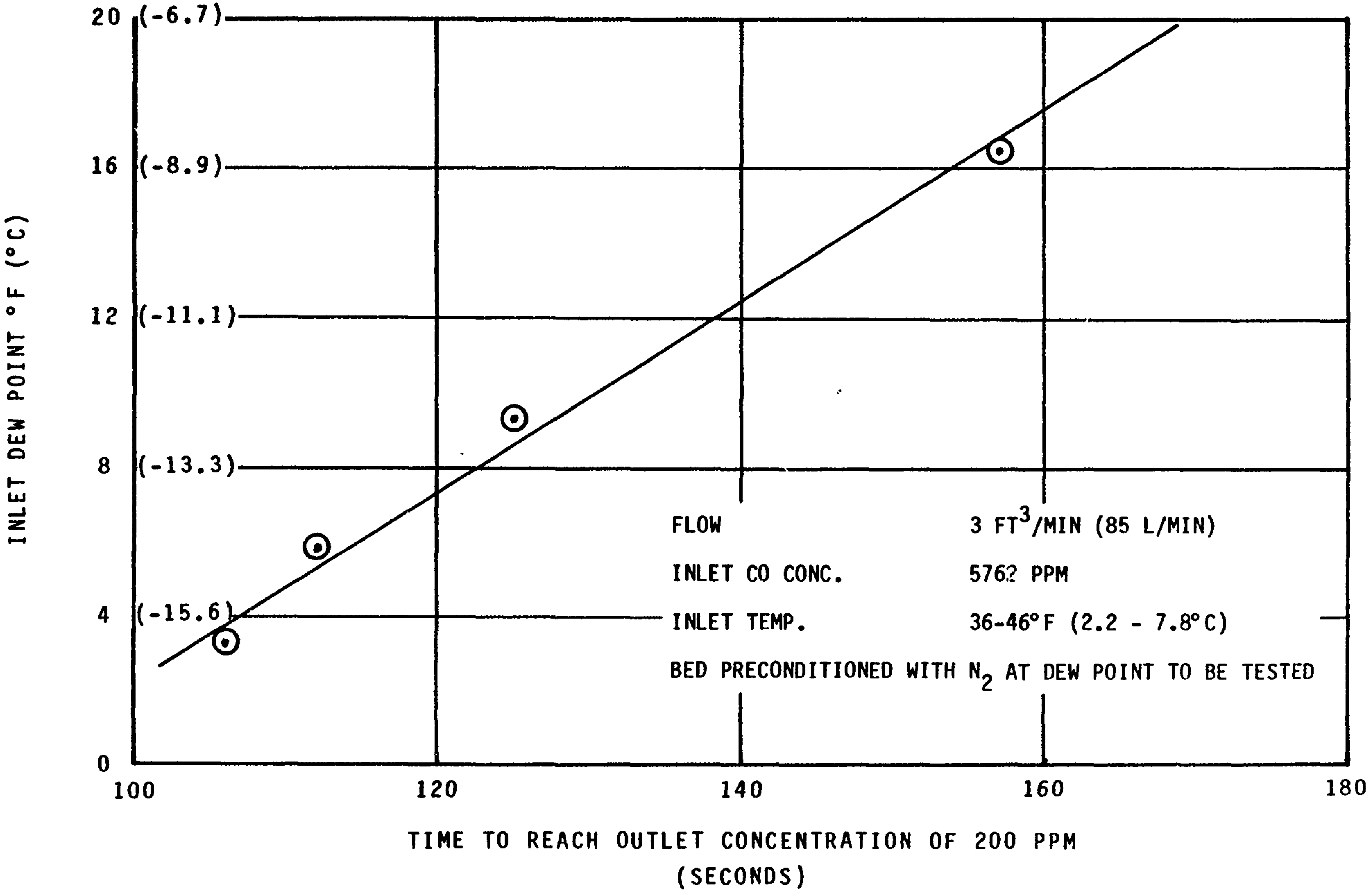


FIGURE 21
EFFECT OF INLET DEW POINT



To dramatize the effect on CO conversion performance of moisture on the bed, two tests were run with higher levels of moisture on the catalyst than would be adsorbed from the test condition flow. For case P5-13, the bed was preconditioned for 6 hours with air at 78°F (24.4°C) temperature and a 56°F (13.3°C) dew point. After 3 minutes of 2.9 ft^3/min (82.1 l/min) flow with a 1.1°F (-17.2°C) dew point, outlet CO concentration had increased to only 56 ppm. Carrying this point to an extreme, for case P5-14 the bed was preconditioned for 15 minutes with nearly saturated 142°F (61.1°C) flow. After 3 minutes of 2.87 ft^3/min (81.3 l/min) dry flow at a temperature of 31.5°F (-0.3°C), outlet CO concentration had increased to only 3.5 ppm. Both of these tests were run with the transient carbon monoxide inlet concentration of 5762 ppm.

Cases P5-15 and P5-16 were run at low temperatures and relative humidities for the transient CO concentration, but flow was 2 seconds on and 2 seconds off, to simulate actual canister usage conditions. When flow was on, the flow rates for the two cases were 3.43 ft^3/min (97.1 l/min) and 3.89 ft^3/min (110.2 l/min), respectively. After 3 minutes of the cyclic flow conditions, outlet CO concentration was only 3.5 ppm for case P5-15 and 5.0 ppm for case P5-16. For both of these cases, the bed was dry prior to the tests. These results clearly show that under cyclic inspiration flow the catalyst bed can easily handle the low temperature and low relative humidity transient test conditions.

Test series P6 was run at high temperature and low relative humidity for the transient CO concentration. Three cases, P6-1 to P6-3, were run, and complete conversion of CO to CO_2 was demonstrated. Although the relative humidity was only near 30 percent for these tests, this corresponds to a dew point of approximately 97°F (36.1°C). Thus, the complete conversion of CO was expected, based on the previous transient condition tests at low dew points.

Test series P7 was run at low temperature and high relative humidity for the transient CO concentration. Cases P7-1 and P7-2 were run at less than the nominal 3.0 ft^3/min (85 l/min) flow. Test P7-1 with flow of 1.40 ft^3/min (39.6 l/min) resulted in nearly complete CO conversion. After 3 minutes outlet CO concentration was only 1.0 ppm. For case P7-2, run at 1.85 ft^3/ min (52.4 l/min) flow, outlet CO concentration was only slightly higher after 3 minutes. The results of cases P7-3 to P7-5 with flows of about 2.75 ft^3/ min (77.9 l/min) were well within the specifications. Outlet CO concentrations at the two-minute point of the tests were 58 ppm, 40 ppm, and 37 ppm, respectively. The final test, P7-6, of this series was conducted with pulsed flow, 2 seconds on and 2 seconds off, to simulate the actual use of the catalyst bed. Average flow rate during the on portion of the cycle was 3.89 ft^3/min (110.2 l/min). After 3 minutes outlet CO concentration increased to only 5.0 ppm, which demonstrates that the catalyst bed can easily convert the transient CO concentration under actual use for the low temperature and high relative humidity conditions.

The final CO catalyst test series, P8, was at high temperature and high relative humidity for the transient CO concentration. Three 2.5 minute tests, P8-1 to P8-3, were conducted. As expected, based on previous test results, nearly complete conversion of CO to CO_2 was achieved.

In summary, for all transient, 6000 ppm inlet CO concentration, tests, the catalyst's performance was well within acceptable limits. Only in test series P5 was the conservative limit, 200 ppm outlet concentration for 2 minutes of 3.0 ft^3/min (85 l/min) flow at 6000 ppm inlet CO concentration, exceeded in some test cases. When inlet dew point was above 8°F (-13.3°C), which corresponds to 35 percent relative humidity at a 30°F (-1.1°C) temperature, the catalyst bed's performance was within this limit. Also, when the flow was pulsed, which is representative of the actual canister's usage, nearly complete CO conversion was achieved.

Preliminary Phase Air Flow Resistance Tests

To establish the total system, OBA and canister, air flow resistance, tests were conducted on separate parts of the system, and the results were added. Individual tests were performed on an OBA without a canister installed, a breadboard canister loaded with a particulate filter, activated charcoal bed, and CO catalyst bed, and a breadboard canister loaded with a sodasorb bed. Data for the OBA and the breadboard canister with a filter, charcoal, and catalyst is displayed in Figure 22. At 3.0 ft^3/min (85 l/min) the air flow resistance for the OBA without a canister is 0.67 inch (17.02 mm) of water and for the breadboard canister with a particulate filter, charcoal bed, and catalyst bed is 1.18 inches (29.97 mm) of water. This particulate filter, charcoal bed, and catalyst bed data was measured on the same material that was used in the catalyst performance tests. Thus, it is for a 0.168 lbm (76 gm) activated charcoal bed and a 0.293 lbm (133 gms) CO catalyst bed. Data for a 1.237 lbm (561 gm) sodasorb bed is displayed in Figure 23. The total system air flow resistance, based on a summation of the three components, is shown in Figure 24. However, the sodasorb portion of the total resistance is adjusted assuming only 20 percent of the total flow is passing through it. At 3.0 ft^3/min (85 l/min) of total system flow the air flow resistance is 1.94 inches (49.28 mm) of water.

FIGURE 22
AIR FLOW RESISTANCE DATA

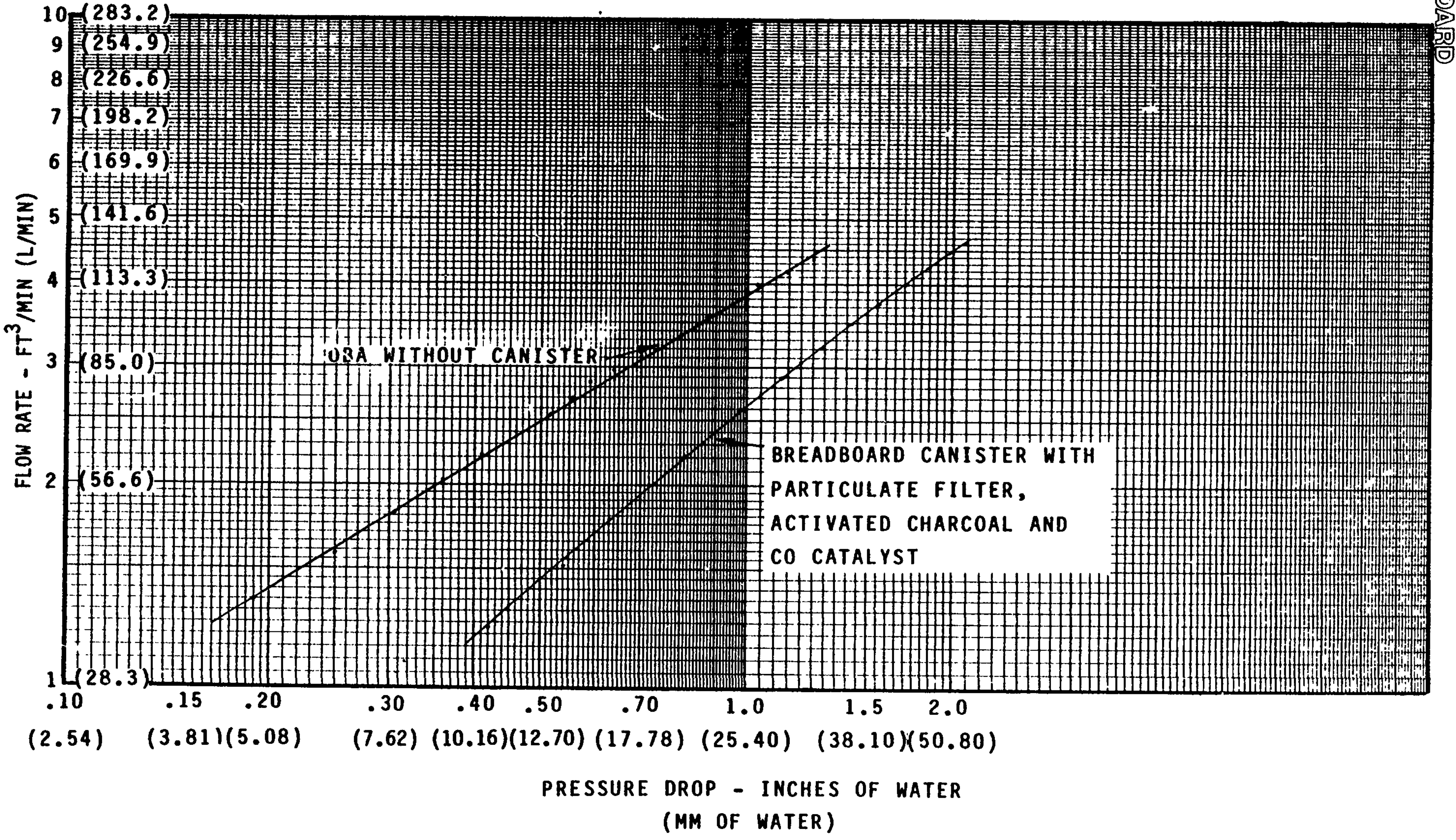


FIGURE 23

SODASORB AIR FLOW RESISTANCE

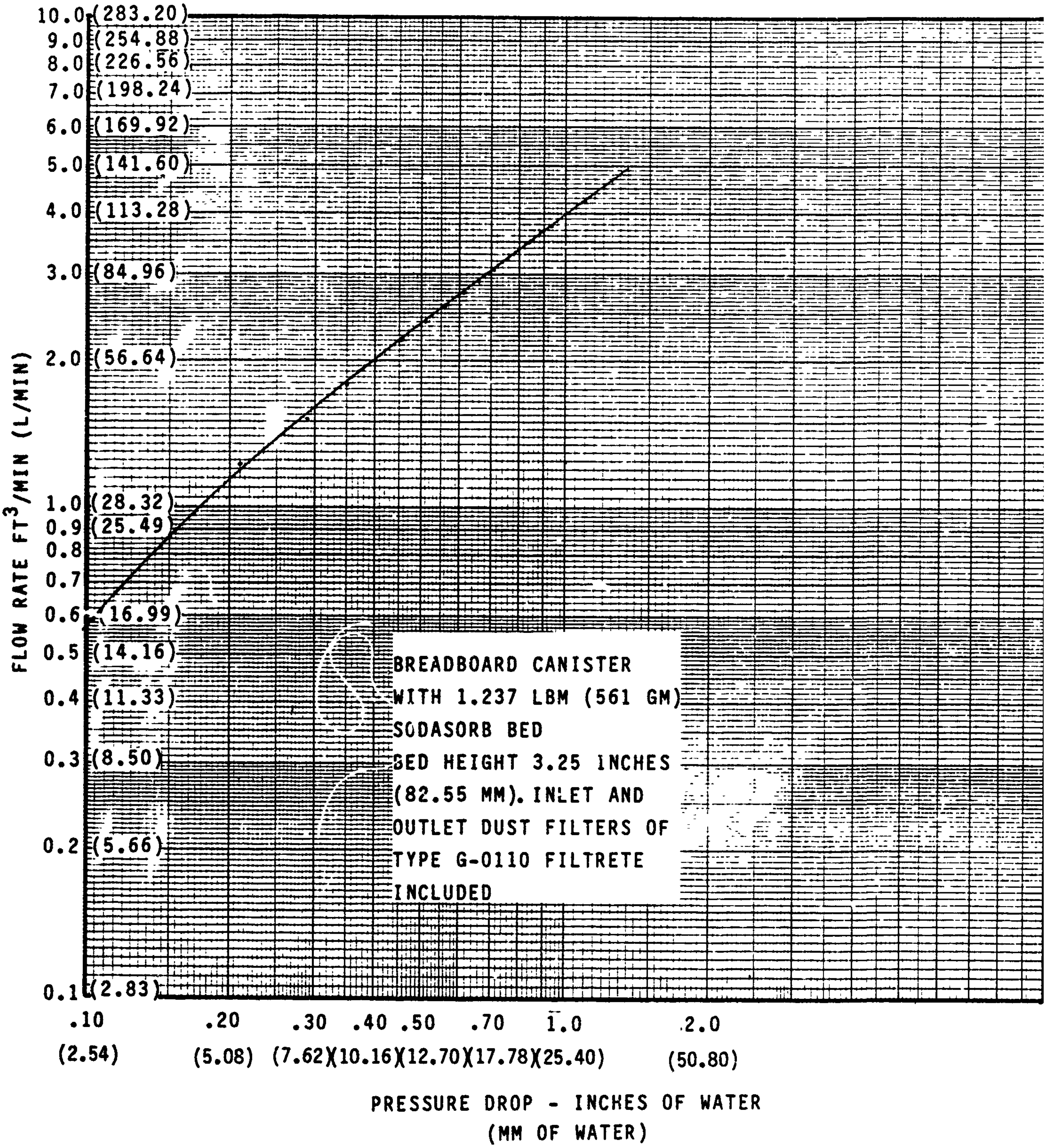
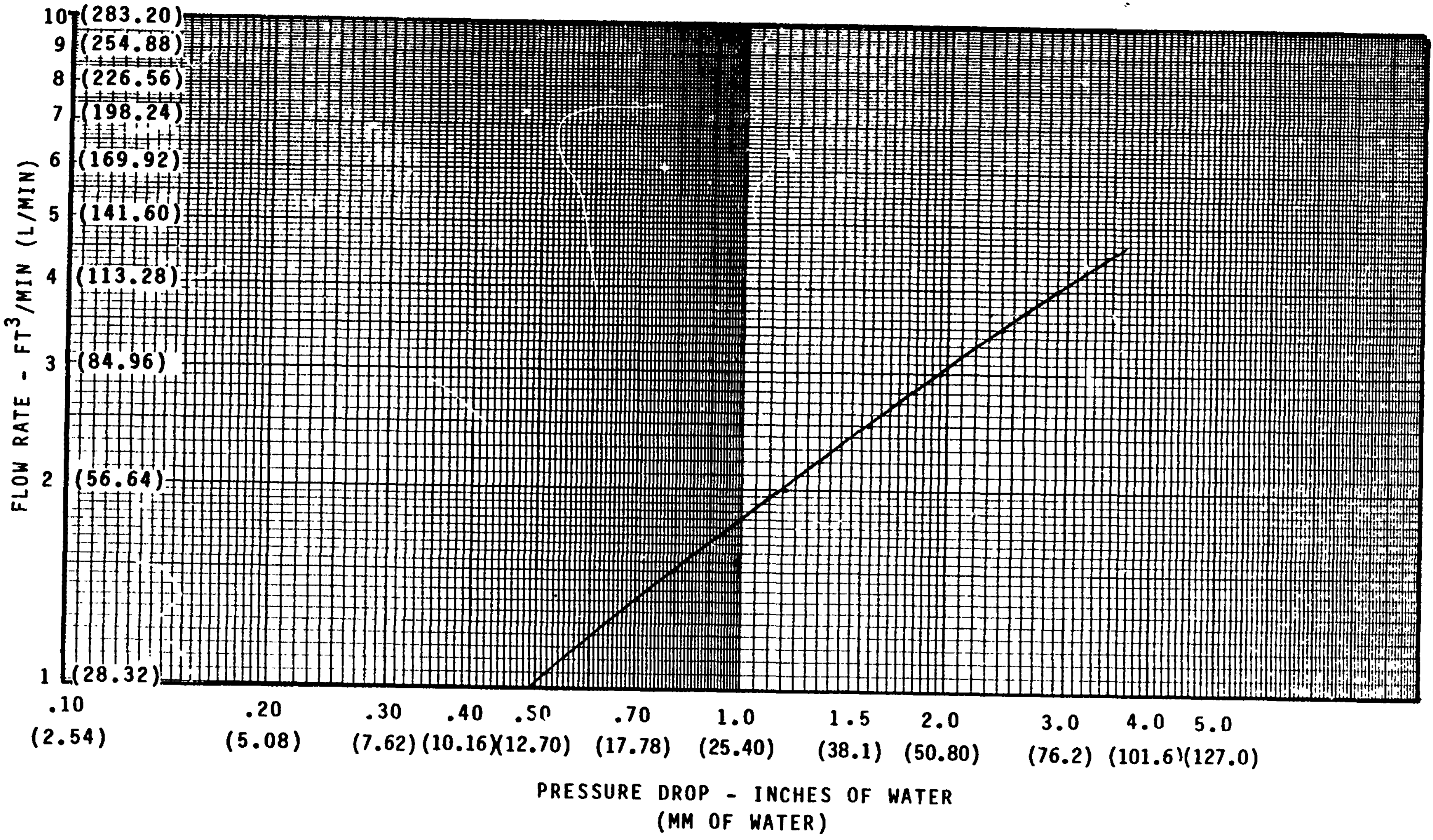


FIGURE 24

OBA AND OBAT AIR FLOW RESISTANCE



Feasibility Test Phase

Background

The major objective of the Feasibility Test Phase of the OBAT program was the successful performance demonstration of the feasibility model canister assembly. Eighteen tests, designated F1 to F18, were planned in this series as outlined in Table 6.

The first test, F1, was to verify that the total system, feasibility model canister assembly mated with an OBA, air flow resistance is less than 3.0 inches (76.2 mm) of water at a flow of 3.0 ft^3/min. (85 l/min). This test was conducted with room temperature air.

Tests F2 to F13 provided performance verification against gaseous contaminants including carbon monoxide, carbon dioxide, propane, and nitrogen dioxide. These tests were conducted for the contaminant concentration levels tabulated in Table 7. At each set of contaminant concentrations, tests were performed at both 30°F (-1.1°C) and 140°F (60°C) and at low, 30 percent, and high, nearly 100 percent, relative humidities for each temperature. The first four tests, F2 through F5, specified 100 percent of the highest average carbon monoxide and carbon dioxide levels that were reported for the bilge fire data in the Fire Fighter Trainer Environmental Considerations Phase II report of 31 July 1981 by Booz, Allen, and Hamilton, Inc. These are representative of the worst average environmental conditions that occur in the 19F1 trainer during bilge fires. The other eight test conditions were for 50 percent and 100 percent of the maximum carbon monoxide and carbon dioxide levels that occurred during bilge fires. The propane and nitrogen dioxide concentrations for all tests were 1000 ppm and 5 ppm, respectively. This propane concentration was selected to conservatively correspond to the maximum level of 700 ppm recorded during bilge fires. The nitrogen dioxide concentration was also selected conservatively based on the maximum levels of less than 20 ppm of nitrous oxides, N_2O measured during bilge fires. A literature search indicated that nitrogen dioxide levels in combined nitric oxide, NO, and nitrogen dioxide, NO_2, measurements are typically about one percent of the total nitrous oxides created by high temperature combustion of hydrocarbon gases. All tests against gaseous contaminants were conducted at 1.0 ft^3/min (85 l/min) flow. This conservatively corresponds to the total inspiration flow in one minute of 0.95 ft^3 (26.89 l) by an individual at a high metabolic rate, 1510 Btu/hr (380 kcal/hr).

Originally, twelve tests, F2 to F13, were planned against gaseous contaminants. These tests were to be conducted with 80 percent of the flow bypassing the sodasorb bed and 20 percent of the flow passing through the bed. Each test was to be completed when either outlet carbon monoxide or carbon dioxide concentration exceeded its limit or when 6 hours had elapsed. However, the outlet carbon monoxide concentrations stabilized at levels well

TABLE 6
FEASIBILITY TEST SUMMARY

TEST TITLE	TEST DESIGNATION	TEST ARTICLE
Performance		MODEL CANISTER ASSEMBLY
CO Conversion		
CO_2 Absorption	F2 through F13	
NO_2 Absorption		
HC Adsorption		
Firing Mechanism Simulator	F16	
Dusting/Settling/Channeling	F17	
Life Tests		
CO Catalyst	F18	
Particulate Filter		BREADBOARD TEST ITEM
Sodium Bicarbonate	F14	
Triaryl Phosphate Smoke		
Air Flow Resistance	F1	MODEL CANISTER ASSEMBLY MATED WITH OBA
Temperature	F15	
Ambient Temperature		
High Temperature		

TABLE 7

PERFORMANCE TEST MATRIX FOR FEASIBILITY DESIGN PHASE

				CONTAMINANT CONCENTRATION (PPM)			
TEST NO.	TEMPERATURE (°F)	RELATIVE HUMIDITY (%)	TEST CONDITION	CO	CO_2	NO_2	HC
F2	30	30	100% Bilge Fire Maximum Average CO & CO_2 Concentrations	700	12,500	5	1000
F3	140						
F4	30	100					
F5	140						
F6	30	30	50% Bilge Fire Maximum CO & CO_2 Concentrations	3000	17,500	5	1000
F7	140						
F8	30	100					
F9	140						
F10	30	30	100% Bilge Fire Maximum CO & CO_2 Concentrations	6000	35,000	5	1000
F11	140						
F12	30	100					
F13	140						

within the specified 35 ppm limit for the 700 ppm tests and 200 ppm limit for 3000 ppm and 6000 ppm tests. Therefore, sodasorb performance was the controlling parameter for these tests. With the anticipated sodasorb carbon dioxide absorption capacity, passing only 20 percent of the flow through the sodasorb would not have exhausted its capacity after 6 hours for most tests. Thus, to fully map the sodasorb's performance, the majority of tests were conducted with all of the flow passing through the sodasorb. This additionally provided conservatism, since the residence time in the sodasorb bed was less than will exist with partial bypass flow. A total of 22 tests were run against gaseous contaminants, including some at room temperature. The final test was conducted with 25 percent of the flow through the sodasorb and 75 percent bypassing to reflect actual anticipated usage of the OBAT canister. Additional variables tested included two ranges of sodasorb particle sizes, 4 to 8 mesh and 8 to 14 mesh, and two types of sodasorb, medical grade and high performance grade. A detailed list of all gaseous contaminant tests is provided in the following test results section.

The two grades of sodasorb, medical and high performance, are nearly identical chemically, but high performance grade is specially processed into porous granules to expose more absorbent surface. These porous granules permit free inter-granular circulation of gases. Both the medical and high performance grades are manufactured by Dewey and Almy Chemical Division of W. R. Grace and Company. Manufacturer's tests have shown the high performance sodasorb to be a significantly more efficient carbon dioxide absorbent than the medical grade. High performance sodasorb has been used extensively for industrial and undersea applications for absorption of carbon dioxide.

The particulate filter tests, F14, provided performance data on two candidate filter systems. The tests were performed in the bilge fire area of the 19F1 Fire Fighter Trainer to provide the most realistic challenge of both butylated triphenol phosphate simulated smoke and sodium bicarbonate simulated dry powder extinguishant. The air flow through each filter system was maintained at 1.0 ft^3/min (28.3 l/min) during the test. The smoke generator in the trainer was run in a manner similar to normal fire fighting training. It was cycled on for about 5 minutes and off for about 5 minutes. This cyclic operation was continued throughout the test. A full dry powder extinguisher was discharged in the vicinity of the filter systems every one-half hour during the test. Each extinguisher contained about 30 lbm (13.61 kg) of sodium bicarbonate simulated extinguishant.

The OBA mask inlet temperature transient tests, F15, were conducted to measure the temperature rise at the face mask for various ambient temperatures. Tests were run with ambient temperatures from 150°F (65.6°C) to 750°F (398.9°C). Air from the oven was drawn through the OBAT canister and OBA at 1.0 ft^3/min (28.3 l/min). The initial canister temperature was approximately 80°F (26.7°C), and the temperature rise was monitored at two locations in the canister and in the facemask. The test facility provided the ability to preheat the oven to the desired temperature, rapidly open the door and position the fiberglass mannequin upper torso with a donned OBA in the oven, and then shut the door and start the air flow through the system. When the temperature in the facemask reached 140°F (60°C), the air flow was stopped, and the manniquin and OBA were removed from the oven.

The firing mechanism simulator test, F16, was performed to verify the physical integrity and workmanship of the firing mechanism. The test simply consisted of exercising the firing mechanism through 100 cycles. Each cycle consisted of moving the slide to its shut position, installing the cotter pin to retain it, and pulling the cotter pin out to let the slide be pulled to its open position by the spring.

The dusting and settling/channeling test, F17, was performed in conjunction with the gaseous contaminant tests to show that these problems do not exist. By monitoring the outlet carbon monoxide and carbon dioxide concentrations during the gaseous contaminant tests, evidence of settling or channeling in the canister's beds could be detected. When the canister was disassembled between tests to change the sodasorb and activated charcoal, the inside of the canister was inspected for dusting, and the beds were inspected for settling. Also, since the sodasorb had an indicator, which turned purple as the bed became exhausted, inspection of the color throughout the bed provided additional information on channeling.

The carbon monoxide catalyst life test, F18, was performed to verify that the catalyst retains its activity for at least 250 hours. Since the same batch of catalyst was used throughout the test program, all of the time on the carbon monoxide reactor prior to the life test was credited toward the 250 hours. The remaining portion of the test was conducted at an inlet carbon monoxide concentration of 700 ppm with 70°F (21.1°C) and approximately 60 percent relative humidity air. The flow rate for the life test was 1.0 ft^3/min (28.3 l/min) and was occasionally increased to 3.0 ft^3/min (85 l/min) for two-minute intervals.

TEST RESULTS

Feasibility Test Phase

Air Flow Resistance Tests (F1)

To establish the air flow resistance of the total system, OBA and OBAT canister, tests were conducted with various air flow rates up to 4.0 ft^3/min (141.5 l/min). Two tests were performed, one with only 25 percent of the flow through the sodasorb bed and one with all of the flow through the sodasorb bed. The pressure drop was measured between the canister inlet and the face mask. Pressure drop versus flow for both cases is shown in Figure 25. At 3.0 ft^3/min (85 l/min) the air flow resistance for the case with 25 percent of the flow through the sodasorb is 2.76 inches (70.1 mm) of water, which is within the specified limit of 3.0 inches (76.2 mm) of water. For the case with all of the flow through the sodasorb, at 3.0 ft^3/min (85 l/min), the air flow resistance is 4.42 inches (112.3 mm) of water. Interpolation between the curves shows that about 40 percent of the flow could be passed through the sodasorb without exceeding the 3.0 inches (76.2 mm) of water limit. These differential pressure tests were conducted with 8 to 14 mesh sodasorb. If it were desirable to pass a larger percentage of flow through the sodasorb, larger grain size sodasorb, such as 4 to 8 mesh, could be used.

Gaseous Contaminant Tests (F2-F13)

The gaseous contaminant tests demonstrated the OBAT feasibility model canister's performance against carbon monoxide, carbon dioxide, propane, and nitrogen dioxide. Test canister inlet condition variables included temperature, dew point, carbon monoxide concentration, and carbon dioxide concentration. Additionally, two grades of sodasorb, medical and high performance, and two ranges of sodasorb granule sizes, 4 to 8 mesh and 8 to 14 mesh were tested. Individual tests were designated by letters A through V. After being exhausted, sodasorb, due to its chemical composition, recovers part of its original absorption capacity after a rest period. Thus, to determine the total absorption capacity of sodasorb for carbon dioxide, most tests were restarted after the sodasorb bed had been allowed to rest overnight. Each restarted test was designated by its original letter and the number (1). For example, the designation for the restarted portion of test B is test B1. A complete summary of all gaseous contaminant tests is provided in Table 8. Breakthrough curves, outlet CO_2 concentration versus time, are provided for all tests in Figures 34 to 71 at the end of this section.

The same 0.362 lbm (164 gm) bed of ten percent platinum-on-alumina carbon monoxide oxidation catalyst was utilized during all of the gaseous contaminant tests. This bed consisted of 0.293 lbm (133 gm) of catalyst that had been used during the preliminary phase tests and 0.068 lbm (31 gm) added to fill the catalyst can. The carbon monoxide catalyst performed well during all of the feasibility tests. Essentially complete conversion of carbon monoxide to

FIGURE 25

OBA AND OBAT AIR FLOW RESISTANCE

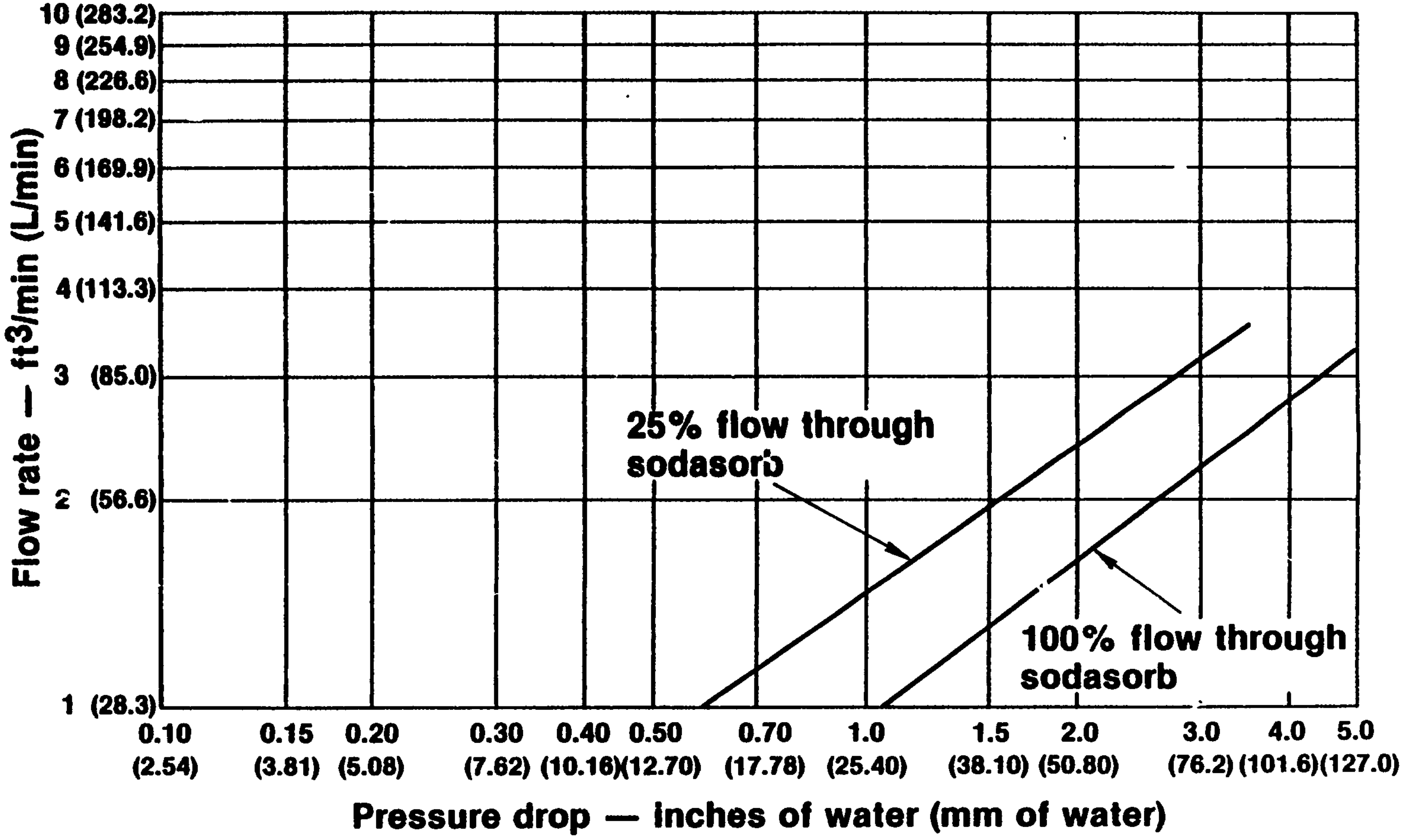


TABLE 8

GASEOUS CONTAMINANT TEST DATA

Test Number	Sodasorb Type & Mesh	Total Flow (Ft^3/min)	Sodasorb Flow (Ft^3/min)	Test Duration (Hrs)	Average Inlet Temperature (°F)	Average Inlet Dewpoint (°F)	Average Inlet Relative Humidity (%)	Inlet CO Conc. (PPM)	Average Outlet CO Conc. (PPM)	Inlet CO_2 Conc. (Vol. %)	Sodasorb CO_2 Loading (Weight %)	
												Cummulative*
A	Medical 4-8 mesh	1.0	0.20	2.33	32.0	6.5	29.75	6000	50	3.50		6.722
B	Medical 4-8 mesh	1.0	1.0	0.82	29.7	8.4	36.08	6000	111	3.50	8.127	13.789
B1	Medical 4-8 mesh	1.0	1.0	0.50	29.1	5.8	32.05	6000	48	3.50	5.662	
C	Medical 4-8 mesh	1.0	1.0	1.66	68.5	43.0	39.56	6000	24	3.50	20.250	23.341
C1	Medical 4-8 mesh	1.0	1.0	0.25	74.7	46.6	37.03	6000	30	3.50	3.091	
D	Medical 4-8 mesh	1.0	1.0	4.00	28.6	8.5	38.03	3000	24	1.75		25.037
E	Medical 4-8 mesh	1.0	1.0	1.66	27.1	6.2	36.00	700	15	1.25	7.882	9.672
E1	Medical 4-8 mesh	1.0	1.0	0.91	26.7	7.6	39.74	700	15	1.25	1.790	
F	Medical 4-8 mesh	1.0	1.0	1.09	26.7	7.0	38.44	700	9	1.25	6.278	12.152
F1	Medical 4-8 mesh	1.0	1.0	1.33	33.2	28.9	82.95	700	8	1.25	5.874	
G	Medical 4-8 mesh	1.0	1.0	1.75	73.0	41.0	31.75	700	4	1.25	9.597	19.512
G1	Medical 4-8 mesh	1.0	1.0	2.56	73.0	41.0	31.75	700	3.5	1.25	9.915	
H	Medical 8-14 mesh	1.0	1.0	3.25	73.5	40.0	30.00	700	2.5	1.25	15.164	21.096
H1	Medical 8-14 mesh	1.0	1.0	1.17	73.6	41.5	31.78	700	1.25	1.25	5.932	
I	Medical 8-14 mesh	1.0	1.0	7.0	138.8	87.3	23.04	700	2	1.25	37.458	43.756
I1	Medical 8-14 mesh	1.0	1.0	1.66	138.0	85.6	22.28	700	1.5	1.25	6.298	
J	Medical 8-14 mesh	1.0	1.0	3.00	137.0	92.5	28.63	3000	10	1.75	25.038	34.964
J1	Medical 8-14 mesh	1.0	1.0	1.50	142.0	90.0	22.80	3000	9	1.75	9.926	
K	Medical 8-14 mesh	1.0	1.0	1.66	136.6	93.4	29.60	6000	55	3.50	19.395	30.097
K1	Medical 8-14 mesh	1.0	1.0	1.17	139.4	102.3	35.93	6000	55	3.50	10.702	
L	Medical 8-14 mesh	1.0	1.0	2.00	130.7	114.0	63.28	6000	18	3.50	28.979	35.889
L1	Medical 8-14 mesh	1.0	1.0	0.66	127.9	107.1	55.81	6000	19	3.50	6.910	

*THE CUMULATIVE SODASORB LOADING HAS CO_2 LOADING VALUES FOR BOTH PARTS OF INDIVIDUAL TESTS. FOR EXAMPLE, THE TOTAL CO_2 LOADING FOR TESTS B AND B1 IS 13.789 PERCENT.

TABLE 8 (Cont.)

GASEOUS CONTAMINANT TEST DATA

Test Number	Sodasorb Type & Mesh	Total Flow (Ft^3/min)	Sodasorb Flow (Ft^3/min)	Test Duration (Hrs)	Average Inlet Temperature (°F)	Average Inlet Dewpoint (°F)	Average Inlet Relative Humidity (%)	Inlet CO Conc. (PPM)	Average Outlet CO Conc. (PPM)	Inlet CO_2 Conc. (Vol. %)	Sodasorb CO_2 Loading (Weight %)	Cummulative*
M	H.P. 8-14 mesh	1.0	1.0	4.17	123.1	119.8	91.75	3000	9	1.75	27.972	48.003
M1	H.P. 8-14 mesh	1.0	1.0	4.41	120.6	117.1	91.75	3000	7.5	1.75	20.031	
N	H.P. 8-14 mesh	1.0	1.0	7.33	122.2	117.0	87.00	700	3	1.25	36.836	43.223
N1	H.P. 8-14 mesh	1.0	1.0	1.50	124.2	112.8	73.00	700	4	1.25	6.387	
O	H.P. 8-14 mesh	1.0	1.0	3.92	28.9	26.5	89.88	700	23	1.25	19.131	27.234
O1	H.P. 8-14 mesh	1.0	1.0	1.66	34.5	31.2	87.15	700	1.5	1.25	8.103	
P	H.P. 8-14 mesh	1.0	1.0	3.08	28.9	8.8	38.07	700	1	1.25	15.873	25.207
P1	H.P. 8-14 mesh	1.0	1.0	2.08	31.2	2.5	24.70	700	1	1.25	9.334	
Q	H.P. 8-14 mesh	1.0	1.0	5.33	29.8	23.6	74.52	3000	4	1.75		25.963
R	H.P. 8-14 mesh	0.8	0.8	3.00	33.8	28.8	80.50	3000	8	1.75	18.080	22.204
R1	H.P. 8-14 mesh	1.0	1.0	1.00	33.1	26.2	73.85	3000	8	1.75	4.124	
S	H.P. 8-14 mesh	1.0	1.0	2.17	26.3	10.5	46.61	3000	21	1.75	15.022	22.216
S1	H.P. 8-14 mesh	1.0	1.0	1.00	29.5	7.2	34.15	3000	24	1.75	7.194	
T	H.P. 8-14 mesh	1.0	1.0	1.50	31.7	27.6	83.65	6000	55	3.50	18.822	25.366
T1	H.P. 8-14 mesh	1.0	1.0	0.58	32.0	26.6	79.10	6000	60	3.50	6.544	
U	H.P. 8-14 mesh	1.0	1.0	1.58	27.9	9.1	40.40	6000	32	3.50	20.197	26.572
U1	H.P. 8-14 mesh	1.0	1.0	0.50	29.7	8.3	35.92	6000	88	3.50	6.375	
V	H.P. 8-14 mesh	1.0	0.25	22.50	74.1	52.5	47.60	700	10	1.25		33.483

*THE CUMULATIVE SODASORB LOADING HAS CO_2 LOADING VALUES FOR BOTH PARTS OF INDIVIDUAL TESTS. FOR EXAMPLE, THE TOTAL CO_2 LOADING FOR TESTS S AND S1 IS 13.789 PERCENT.

carbon dioxide was achieved. The average canister outlet carbon monoxide concentrations listed in Table 8 are attributable to small fractions of the flow bypassing the catalyst bed via the feasibility canister's internal gaskets. However, the outlet carbon monoxide concentrations were well within the limits of 35 ppm for the steady state, 700 ppm inlet concentration, and 200 ppm for the transient, 6000 ppm inlet concentration. With no catalyst canister bypass flow, which is achievable in a production design canister, outlet carbon monoxide concentrations under the feasibility test conditions would be near zero.

The charcoal can was loaded with 0.110 lbm (50 gm) of Barnebey Cheney type MI, 12 to 20 mesh, activated charcoal prior to test A. Canister outlet propane concentration was nearly equal to inlet concentration throughout the test, which indicated that activated charcoal is an ineffective adsorbent for propane. Therefore, the can was not filled with fresh activated charcoal prior to tests B through U, and outlet propane concentration was not monitored during these tests. Prior to test V, a fresh 0.110 lbm (50 gm) bed of charcoal was challenged with a 1.0 ft^3/min (28.3 l/min), 74°F (23.3°C) air flow with 1000 ppm of propane contaminant. The test was continued for 1.5 hours, during which the outlet concentration of propane increased from 850 ppm to 950 ppm. Thus, a limited adsorption capacity for propane was demonstrated.

The sodasorb can was refilled prior to each test. The can was vibrated as part of the filling procedure to settle the sodasorb granules. For tests A through H the sodasorb weight varied between about 1.145 to 1.213 lbm (520 to 550 gm). For test I and subsequent tests, a 22.046 lbm (10.0 kg) weight was placed on the sodasorb while the can was vibrated. This load was distributed over the sodasorb by placing the weight on an aluminum plate, which matched the cross-sectional shape of the bed. Also, the bed was loaded and vibrated in about four increments. With this packing procedure, the can was consistantly loaded with approximately 1.257 lbm (570 gm) of sodasorb.

Based on manufacturer's data, approximately 28 percent loading of carbon dioxide on sodasorb can be expected. This is defined as 0.28 lbm (127.0 gm) of carbon dioxide per 1.0 lbm (453.6 gm) of sodasorb. However, the manufacturer's testing was at room temperature and moderate relative humidity conditions.

Gaseous contaminant test A was conducted at a carbon dioxide partial pressure of 3.5 percent and at low inlet temperature and low relative humidity. The sodasorb tested was medical grade with 4 to 8 mesh granule sizes. Only about 20 percent of the total 1.0 ft^3/min (28.3 l/min) flow was passed through the sodasorb bed. This flow split corresponds to that initially intended during actual usage in the fire fighter trainer. The sodasorb performed poorly, indicating exhaustion with less than 7 percent carbon dioxide loading. Since the cause of the poor performance was not yet known, and the exact flow split was difficult to determine, it was decided that subsequent tests would be performed with all of the flow through the sodasorb bed. This provided a more accurate determination of sodasorb's performance. Breakthrough curves, outlet carbon dioxide concentration versus time, for gaseous contaminant tests A through V are provided in Figures 34 to 71 at the end of this section.

Gaseous contaminant test B was a repeat of test A, except all flow was passed through the sodasorb. After only 15 minutes, outlet carbon dioxide concentration had reached one-third of inlet, and nearly complete breakthrough had occurred after about 40 minutes with only 8.127 percent loading. Since sodasorb recovers part of its absorptive capacity if rested, without exposure to carbon dioxide, this test was restarted on the following morning. Again, breakthrough occurred quickly, and total carbon dioxide loading for tests B and B1 was only 13.789 percent.

Since it was suspected that the poor sodasorb performance of test B was caused by the low temperature and/or the low humidity level, test C repeated the carbon dioxide concentration of test B, but was performed at room temperature and at a higher inlet dew point. Performance was improved with 20.25 percent loading achieved on test C. It is of interest to note that with higher loading achieved on the first usage of a sodasorb bed, test C, less recovery of absorptive capacity was shown by test C1. The total loading for tests C and C1 was 23.341 percent.

Gaseous contaminant test D was performed at the moderate carbon dioxide level, 1.75 percent, and at low temperature and low relative humidty. The sodasorb's performance was good with 25.037 percent carbon dioxide loading achieved. The bed had a short mass transfer zone, as indicated by the visible movement of the sodasorb's color change interface in the canister's window. This is necessary for good absorbent utilization. Mass transfer zone is defined as the finite length of an absorbent bed through which the concentration of the absorbed substance is reduced from essentially inlet to outlet conditions.

The previous tests, A through C, did not exhibit a short mass transfer zone as evidenced by nearly uniform sodasorb color change over the entire length of the viewing window. The results of test D showed excellent potential for sodasorb's performance at low temperatures and low humidity levels. However, as discussed below for tests E and F, which were at similar temperature and humidity conditions, these results were not repeatable with the 4 to 8 mesh medical grade sodasorb.

Tests E and F were also run at the low temperature conditions, but for the 1.25 percent carbon dioxide concentration. Based on test D results, excellent performance was anticipated. However, as with tests A through C, rapid breakthrough occurred and poor carbon dioxide loading resulted. For test F1, the dew point was increased to determine the effect of higher humidity while still at low temperature. This approach was taken to an extreme by actually adding a small quantity of water to the sodasorb bed at two times during the test. As shown in Figure 42, immediately after the water was added, the outlet carbon dioxide concentration was significantly reduced, which verified the importance of moisture to the absorption process.

Tests G and H were run at similar inlet conditions of room temperature and approximately a 41°F (5°C) dew point with a 1.25 percent carbon dioxide concentration. The only difference in the tests was the sodasorb granule size. The sodasorb mesh size for test G was 4 to 8 and that for test H was 8 to 14. Both tests resulted in similar carbon dioxide loading, 19.[illegible] percent for tests G and G1 and 21.096 percent for tests H and H1. But, a significant conclusion can be drawn from the results by observing the breakthrough curves of Figures 43 to 45. The outlet carbon dioxide concentration during test G rose continuously until the absorbent capacity of the bed was exhausted, while that during test H remained relatively low and then rose quickly when the bed was expended. This latter case is indicative of a short mass transfer zone, which results in better absorbent utilization. The longer mass transfer zone of test G can be attributed to less surface area available for carbon dioxide absorption, and potentially to some channeling through the bed. Based on these results, the remaining tests were conducted with 8 to 14 mesh sodasorb granules.

Gaseous contaminant tests I, J, and K were the first tests conducted at high temperatures, approximately 140°F (60°C), and low relative humidities, approximatley 30 percent. Medical grade sodasorb with 8 to 14 mesh granules was utilized with 1.25, 1.75, and 3.5 percent inlet carbon dioxide partial pressures for tests I, J, and K, respectively. Excellent carbon dioxide loadings were achieved at these conditions. The data in Table 8 shows that increased loading was obtained at lower inlet carbon dioxide partial pressure. Specifically, loading was 43.756 percent at 1.25 percent carbon dioxide, 34.964 percent at 1.75 percent carbon dioxide, and 30.097 percent at 3.50 percent carbon dioxide.

Test L was performed at high temperature and high relative humidity and 3.5 percent inlet carbon dioxide partial pressure, with 8 to 14 mesh medical grade sodasorb. With all other parameters similar to those of test K, the increased inlet dew point of tests L and L1 resulted in a higher carbon dioxide loading, 35.889 percent versus 30.097 percent for tests K and K1.

Based on tests I through L, it was apparent that medical grade sodasorb performed better than anticipated at high temperature and high dew point conditions. However, at low temperature and low dew point conditions, the carbon dioxide loadings achieved were lower than expected. Thus, 8 to 14 mesh, high performance grade sodasorb was utilized for the remaining tests, primarily to obtain better carbon dioxide loading at low temperatures and low dew points. The final two tests, M and N, at high temperature and high humidity were conducted with high performance sodasorb to provide comparative data to medical grade at these conditions. Carbon dioxide loadings for both tests were well in excess of 40 percent, which compares favorably with medical grade sodasorb's performance at similar conditions. Also, the high performance grade sodasorb exhibited a sharper breakthrough, which can be seen by reviewing Figures 52 to 57.

All of the low temperature, 30°F (-1.1°C), test conditions were repeated as tests O through U utilizing 8 to 14 mesh, high performance grade sodasorb. Due to test system problems during test Q, it was repeated as test R. The carbon dioxide absorption performance was consistant during these tests with carbon dioxide loadings between 22.204 and 27.234 percent, which is a significant improvement over the loadings achieved during low temperature tests conducted with 4 to 8 mesh medical grade sodasorb. The breakthrough curves for tests O through U are shown in Figures 58 to 70. In general, these curves have a sharp rise as the sodasorb exhaustion is approached, which is indicative of a desirable short mass transfer zone.

The final gaseous contaminant test, V, was conducted to determine the sodasorb's performance under usage conditions anticipated in the 19F1 trainer. Inlet conditions included room temperature, moderate relative humidity, and the maximum average carbon dioxide partial pressure of 1.25 percent. The bypass around the sodasorb was opened, so that only 25 percent of the flow passed through the bed. The test was run continuously for 22.5 hours, and the sodasorb was loaded to 33.483 percent. The breakthrough curve for the test is given in Figure 71.

During all of the gaseous contaminant tests, the canister's inlet air stream contained 5 ppm of nitrogen dioxide. The canister's inlet and outlet nitrogen dioxide concentrations were measured periodically with number 30001 Draiger tubes, which have a range of 0 to 10 ppm of nitrogen dioxide. Canister outlet concentration was undetectable on all measurements, including those taken when the sodasorb was nearing exhaustion. During test V, which had only 25 percent of the total flow passing through the sodasorb, outlet nitrogen dioxide concentration was still undetectable. This result was surprising, but a subsequent literature search and a discussion with the activated charcoal manufacturer revealed that with normal levels of moisture present, nitrogen dioxide is strongly adsorbed on activated charcoal. Thus, the combination of the activated charcoal bed and the sodasorb bed provide effective removal of nitrogen dioxide.

In summary, the gaseous contaminant tests demonstrated excellent performance for the feasiblity canister at the range of contaminant levels and temperature and humidity conditions measured in the 19F1 Fire Fighter Trainer. The carbon monoxide catalyst provided essentially complete conversion of carbon monoxide to carbon dioxide under all conditions. With 8 to 14 mesh high performance grade sodasorb, carbon dioxide loadings between 25 and 40 percent were achieved with the highest at increased temperature and humidity conditions. The combination of activated charcoal and sodasorb provided complete removal of nitrogen dioxide. Activated charcoal was found to be relatively ineffective as a propane adsorbent. However, this is not a problem with respect to the OBAT canister's use in the 19F1 trainer, since the peak propane levels are less than the eight-hour permissible exposure limit.

Particulate Filter Test (F14)

The particulate filter test provided performance data on two candidate filter systems. As discussed earlier, the difference between the two systems was the material for filtering the coarse sodium bicarbonate extinguishant. System #1 had a 400 mesh stainless steel screen for this purpose, and system #2 had a layer of Kimre Incorporated polypropylene style 4/96 mist eliminator filter media.

The efficiency of the filter systems was measured by gravimetric analyses on 0.45 micron Gelman metricel filters. By comparing the weight gain between a Gelman filter positioned downstream of the filter system being tested to that of a Gelman filter positioned near the filter system's inlet, the filter system's performance was determined. The Gelman filters were in cassettes and had a constant flow of 0.071 ft^3/min (2.0 l/min) drawn through them. Pre-test and post-test Gelman filter weights were measured by an independent laboratory. The laboratory's report is provided on pages 70 and 71. The analytical results column of the report gives the weight change in milligrams of the twenty-one Gelman filters used.

A summary of the particulate filter test data is given in Table 9. Prior to the filter systems' test, the simulated smoke concentration was measured with no dry powder extinguishant in use. This measurement was made in the bilge fire area during a twenty-seven minute period when actual advanced team training was in progress. The average smoke concentrations measured with filter cassettes 76031 and 76041 were 128.48 mg/m^3 and 115.0 mg/m^3, respectively.

The particulate filter test was run for 168 minutes. The filter systems were positioned in the 19F1 Fire Fighter Trainer bilge fire area at about waist level three feet from the bilge fire propane burners. Simulated smoke was continuously present during the test. The smoke generator was operated cyclically with on and off periods of approximately five minutes. This operating schedule is typical of that utilized during training. Approximately every half-hour during the test a dry powder extinguisher, charged with 30 lbm (13.61 kg) of sodium bicarbonate dry powder extinguishant, was discharged in the bilge fire area. A total of five extinguishers were expended during the test. The Gelman filter cassettes for measuring ambient particulate concentration were replaced between each extinguisher discharge, but after the dry powder had settled from the previous extinguisher discharge. This provided the average ambient particulate concentration for each half-hour period of the test as shown in Table 9 by data for cassettes 76032 to 76036 and 76042 to 76046. After the first thirty-six minutes, during which one extinguisher was discharged, the filter cassettes were changed, including cassettes 76032 and 76042 for ambient concentration measurements and cassettes 76011 and 76021 for measuring concentrations downstream of the filter systems. Filter system #1 reduced the average inlet particulate concentration of 629.44 mg/m^3 to 0.69 mg/m^3, which is a removal efficiency of 99.89 percent. Filter system #2 reduced the average inlet particulate concentration of 489.58 mg/m^3 to less

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No. H83G016

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LABORATORIES IN MACON, GA AND HARTFORD, CT

LABORATORY ANALYSIS REPORT

SAMPLE CONTAINER NO.	ANALYZED FOR	METHOD OF ANALYSIS	ANALYTICAL RESULTS
76011			-0.13
76012			0.05
76021			-0.18
76022			0.03
76031			5.73 *
76032			45.14 *
76033			27.50 *
76034			19.49 *
76035			13.91 *
76036			20.83 *

SPECIAL REMARKS:

* Filter became stuck to filter cassette and had to be scraped off. Actual weight could be higher than indicated.

The filters were allowed to equilibiate at room conditions (72°F, 63RH) prior to the initial weight. The filters were not initially desicated. After sampling, the filters were desicated and then allowed to equilibiate at room conditions (73°F, 62RH) before the final weight was taken.

CHEMIST James A. Kenny, Jr. (Signature)

DATE July 13, 1983

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LABORATORIES IN MACON, GA AND HARTFORD, CT

LABORATORY ANALYSIS REPORT

SAMPLE CONTAINER NO.	ANALYZED FOR	METHOD OF ANALYSIS	ANALYTICAL RESULTS
76041			6.03 *
76042			35.07 *
76043			25.29 *
76044			19.80 *
76045			14.66 *
76046			19.73 *
76051			-0.22
76052			-0.18
76053			-0.53
Blk 1578			-0.15
Blk 1580			-0.16

SPECIAL REMARKS:

* Filter became stuck to filter cassette and had to be scraped off. Actual weight could be higher than indicated.

CHEMIST James A. Kenny, Jr.
(Signature)

DATE July 13, 1983

TABLE 9

Particulate Filter Test Data

Gelman Cassette Number	Cassette Location	Corrected Weight Change(Mg)	Sample Duration (Min.)	Volume Sampled (Liter)	Particulate Inlet Conc. (Mg/M^3)	Notes
76011	Downstream Filter System #1	0.05	36	72	0.69	5
76012	Same as Above	0.23	132	264	0.87	7
76021	Downstream Filter System #2	<0.03	36	72	<0.42	6
76022	Same as Above	0.21	132	264	0.80	7
76031	Ambient Outside Test Canister #1	5.91	23	46	128.48	4
76032	Same as Above	45.32	36	72	629.44	5
76033	Same as Above	27.68	29	58	477.24	8
76034	Same as Above	19.67	38	76	258.82	8
76035	Same as Above	14.09	37	74	190.41	8
76036	Same as Above	21.01	28	56	375.18	8
76041	Ambient Outside Test Canister #2	6.21	27	54	115.00	4
76042	Same as Above	35.25	36	72	489.58	6
76043	Same as Above	25.47	29	58	439.14	9
76044	Same as Above	19.98	38	76	262.89	9
76045	Same as Above	14.84	37	74	200.54	9
76046	Same as Above	19.91	28	56	355.54	9

TABLE 9 (Cont.)

Particulate Filter Test Data

Gelman Cassette Number	Cassette Location	Corrected Weight Change(Mg)	Sample Duration (Min.)	Volume Sampled (Liter)	Particulate Inlet Conc. (Mg/M^3)	Notes
76051	Blanks - Not used in Particulate Tests	-0.22	0	0	-	1,3
76052	Same as Above	-0.18	0	0	-	1,3
76053	Same as Above	-0.53	0	0	-	2
1578	Same as Above	-0.15	0	0	-	1
1580	Same as Above	-0.16	0	0	-	1

TABLE 9 (Cont.)

Particulate Filter Test Data Notes

(1) The cassette was not used in the particulate tests. Its pre-test weight and post-test weight serve as a blank, and the average weight difference of the four blanks, cassettes 76051, 76052, 1578, and 1580, was used to correct the other filter weights. The average blank weight difference was -0.18 mg. Thus, all other filter weights were corrected by +0.18 mg.

(2) The filter in cassette 76053 was not used in the particulate tests. However, it had 70 mg. of water added to it. The laboratory performing the gravimetric analyses was not told that this cassette had not been used in the tests or that water had been added. The cause of the weight loss of 0.53 mg from this filter is not known.

(3) The laboratory performing the gravimetric analyses was not told that cassettes 76051 and 76052 were blanks and had not been used in the tests.

(4) Cassettes 76031 and 76041 were used to measure simulated smoke concentration. No dry powder extinguishant was discharged while these filter cassettes were in use.

(5) Cassettes 76011 and 76032 were downstream of filter system #1 and in the ambient near filter system #1, respectively, for the first 36 minutes of the test. One 30 lbm. (13.61 kg.) sodium bicarbonate dry powder extinguisher was discharged near the beginning of this period. Simulated smoke was also present.

(6) Cassettes 76021 and 76042 were downstream of filter system #2 and in the ambient near filter system #2, respectively, for the first 36 minutes of the test. One 30 lbm. (13.61 kg.) sodium bicarbonate dry powder extinguisher was discharged near the beginning of this period. Simulated smoke was also present.

(7) Cassettes 76012 and 76022 were downstream of filter systems #1 and #2, respectively, for 132 minutes during the test. Four 30 lbm. (13.61 kg.) dry powder extinguishers were discharged during this period, and simulated smoke was present.

(8) Cassettes 76033, 76034, 76035, and 76036 were used to measure ambient particulate concentration near filter system #1. While each cassette was in use, one 30 lbm. (13.61 kg.) dry powder extinguisher was discharged, and simulated smoke was present. The time-averaged particulate concentration measured by the four cassettes was 312.16 mg./m^3.

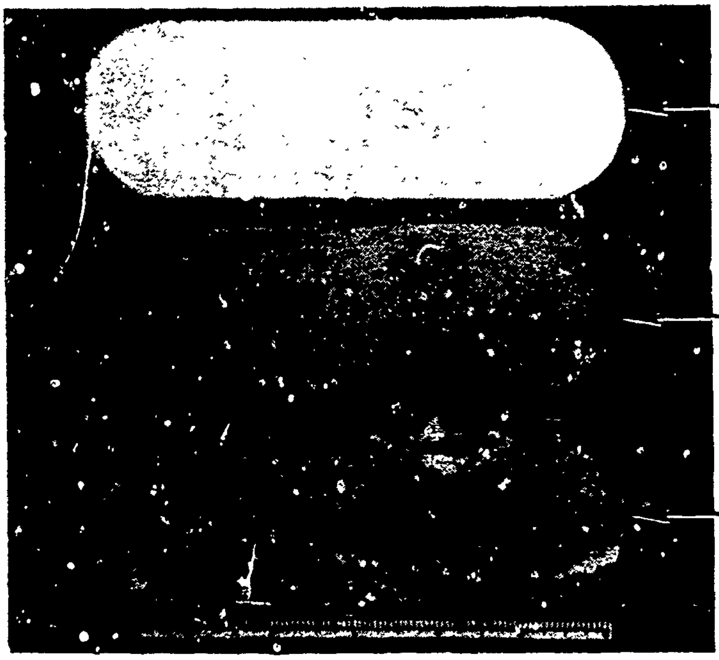
(9) Cassettes 76043, 76044, 76045, and 76046 were used to measure ambient particulate concentration near filter system #2. While each cassette was in use, one 30 lbm. (13.61 kg.) dry powder extinguisher was discharged and simulated smoke was present. The time-averaged particulate concentration measured by the four cassettes was 303.74 mg./m^3.

than 0.42 mg/m^3, which is a removal efficiency of 99.91 percent. For the remaining 132 minutes of the test, the ambient particulate concentration near filter system #1 was 312.16 mg/m^3 based on a time-weighted average of the data from cassettes 76033 to 76036. The average concentration downstream of filter system #1 during this period was 0.81 mg/m^3, which corresponds to a removal efficiency of 99.72 percent. Similarly for the final 132 minutes, the average particulate concentration near filter system #2 was 303.76 mg/m^3, based on a time-weighted average of data from cassettes 76043 to 76046. The average concentration downstream of filter system #2 was 0.80 mg/m^3, which corresponds to a removal efficiency of 99.74 percent.

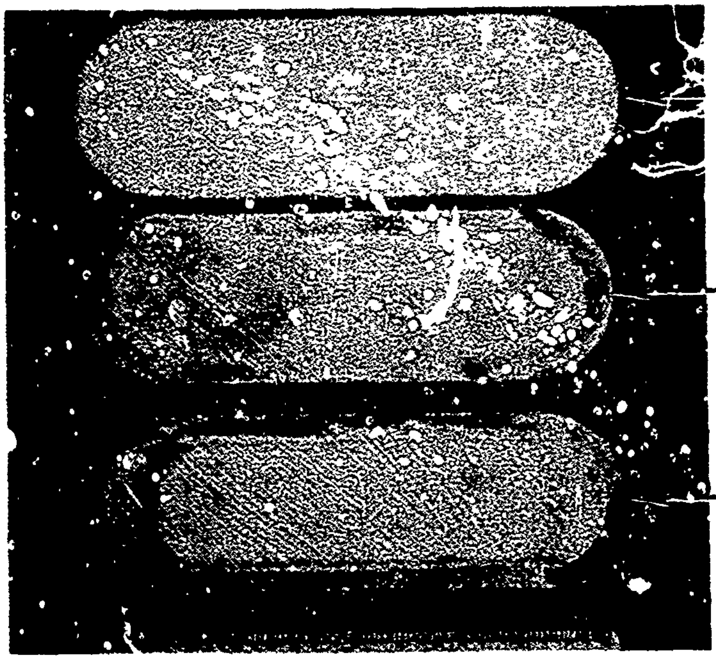
The differential pressure across the filter systems was monitored continuously during the particulate tests. During test periods when only simulated smoke was present, no measurable change in differential pressure across the filter systems was noted. When dry powder was introduced, filter system #1 with the 400 mesh stainless steel screen began clogging immediately. After the first dry powder extinguisher had been discharged, the pressure drop across filter system #1 had increased from its original 0.11 inch (2.70 mm) of water to greater than 0.50 inch (12.7 mm) of water at 1.0 ft^3/min (28.3 l/min) flow. After the third extinguisher had been discharged, the differential pressure across filter system #1 exceeded 2.0 inches (50.8 mm) of water. Figure 26 shows top and bottom views of the elements of filter system #1 after the particulate tests. A significant build-up of dry powder extinguishant can be seen on the bottom side of the 40 mesh and 400 mesh screens. The increase in differential pressure across filter system #2, with the Kimre mist eliminator in place of the 400 mesh screen, was much more gradual. After the first dry powder extinguisher had been discharged, the pressure drop across filter system #2 had increased from its original 0.12 inch (3.048 mm) of water to only 0.15 inch (3.81 mm) of water at 1.0 ft^3/min (28.3 l/min). At the end of the particulate tests, the pressure drop across system #2 was 0.76 inch (19.05 mm) of water. This included the discharge of five dry powder extinguishers. Figure 27 shows top and bottom views of the elements of filter system #2 after the particulate tests. The 40 mesh retaining screen had a build-up of extinguishant, but the mist eliminator still had significant open volume. After the 40 mesh retaining screen was cleaned, filter system #2 was reassembled without disturbing the dry powder on the mist eliminator or filtrete. Its pressure drop was only 0.13 inch (3.30 mm) of water at 1.0 ft^3 (28.3 l/min). Thus, the majority of the differential pressure increase was caused by the dry powder extinguishant on the 40 mesh retaining screen. If a lower mesh retaining screen were used at the inlet, the dry powder would build-up in the depth of the mist eliminator, and the increase in differential pressure would be more gradual.

OBA Mask Inlet Temperature Transient (F15)

The OBA mask inlet temperature transient tests were conducted to determine the time required for OBA facemask temperature to reach 140°F (60°C) at various ambient temperatures with an OBAT canister installed in the OBA. The test procedure required placing a mannequin wearing an OBA and OBAT in an oven, which had been preheated to the desired test temperature. A flow of 1.0 ft^3/min (28.3 l/min) was drawn through the OBAT canister and OBA to simulate



TOP VIEW

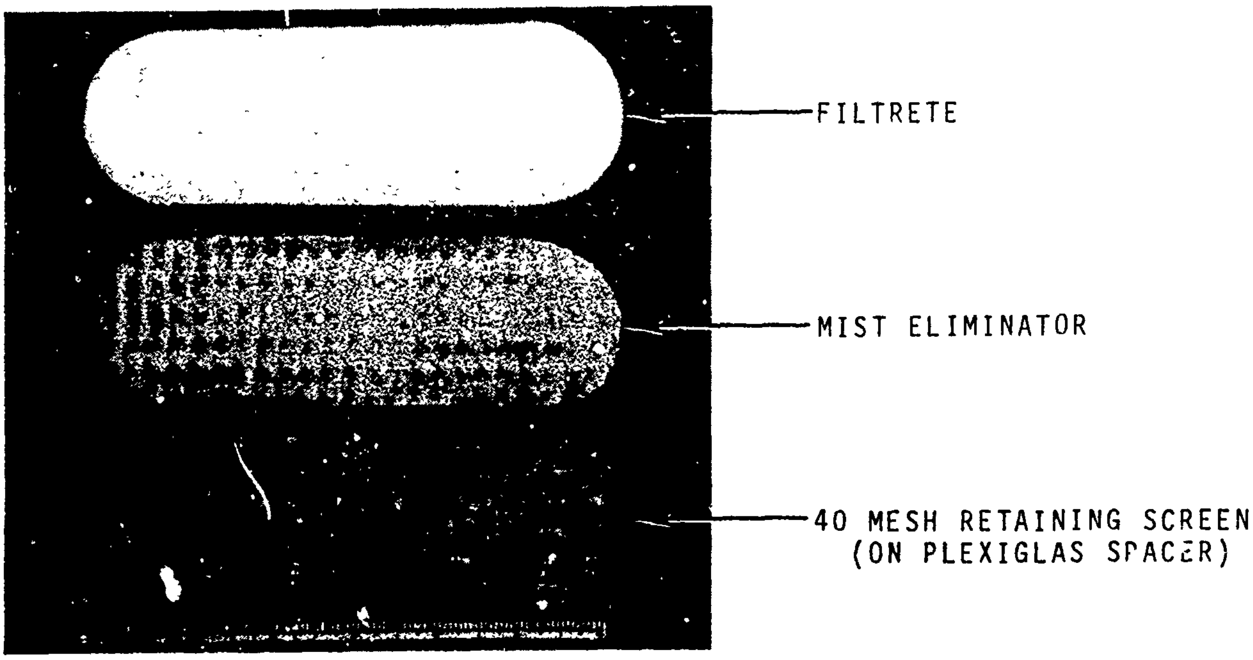


BOTTOM VIEW

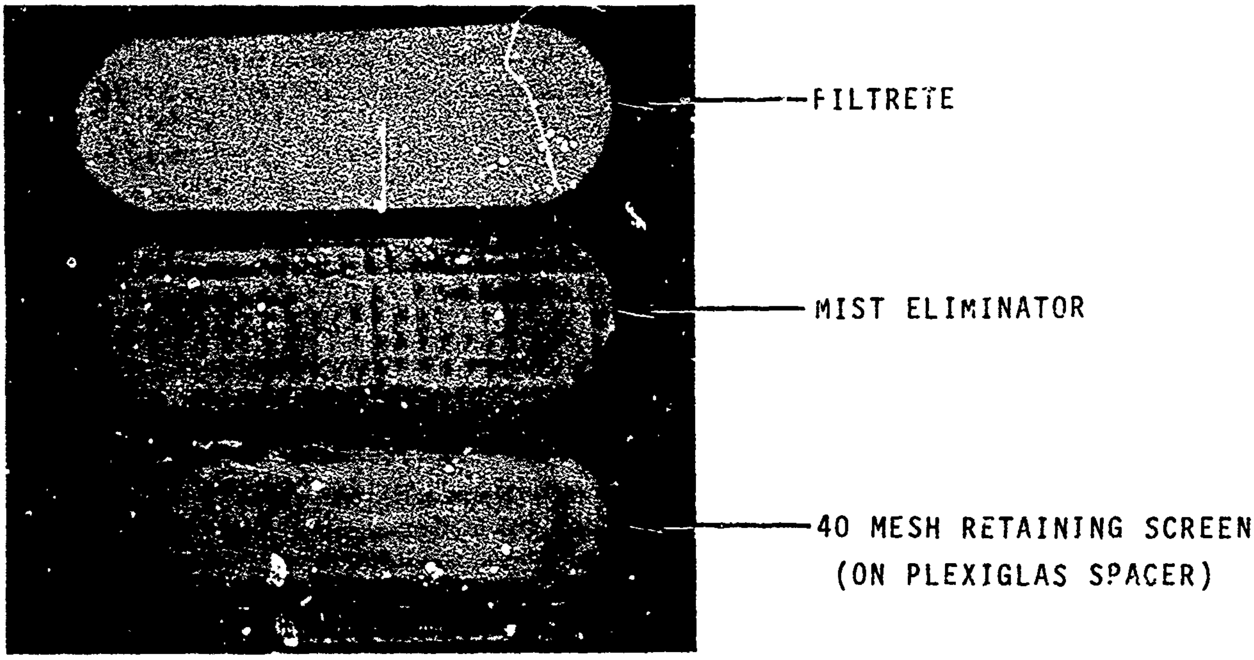
FIGURE 26

FILTER ELEMENTS (POST TEST)

FILTER SYSTEM #1



TOP VIEW



BOTTOM VIEW

FIGURE 27

FILTER ELEMENTS (POST TEST)

FILTER SYSTEM #2

the inspiration of a person at a high metabolic rate. The mannequin, OBA, and OBAT canister were at approximately 80°F (26.7°C) prior to being placed in the oven. Four tests were conducted as summarized in Table 10. The average oven air temperature during each test was lower than the preheat temperature, since some heat was lost when the door was opened to put the mannequin and OBA in the oven. However, the oven's wall temperature remained near the preheat temperature, which caused the test article to receive significant radiant heat in addition to the heat by conduction and convection from the air. Figures 28 to 31 show the temperature transients in the canister and facemasks for tests #1 through #4. During test #3, the facemask and charcoal bed thermocouples failed, so only the canister outlet temperature is shown in Figure 30. During test #4, the plexiglas viewing window began melting, which caused its seal with the facemask to be broken. Thus, tests at higher temperatures would not have provided meaningful data on the temperature transient inside the facemask. Also, during test #4 the OBA's rubber hoses began deteriorating rapidly and the harnesses began burning. A post-test photograph of the mannequin and OBA is given in Figure 32. It can be concluded from these test results that the OBA's Plexiglas viewing window would be destroyed under an extremely high temperature condition before the facemask's air temperature would reach 140°F (60°C) with an OBAT canister in use. Figure 33 shows the time for the facemask temperature to reach 140°F (60°C) versus oven temperature.

Firing Mechanism Simulator Test (F16)

The firing mechanism simulator test was performed to insure the mechanism would operate smoothly for numerous cycles. Each cycle consisted of pulling the slide plate to its shut position and installing the cotter pin. Then, the cotter pin was pulled out with its lonyard, and the slide plate slid to its open position. The mechanism for each of the three feasibility canisters was cycled 100 times.

Dusting/Settling/Channeling Test (F17)

The dusting and settling/channeling test, F17, was performed in conjunction with the gaseous contaminant tests to show that these problems do not exist. By monitoring the outlet carbon monoxide and carbon dioxide concentrations during the gaseous contaminant tests, evidence of settling or channeling in the canister's beds could be detected. When the canister was disassembled between tests to change the sodasorb and activated charcoal, the inside of the canister was inspected for dusting, and the beds were inspected for settling. Also, since the sodasorb had an indicator which turned purple as the bed became exhausted, inspection of the color throughout the bed provided additional information on channeling.

Carbon Monoxide Catalyst Life Test (F18)

The carbon monoxide catalyst life test, F18, was performed to verify that the catalyst retained its activity for at least 250 hours. Since the same batch of catalyst was used throughout the test program, all of the time on the carbon monoxide reactor prior to the life test was credited toward the 250

TABLE 10

OBA Mask Inlet Temperature Transient Test
Data Summary

Test No.	Oven Preheat Temp. °F (°C)	Average Oven Air Temp. °F (°C)	Time for Mask to reach 140°F (60°C) (min.)
1	154 (67.8)	154 (67.8)	14.8
2	256 (124.4)	245 (118.3)	3.75
3	491 (255.0)	430 (221.1)	1.65*
4	750 (398.9)	501 (260.6)	0.74

*Time for canister outlet temperature to reach 140°F (60°C). The facemask thermocouple failed during this test.

FIGURE 28

OBA MASK INLET TEMPERATURE
TRANSIENT TEST #1
Ambient Temperature 154°F/67.8°C

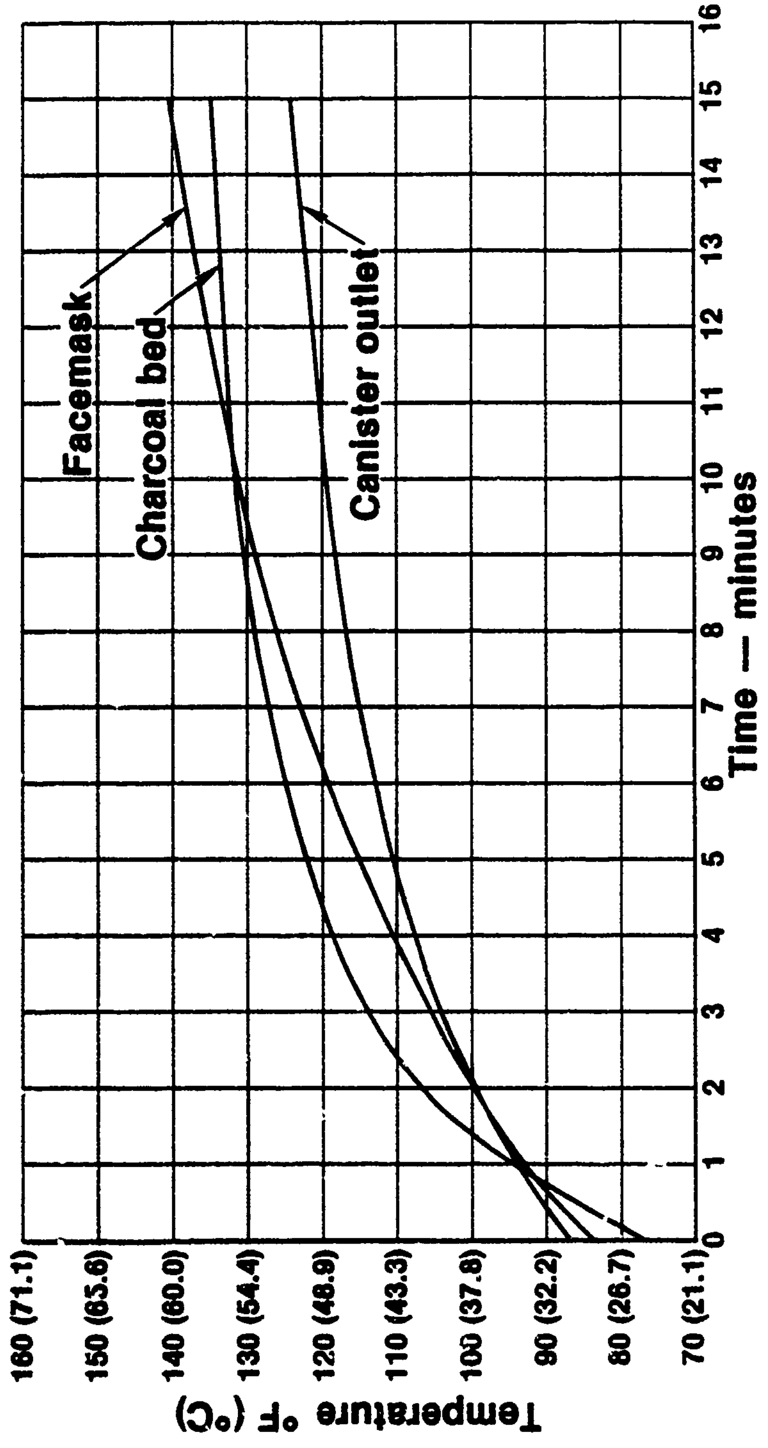


FIGURE 29

OBA MASK INLET TEMPERATURE
TRANSIENT TEST #2
Ambient Temperature 245°F (118.3°C)

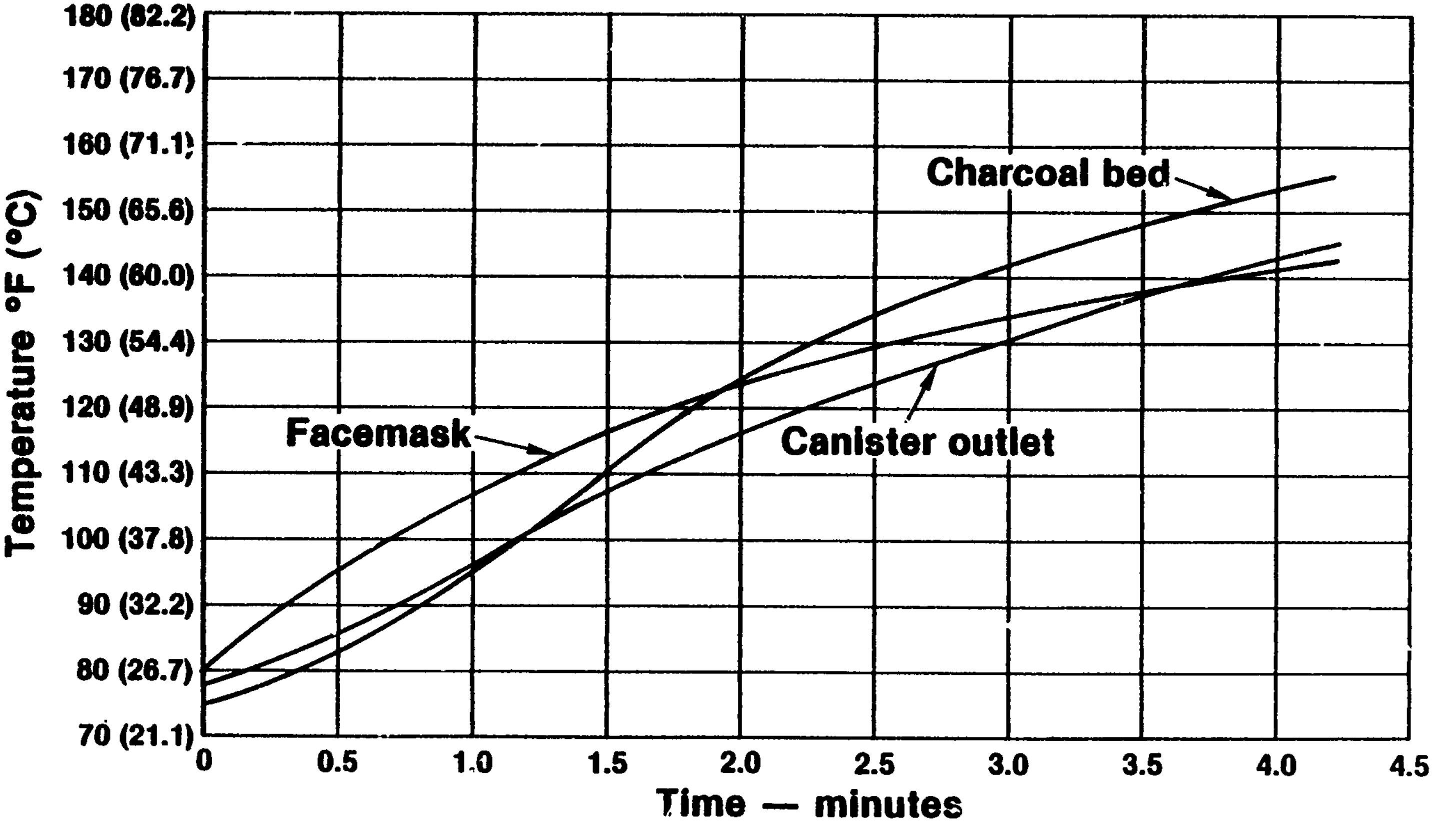


FIGURE 30

OBA MASK INLET TEMPERATURE TRANSIENT TEST #3

Ambient Temperature 430°F (221.1°C)

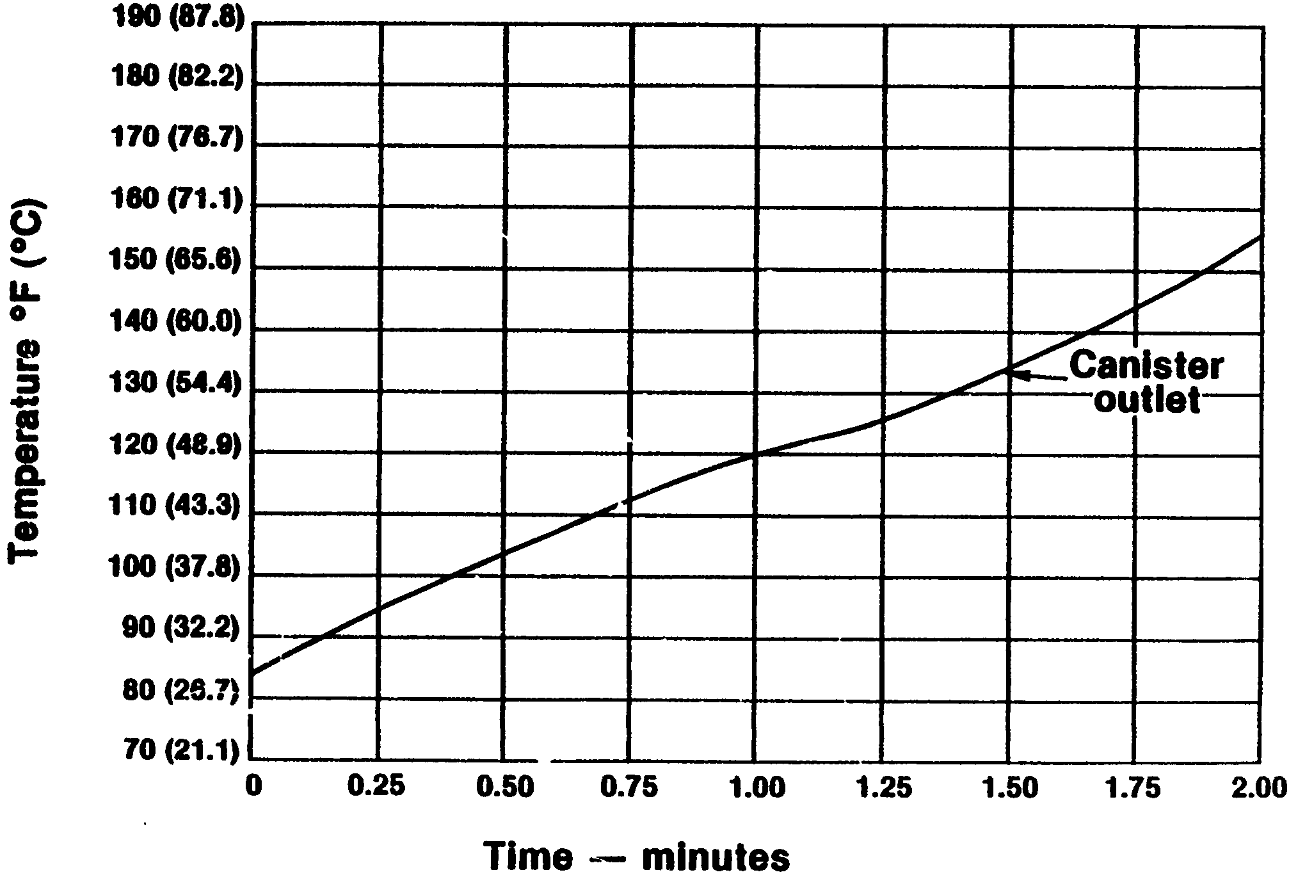
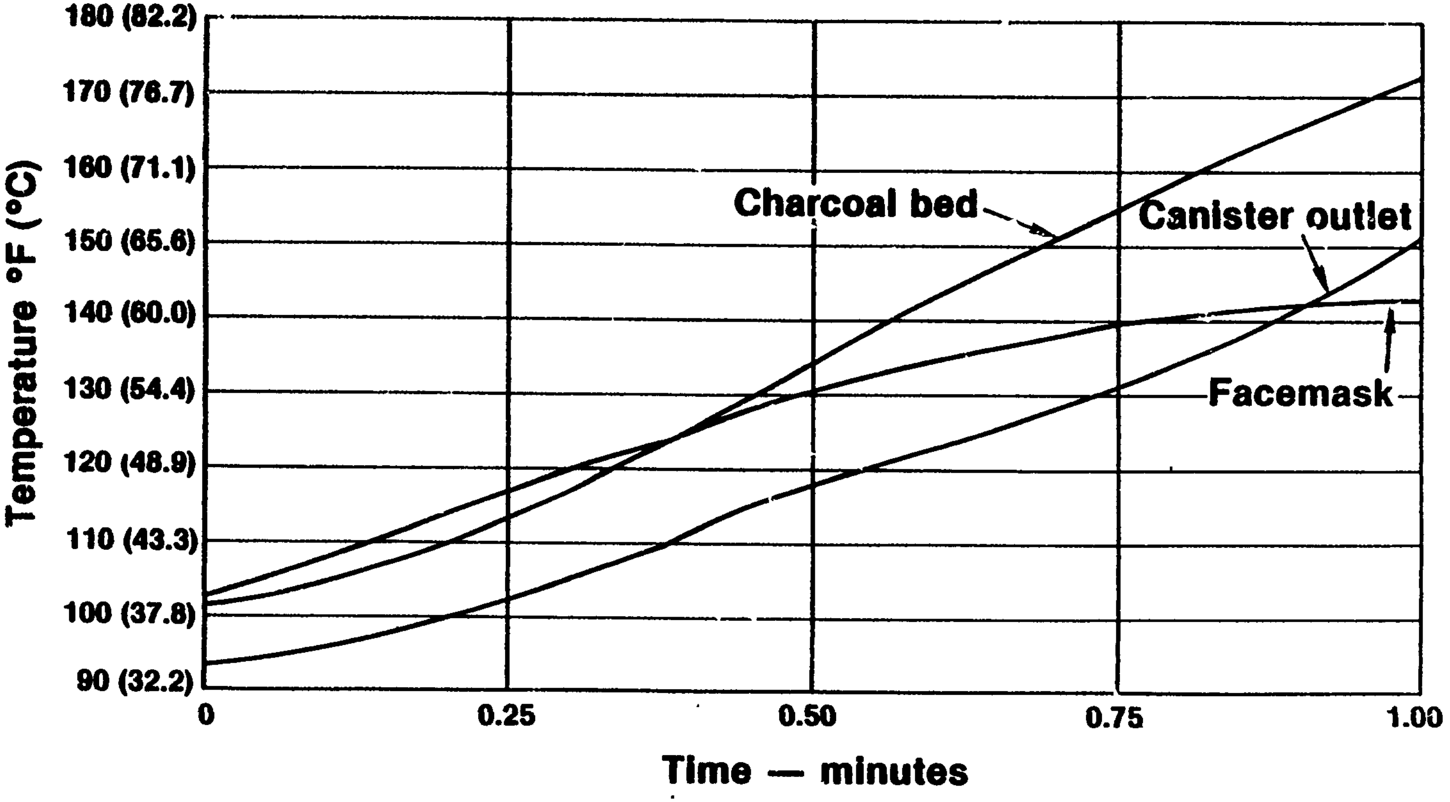


FIGURE 31

OBA MASK INLET TEMPERATURE TRANSIENT TEST #4

Average Ambient Temperature 501°F (260.6°C)
Oven Wall Temperature 750°F (398.9°C)



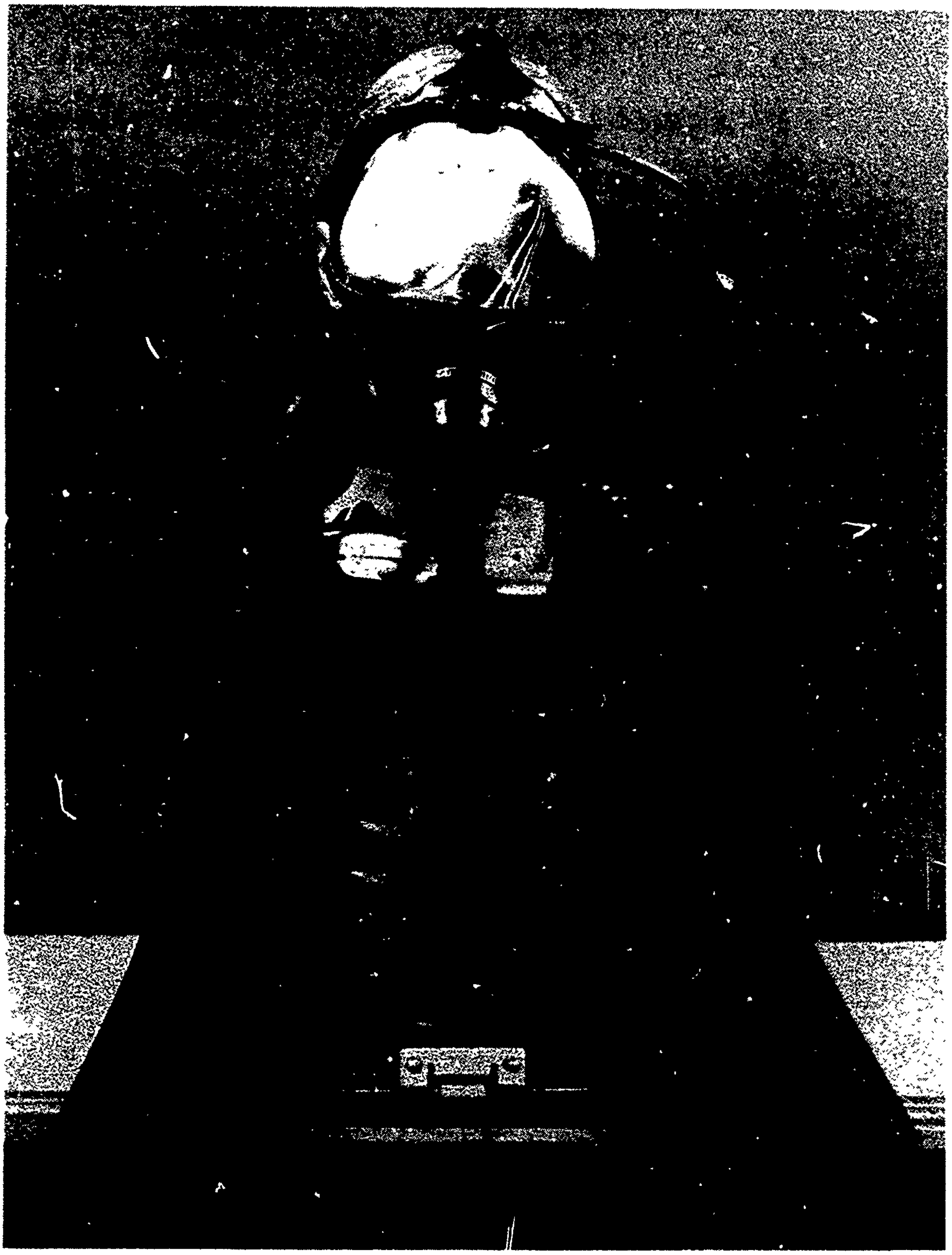
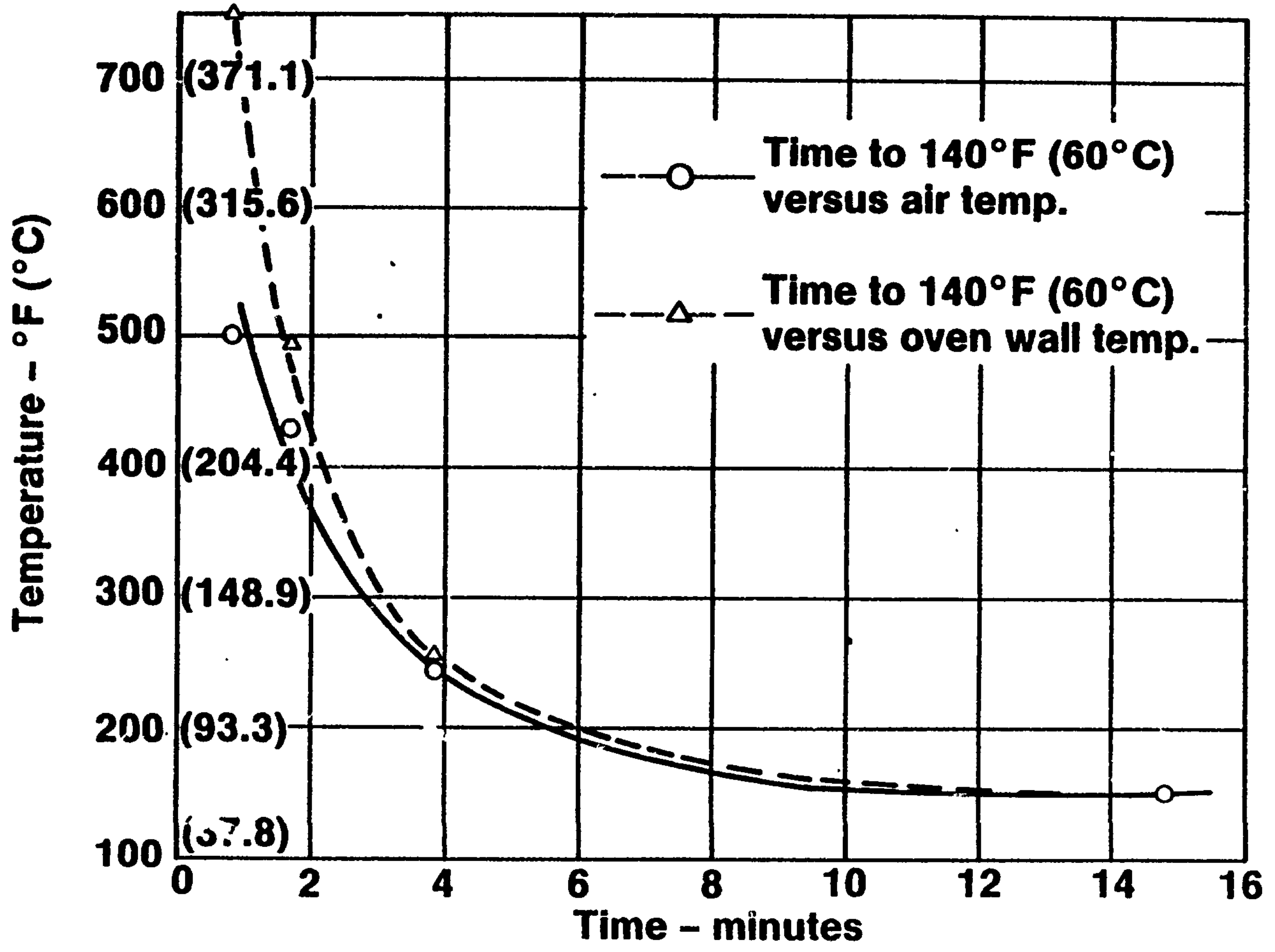


FIGURE 32

OXYGEN BREATHING APPARATUS
(POST HIGH TEMPERATURE TESTS)

FIGURE 33

OBA FACEMASK TEMPERATURE TRANSIENTS TO 140°F (60°C)



hours. The remaining portion of the test was conducted at an inlet carbon monoxide concentration of 700 ppm with 70°F (21.1°C) and approximately 60 percent relative humidity air. The flow rate for the life test was 1.0 ft^3/min (28.3 l/min) with occasional increases to 3.0 ft^3/min (85 l/min) for two-minute intervals. The cummulative test time on the catalyst at the end of the test program was 253 hours. No measurable degradation in catalyst performance was noted throughout the test program.

FIGURE 34
SODASORB PERFORMANCE
TEST A

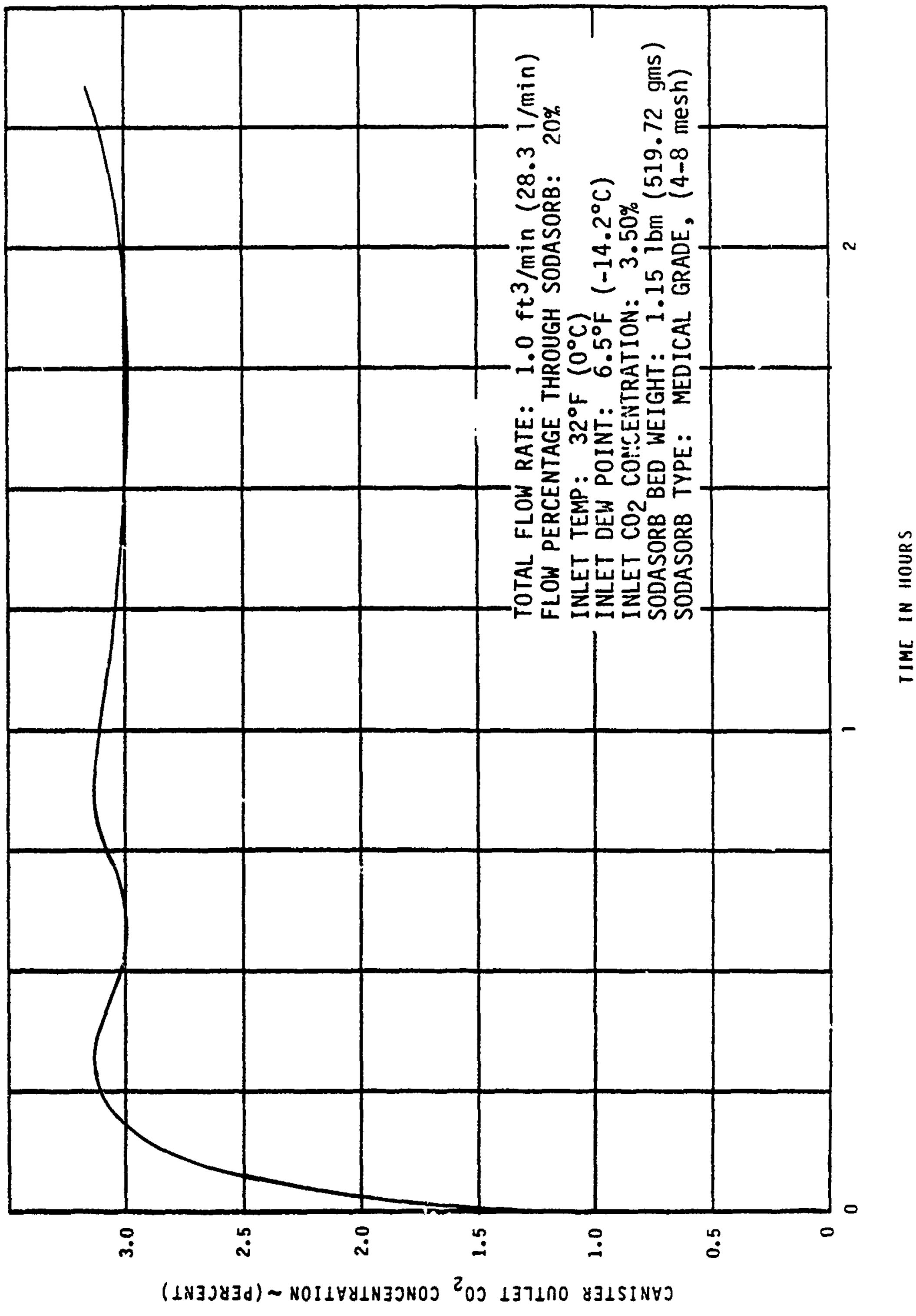


FIGURE 35

SODASORB PERFORMANCE
TEST B

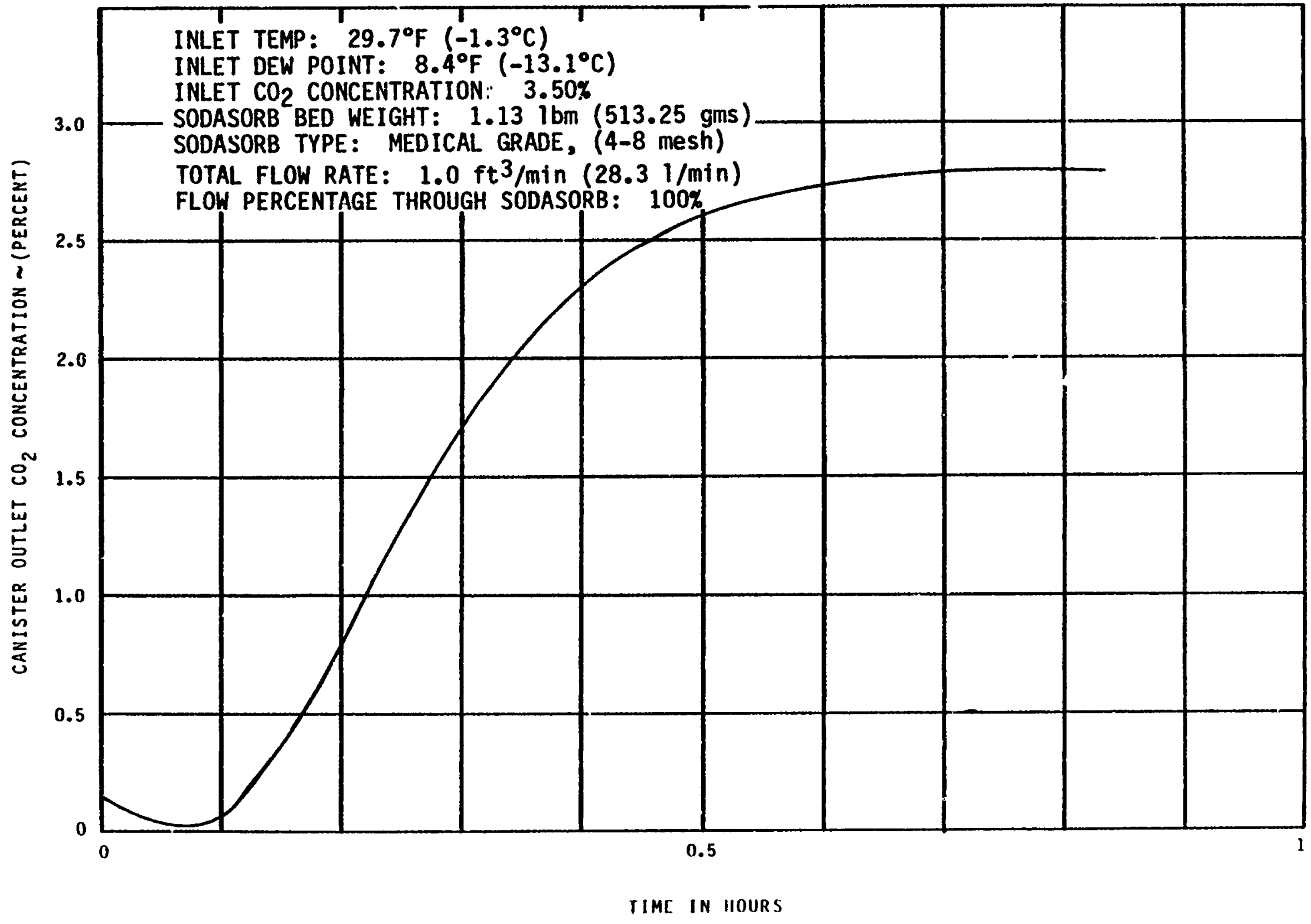


FIGURE 36
SODASORB PERFORMANCE
TEST B_1

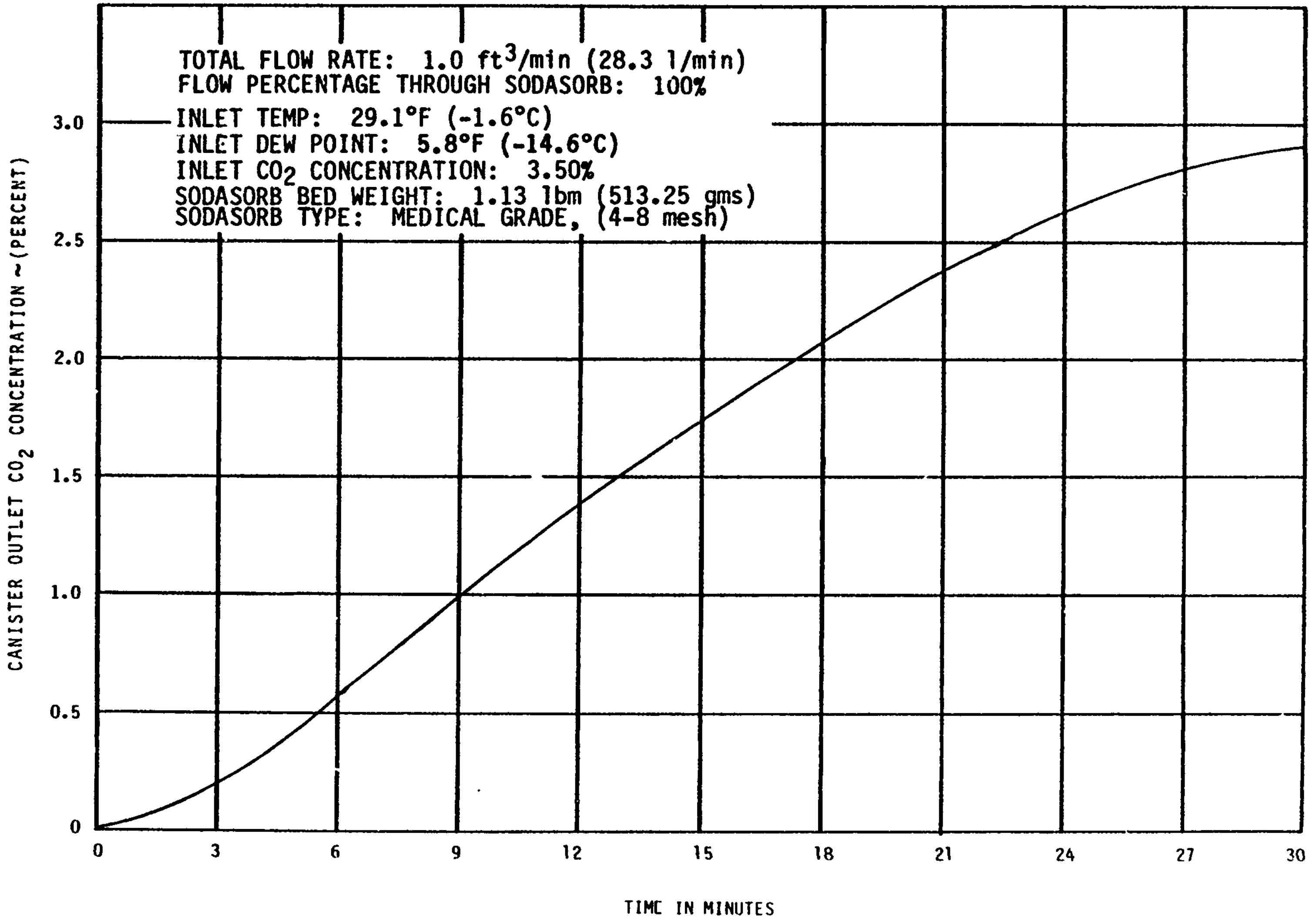


FIGURE 37

SODASORB PERFORMANCE
TEST C

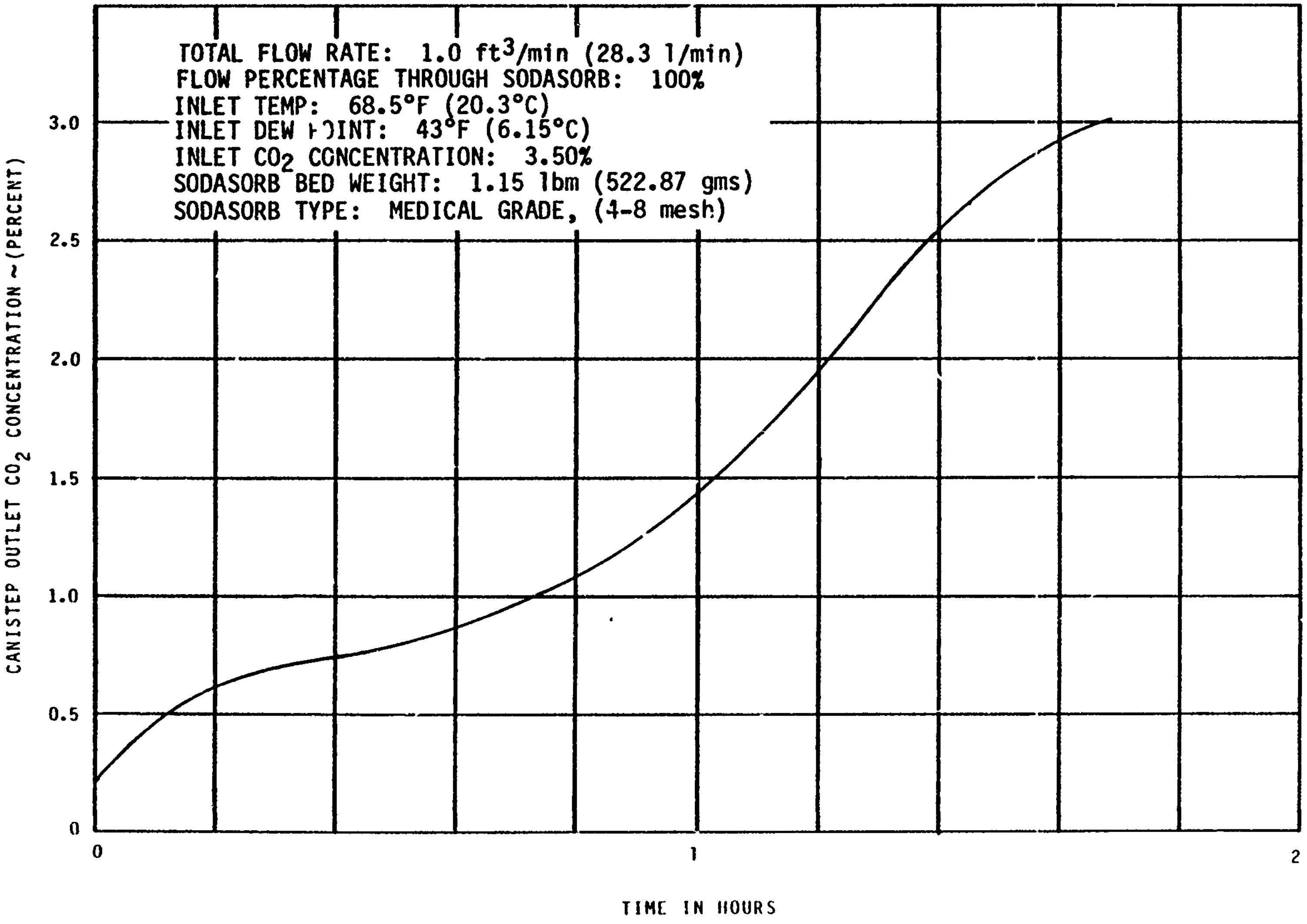
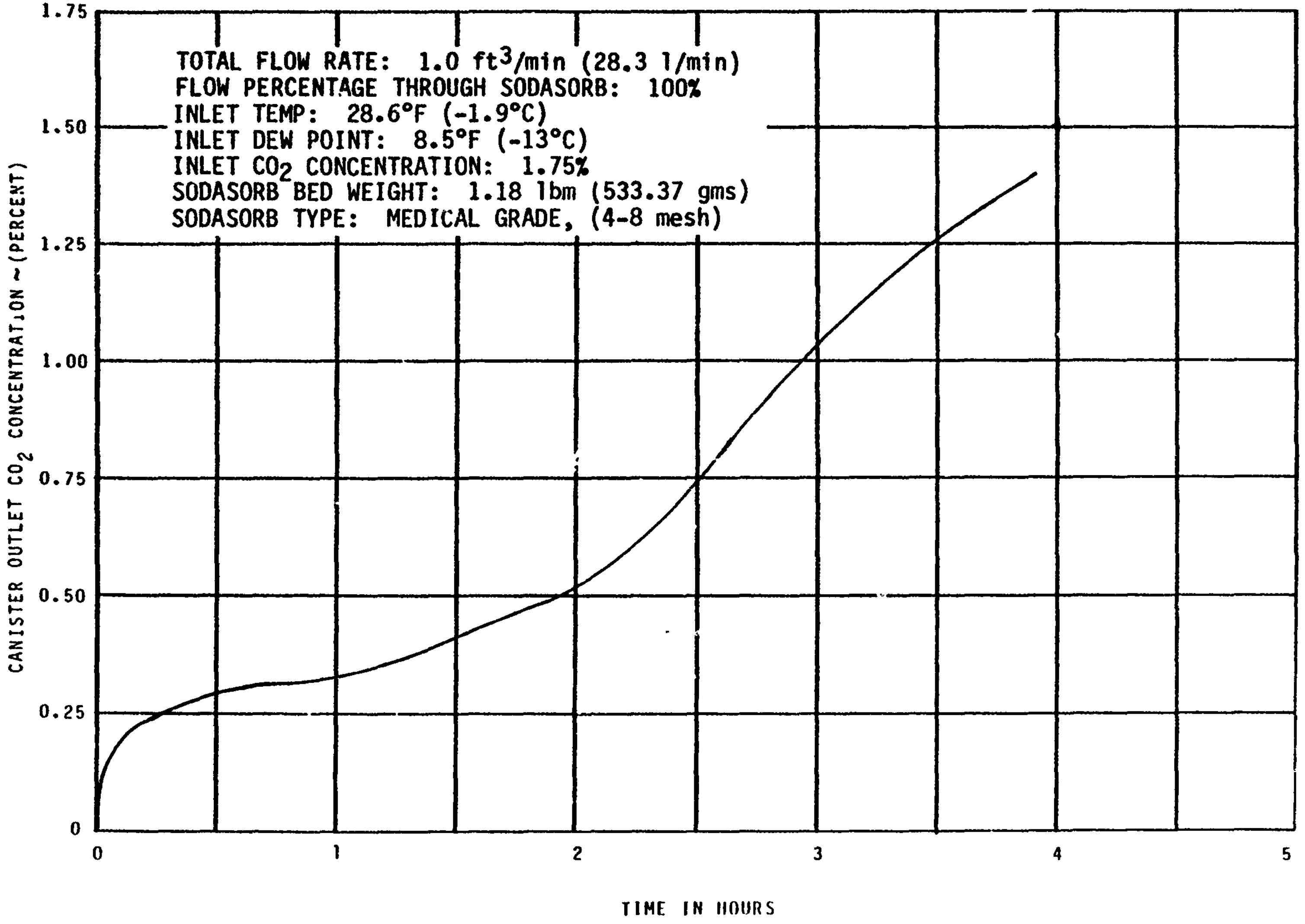


FIGURE 38

SODASORB PERFORMANCE
TEST D



TOTAL FLOW RATE: 1.0 ft^3/min (28.3 l/min)
FLOW PERCENTAGE THROUGH SODASORB: 100%
INLET TEMP: 28.6°F (-1.9°C)
INLET DEW POINT: 8.5°F (-13°C)
INLET CO_2 CONCENTRATION: 1.75%
SODASORB BED WEIGHT: 1.18 lbm (533.37 gms)
SODASORB TYPE: MEDICAL GRADE, (4-8 mesh)

FIGURE 39
SODASORB PERFORMANCE
TEST E

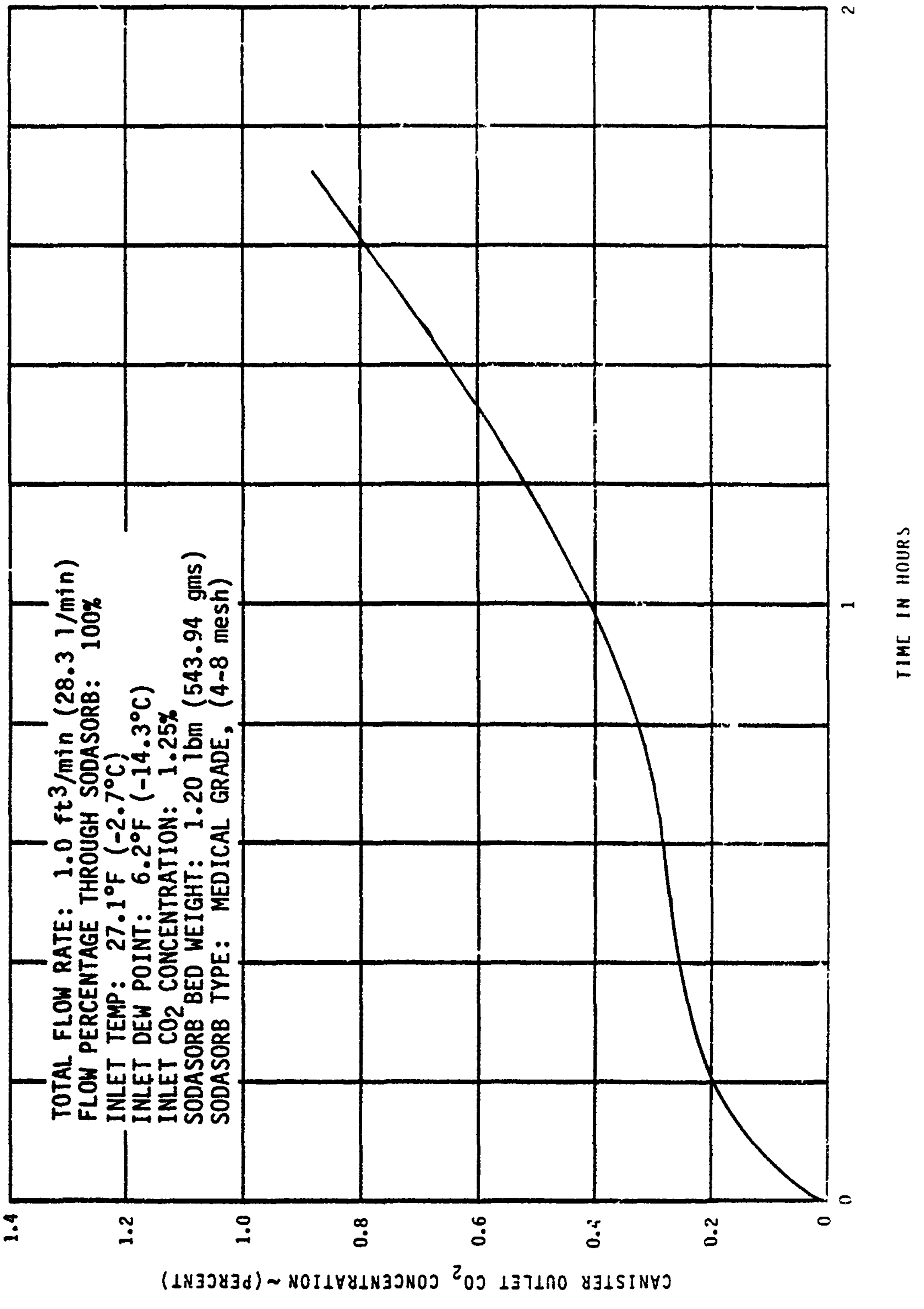


FIGURE 40

SODASORB PERFORMANCE
TEST E_1

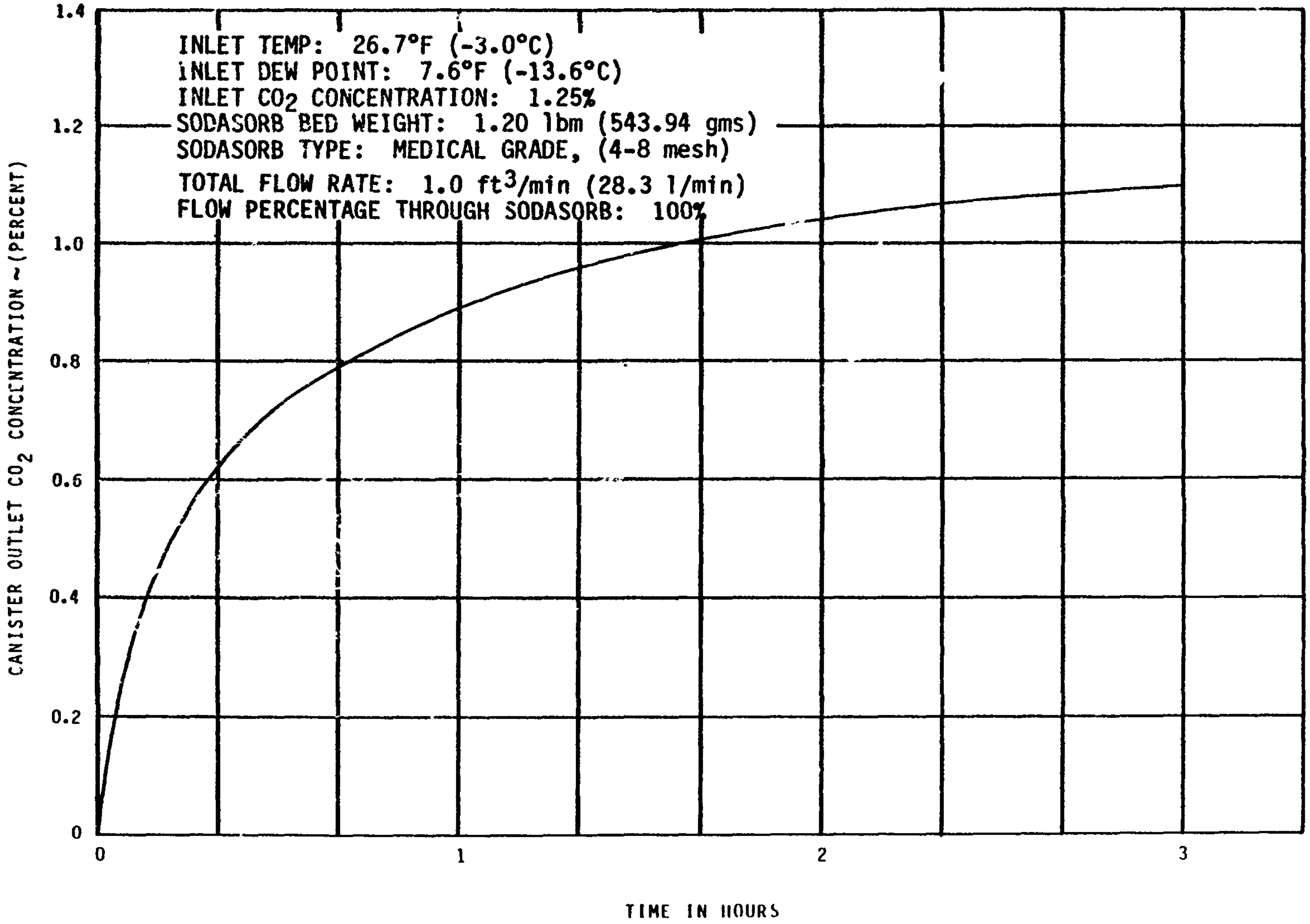
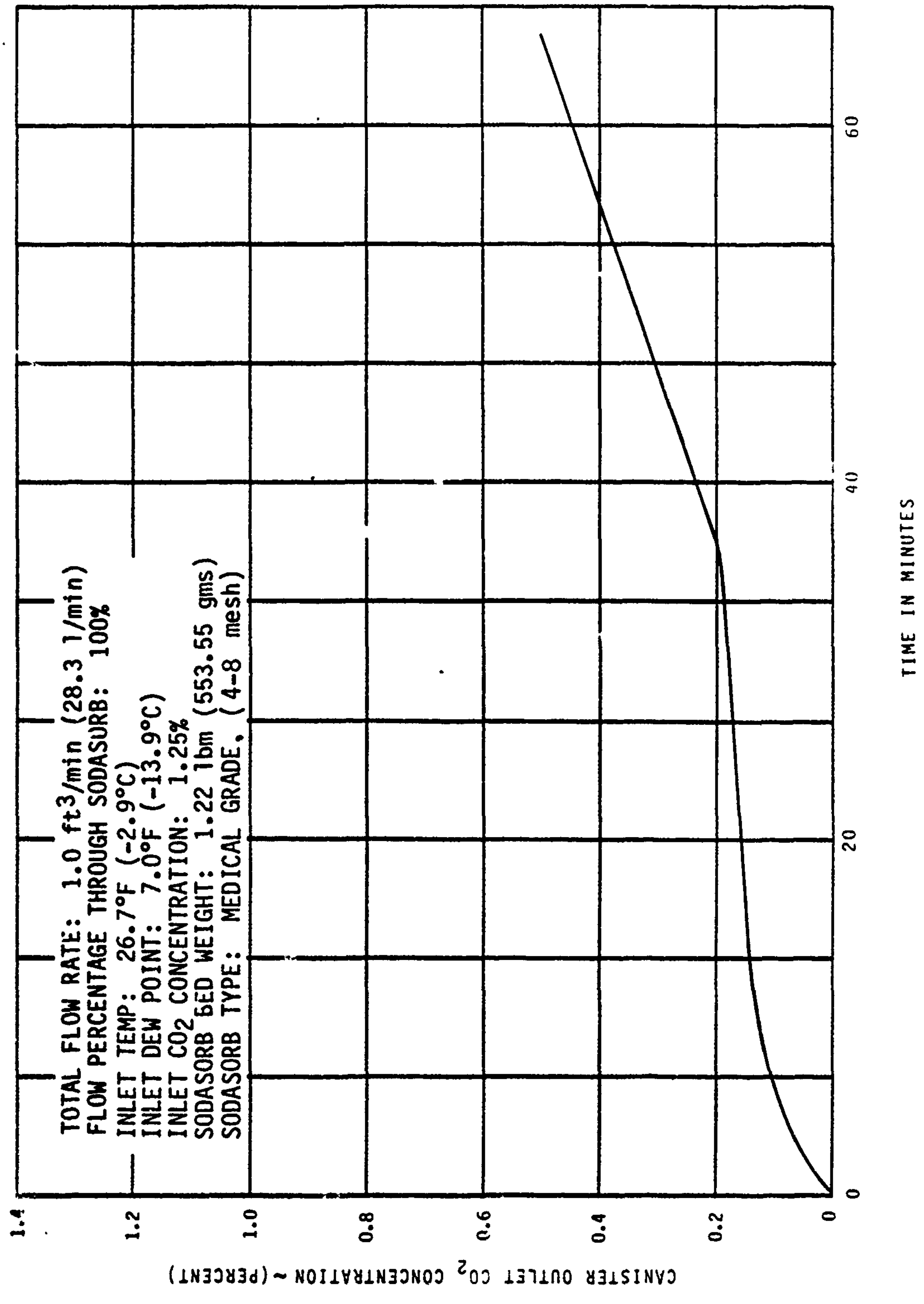


FIGURE 41
SODASORB PERFORMANCE
TEST F



TOTAL FLOW RATE: 1.0 ft^3/min (28.3 l/min)
FLOW PERCENTAGE THROUGH SODASORB: 100%
INLET TEMP: 26.7°F (-2.9°C)
INLET DEW POINT: 7.0°F (-13.9°C)
INLET CO_2 CONCENTRATION: 1.25%
SODASORB BED WEIGHT: 1.22 lbm (553.55 gms)
SODASORB TYPE: MEDICAL GRADE, (4-8 mesh)

FIGURE 42

SODASORB PERFORMANCE
TEST F1

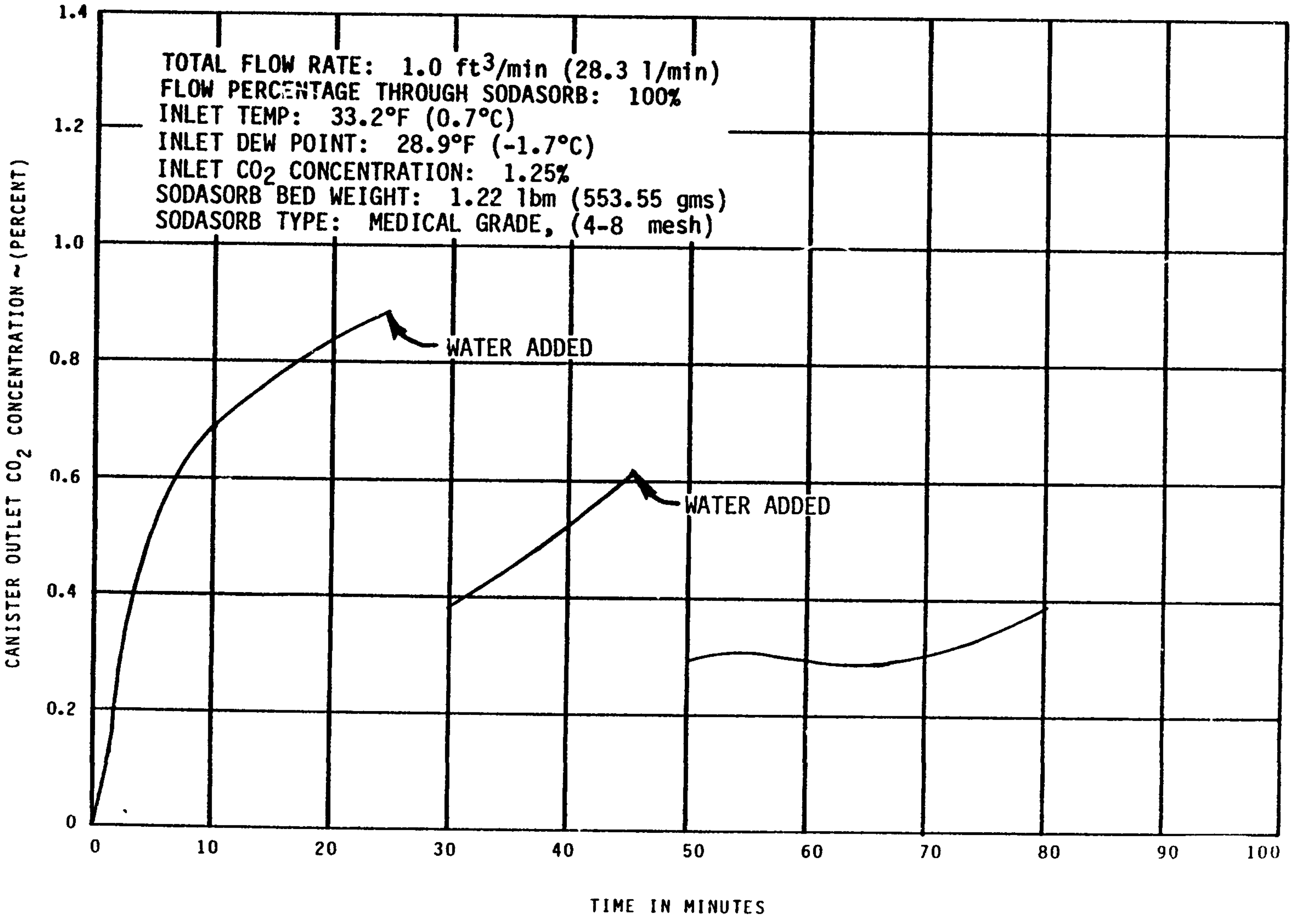
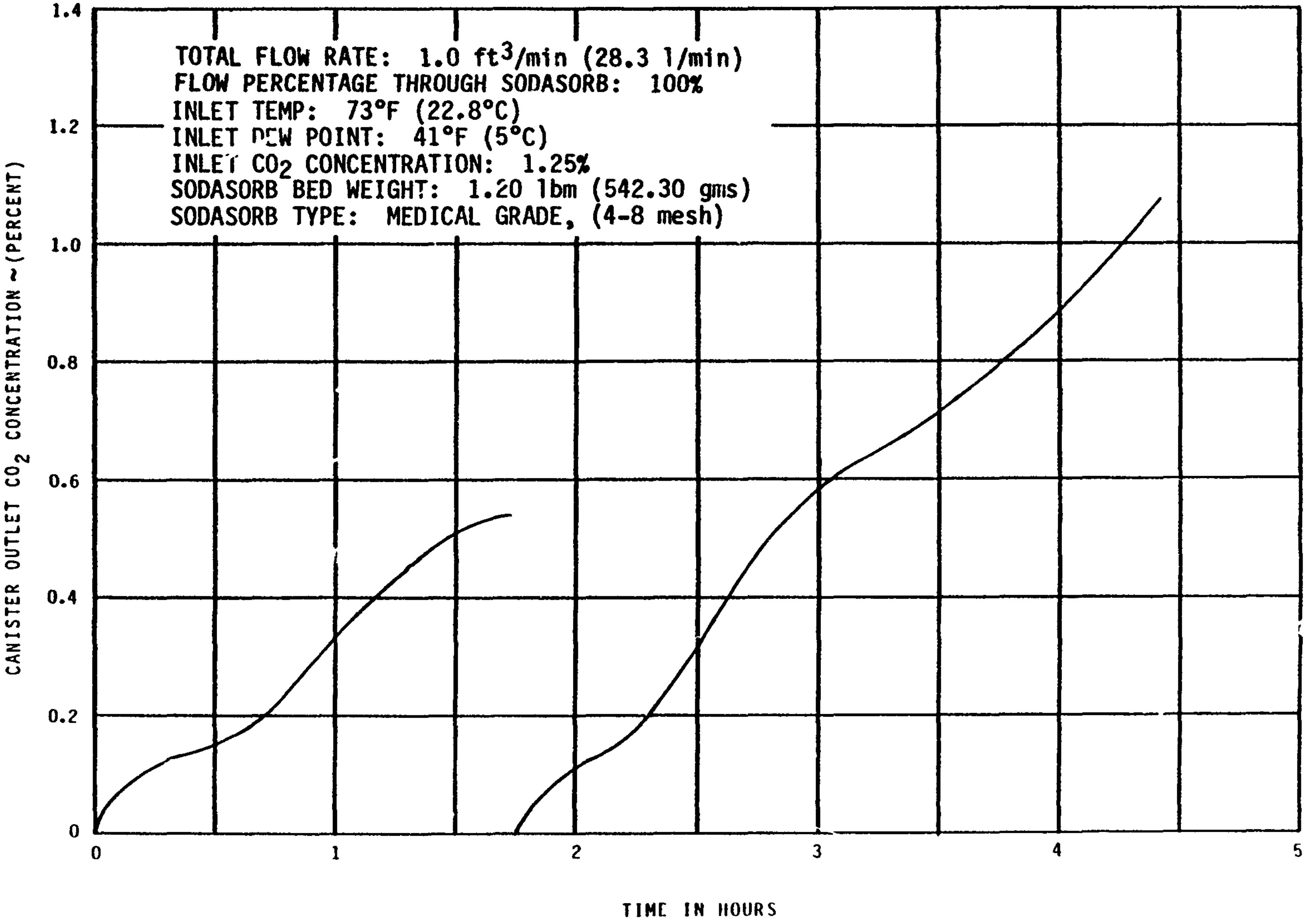


FIGURE 43

SODASORB PERFORMANCE
TEST G & G_1



TOTAL FLOW RATE: 1.0 ft^3/min (28.3 l/min)
FLOW PERCENTAGE THROUGH SODASORB: 100%
INLET TEMP: 73°F (22.8°C)
INLET DEW POINT: 41°F (5°C)
INLET CO_2 CONCENTRATION: 1.25%
SODASORB BED WEIGHT: 1.20 lbm (542.30 gms)
SODASORB TYPE: MEDICAL GRADE, (4-8 mesh)

FIGURE 44

SODASORB PERFORMANCE
TEST H

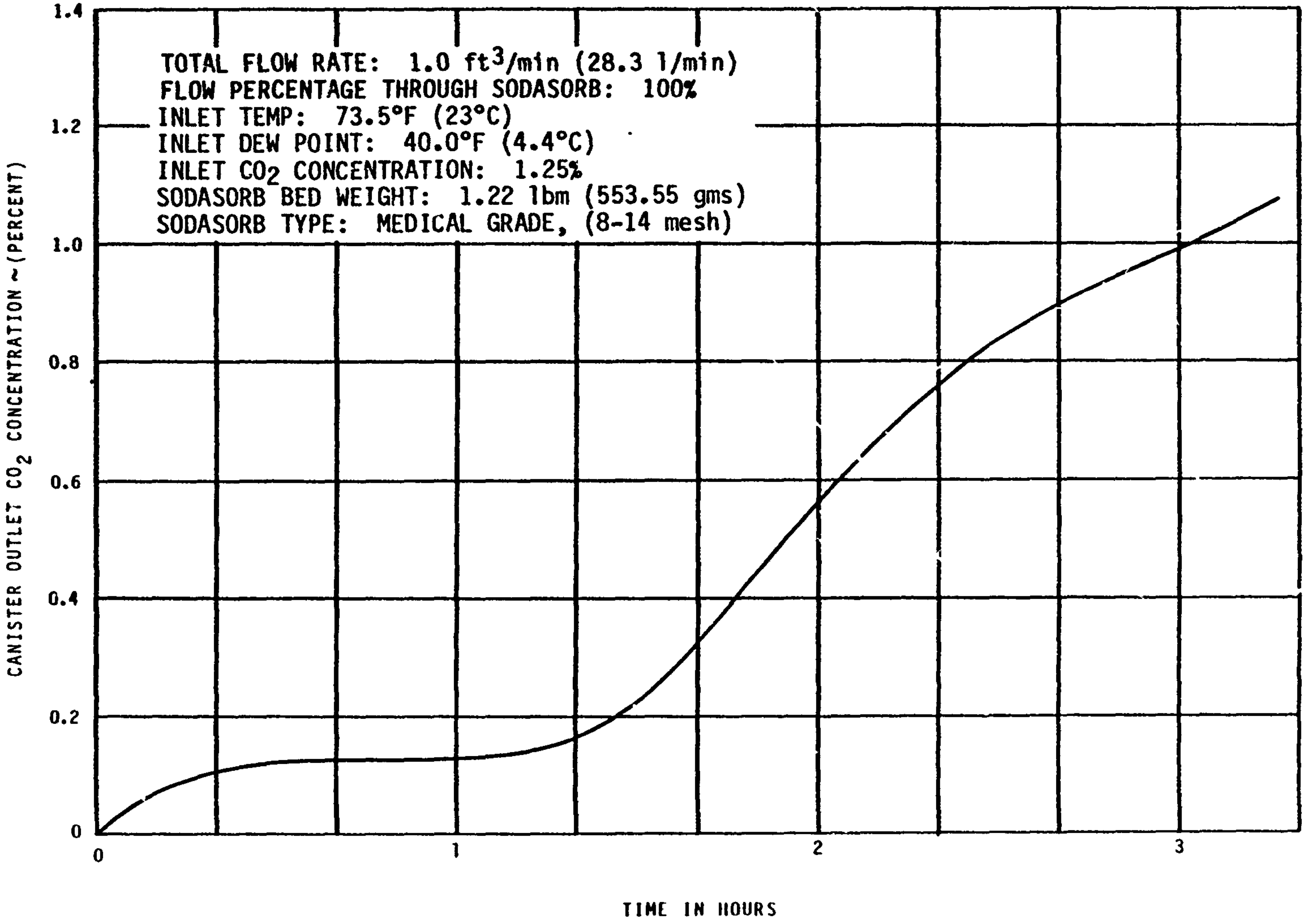


FIGURE 45
SODASORB PERFORMANCE
TEST H1

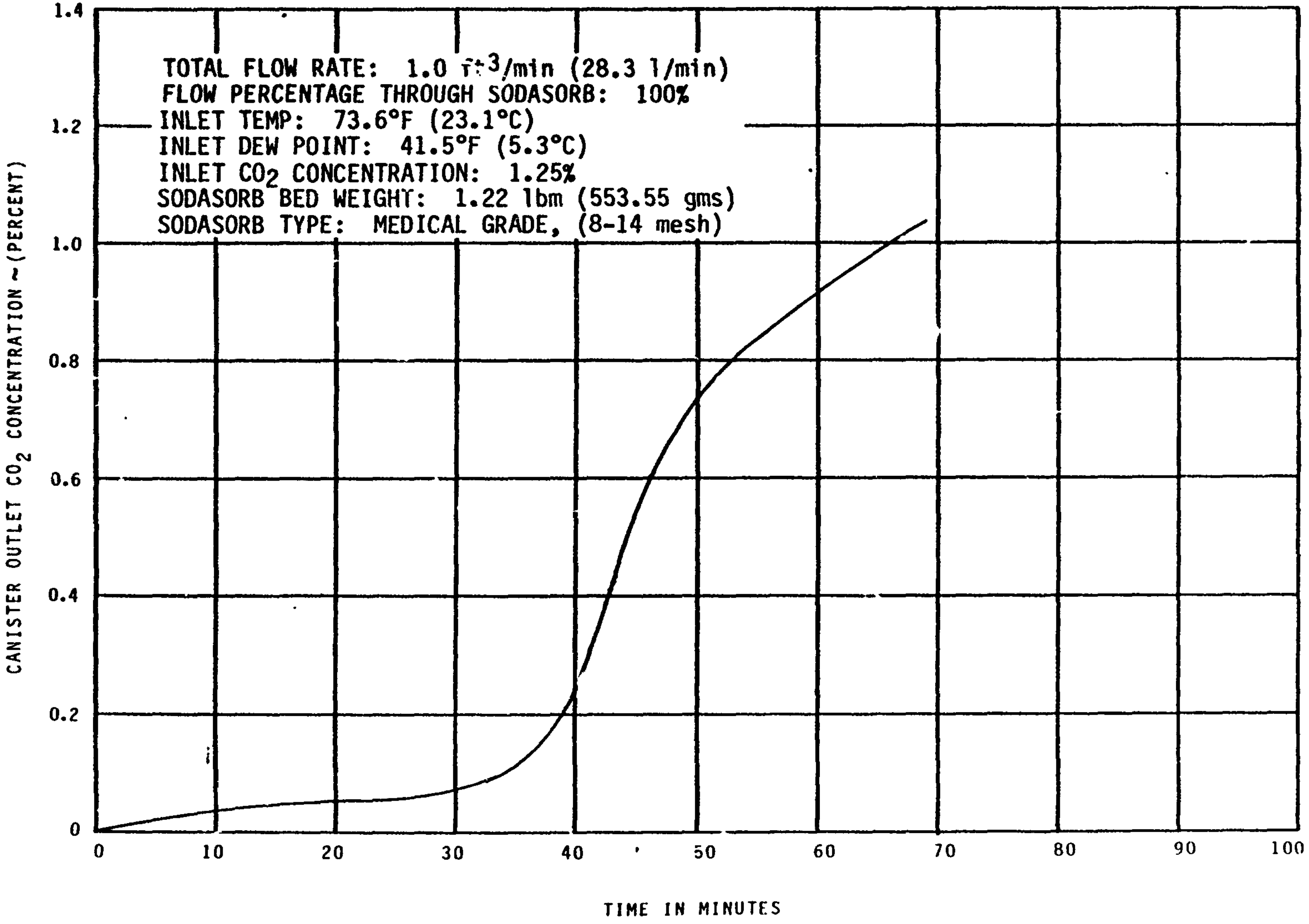
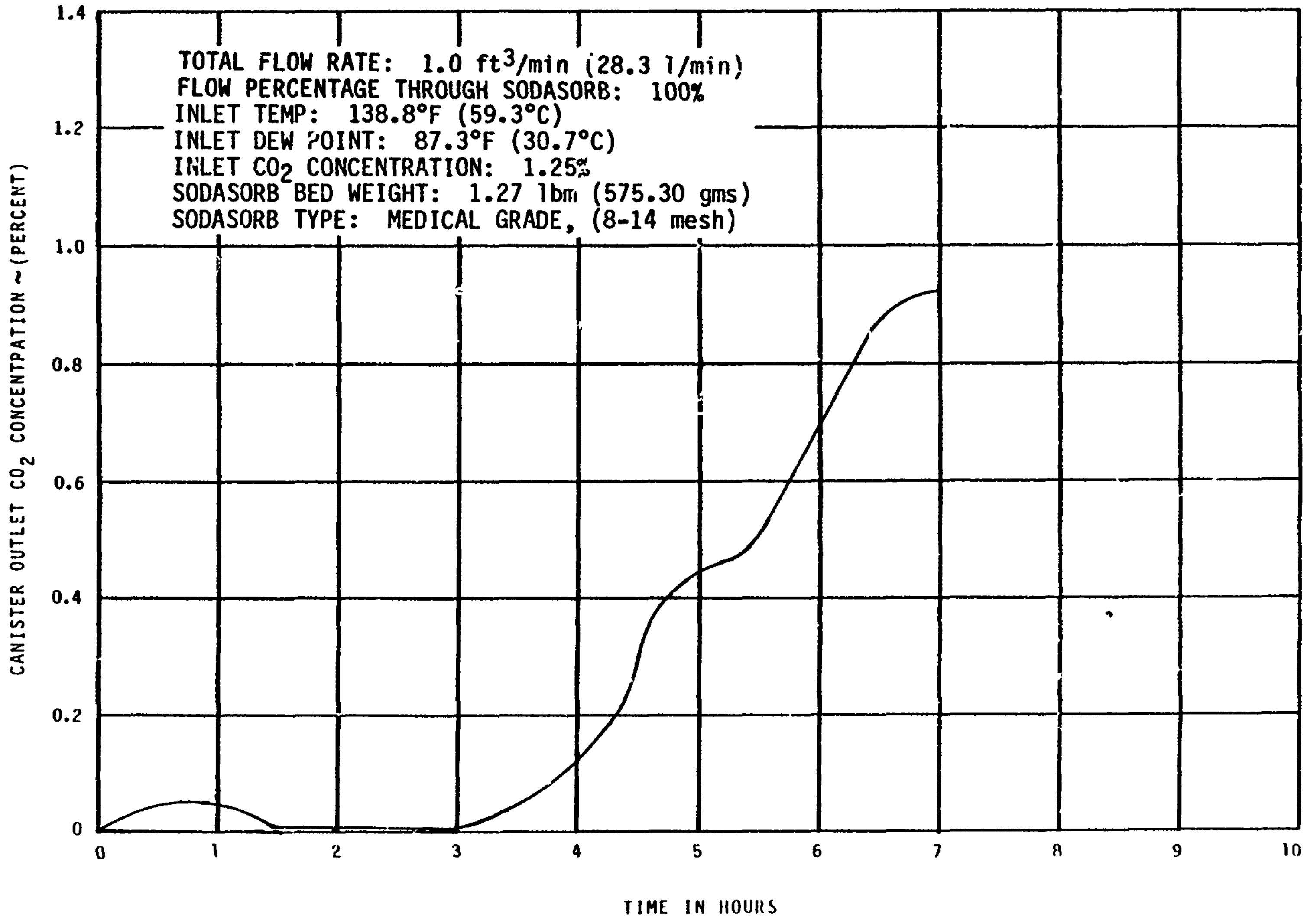


FIGURE 46

SODASORB PERFORMANCE
TEST I



TOTAL FLOW RATE: 1.0 ft^3/min (28.3 l/min)
FLOW PERCENTAGE THROUGH SODASORB: 100%
INLET TEMP: 138.8°F (59.3°C)
INLET DEW POINT: 87.3°F (30.7°C)
INLET CO_2 CONCENTRATION: 1.25%
SODASORB BED WEIGHT: 1.27 lbm (575.30 gms)
SODASORB TYPE: MEDICAL GRADE, (8-14 mesh)

FIGURE 47

SODASORB PERFORMANCE
TEST I_1

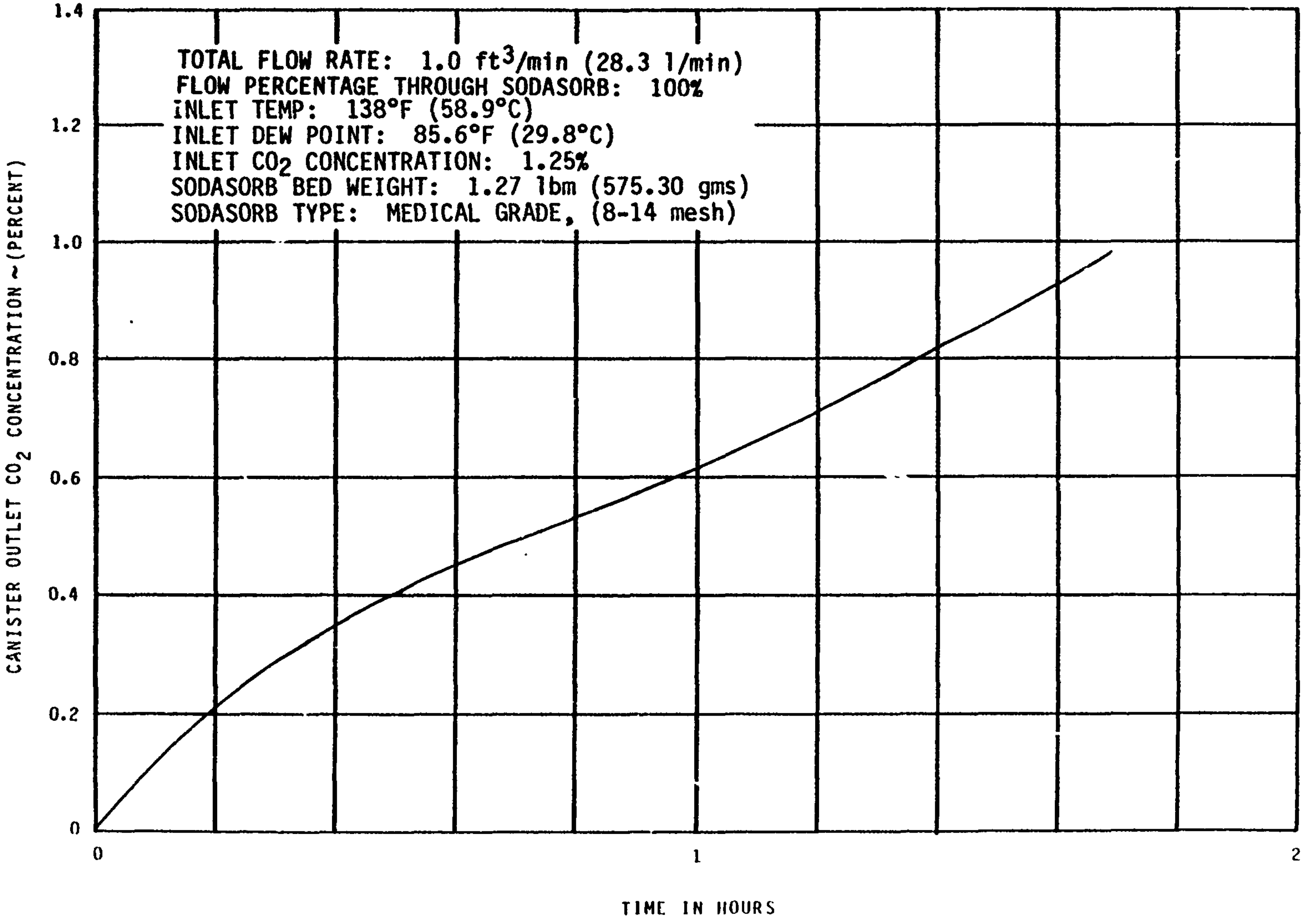


FIGURE 48

SODASORB PERFORMANCE
TEST J

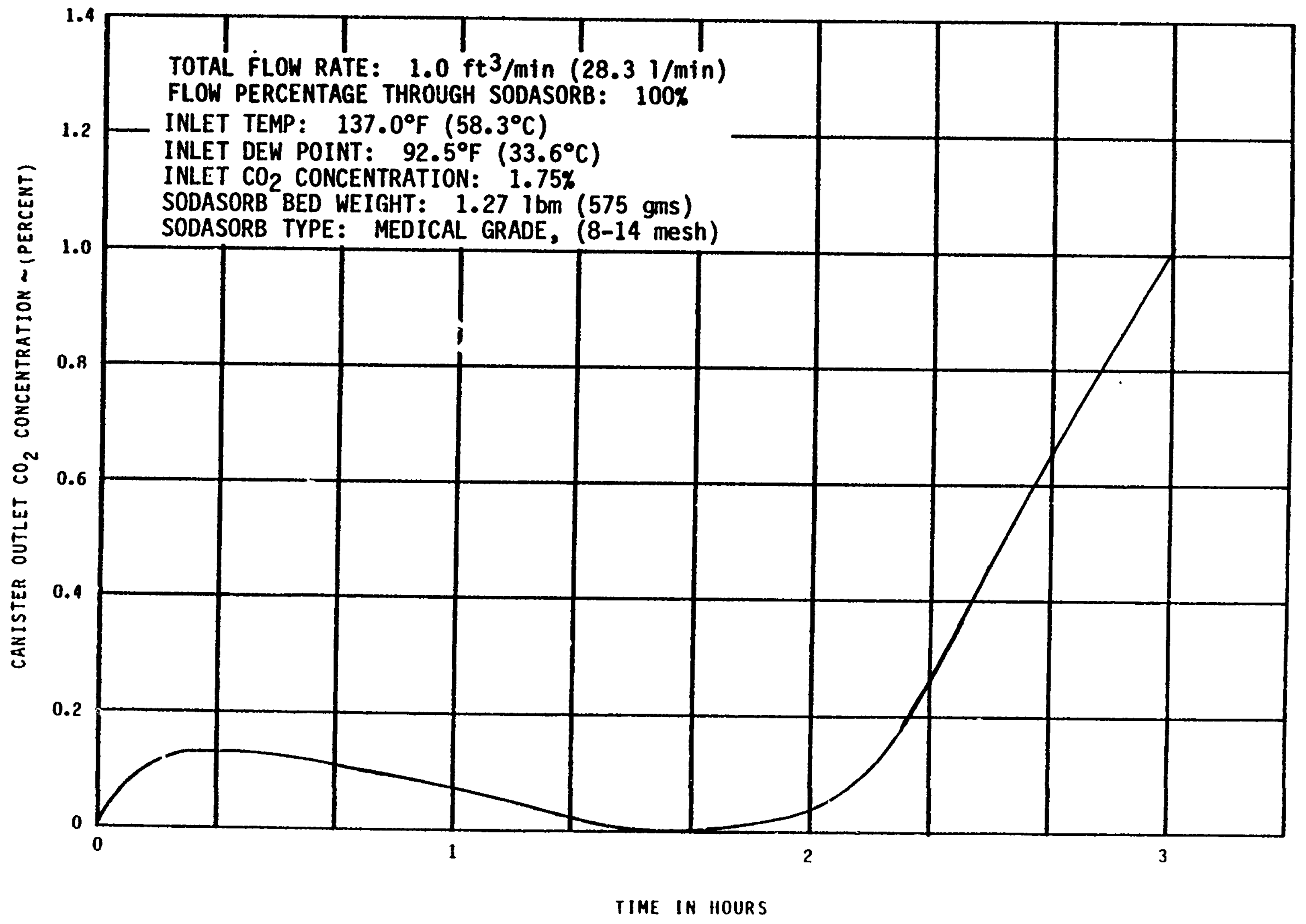


FIGURE 49

SODASORB PERFORMANCE
TEST J1

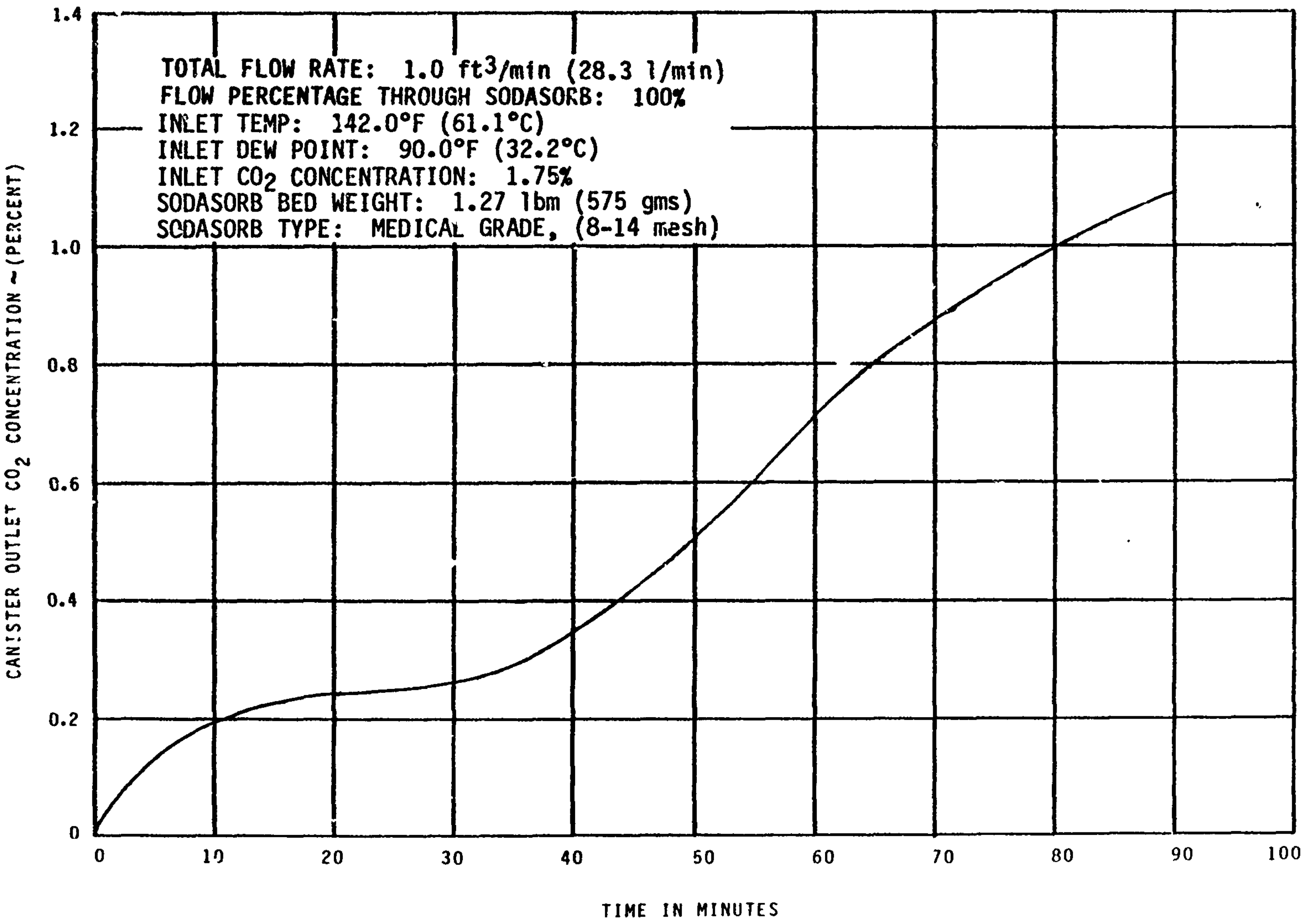


FIGURE 50

SODASORB PERFORMANCE
TEST K

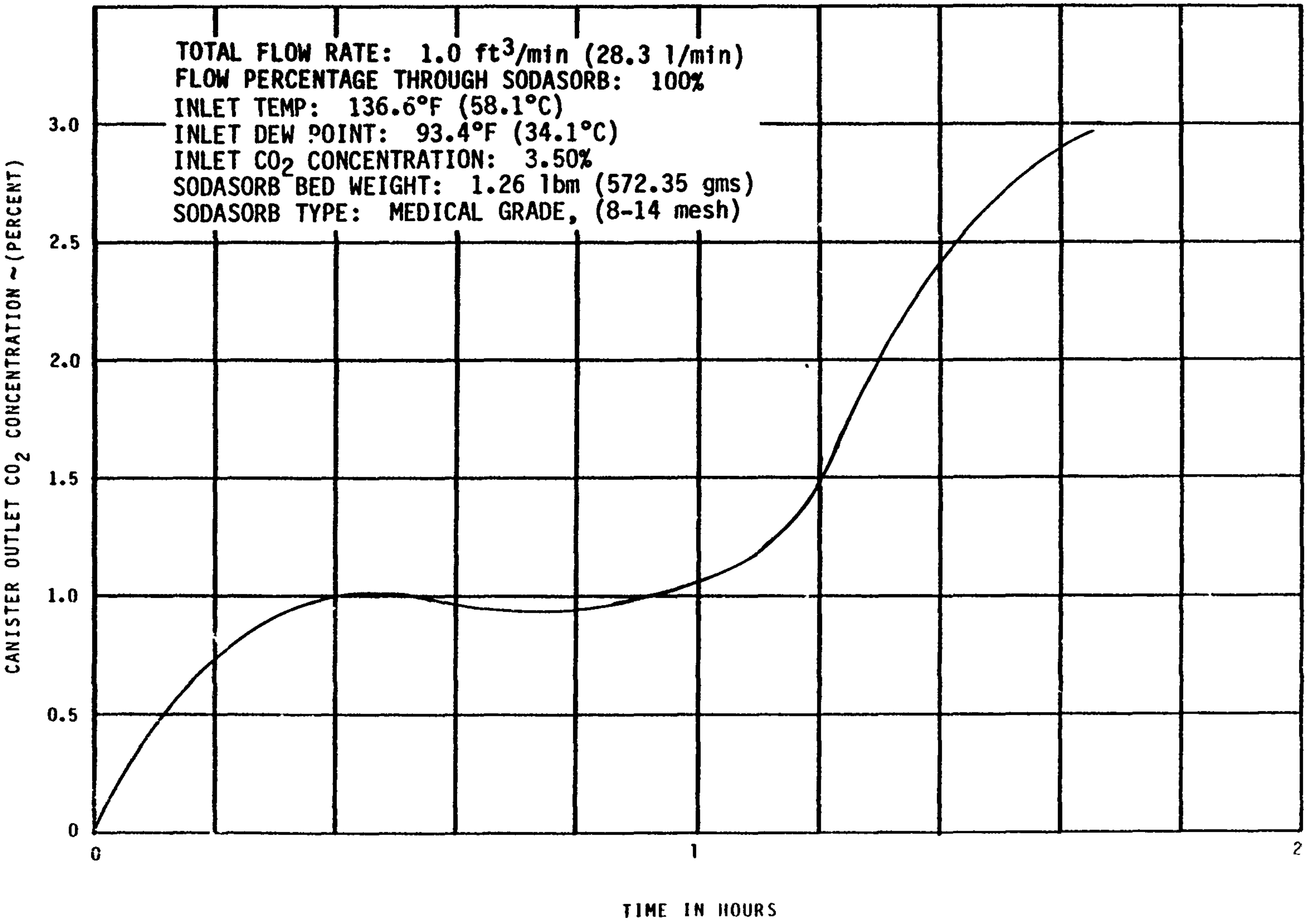
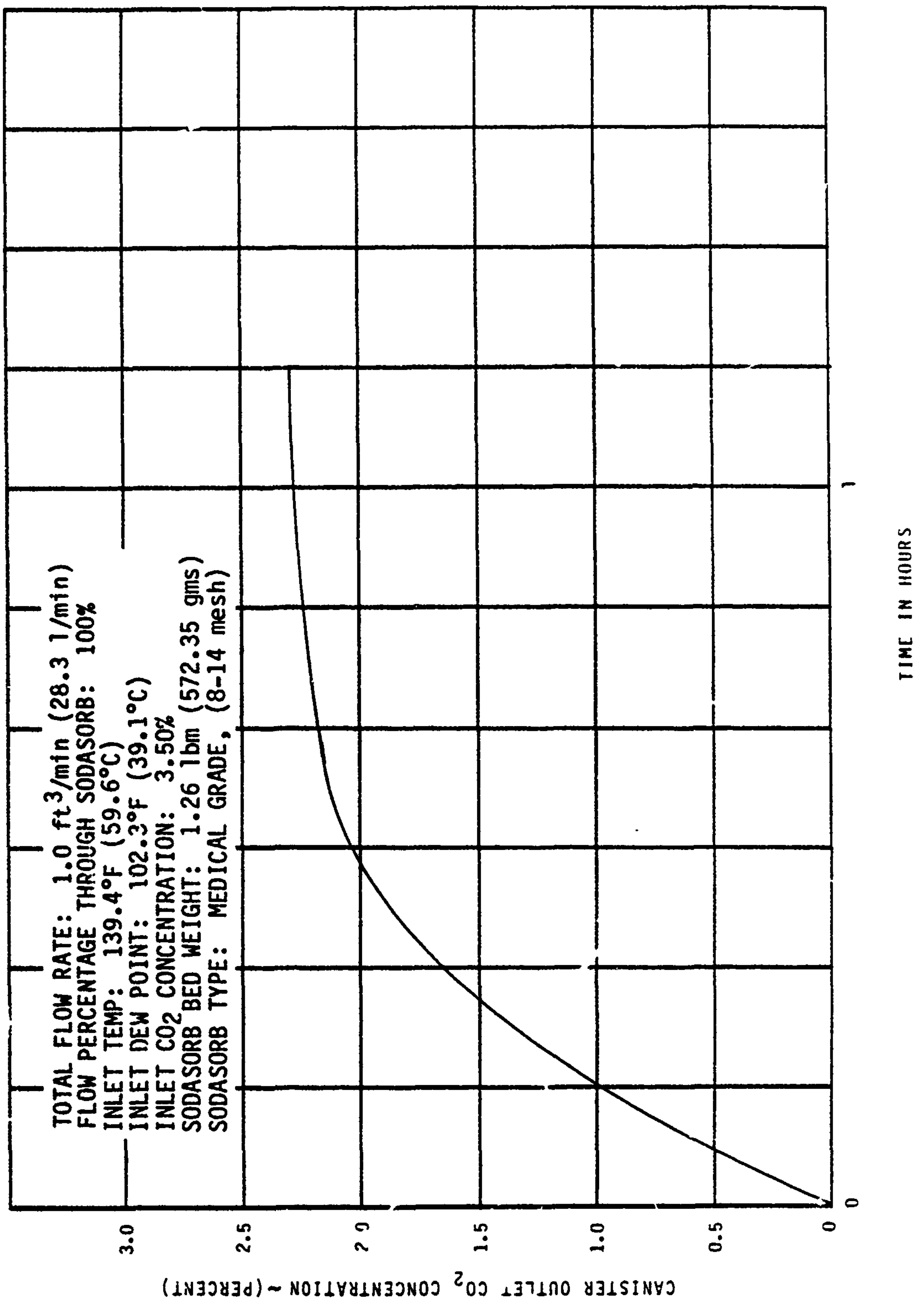


FIGURE 51

SODASORB PERFORMANCE

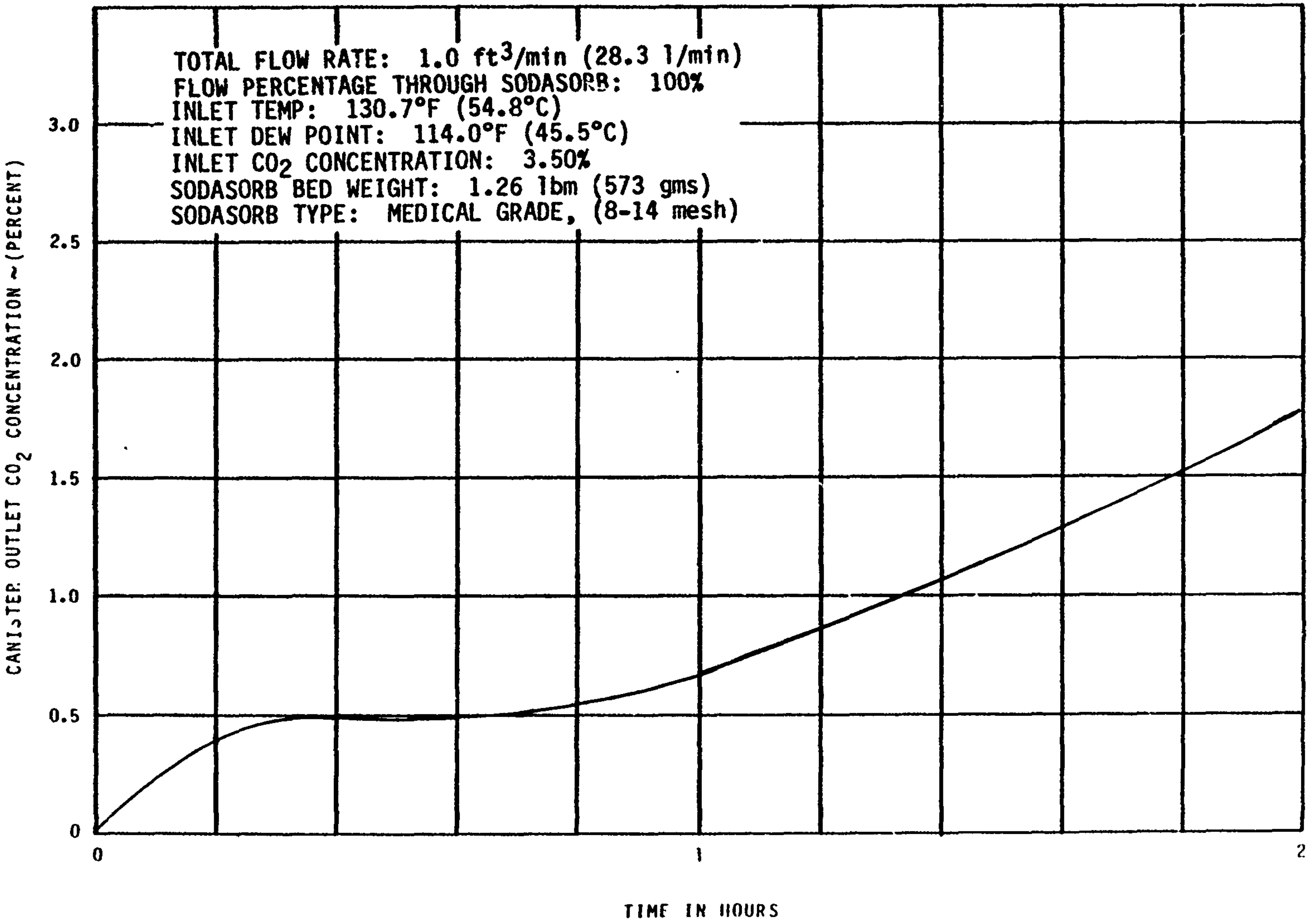
TEST K_1



TOTAL FLOW RATE: 1.0 ft^3/min (28.3 l/min)
FLOW PERCENTAGE THROUGH SODASORB: 100%
INLET TEMP: 139.4°F (59.6°C)
INLET DEW POINT: 102.3°F (39.1°C)
INLET CO_2 CONCENTRATION: 3.50%
SODASORB BED WEIGHT: 1.26 lbm (572.35 gms)
SODASORB TYPE: MEDICAL GRADE, (8-14 mesh)

FIGURE 52

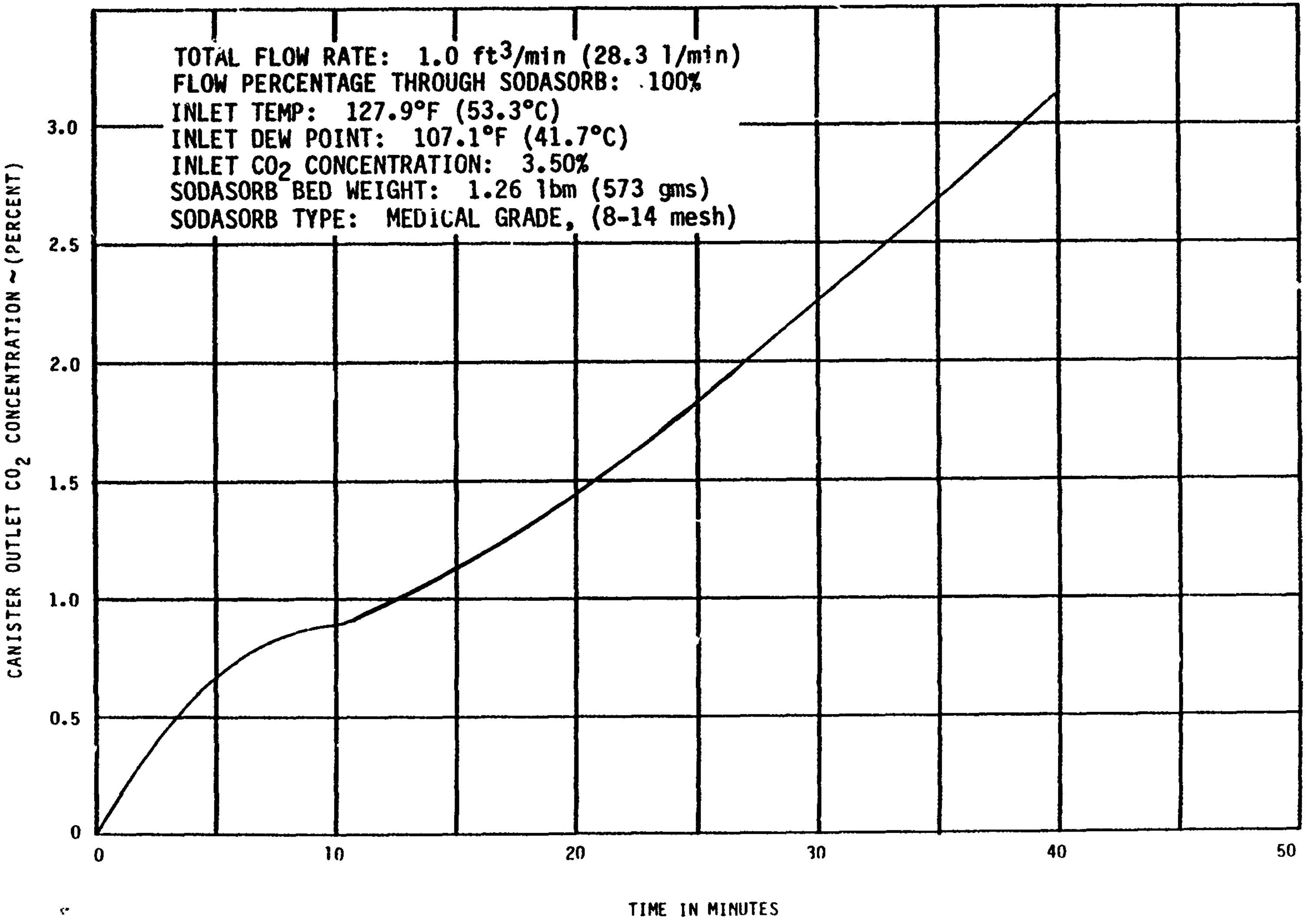
SODASORB PERFORMANCE
TEST L



TOTAL FLOW RATE: 1.0 ft^3/min (28.3 l/min)
FLOW PERCENTAGE THROUGH SODASORB: 100%
INLET TEMP: 130.7°F (54.8°C)
INLET DEW POINT: 114.0°F (45.5°C)
INLET CO_2 CONCENTRATION: 3.50%
SODASORB BED WEIGHT: 1.26 lbm (573 gms)
SODASORB TYPE: MEDICAL GRADE, (8-14 mesh)

FIGURE 53

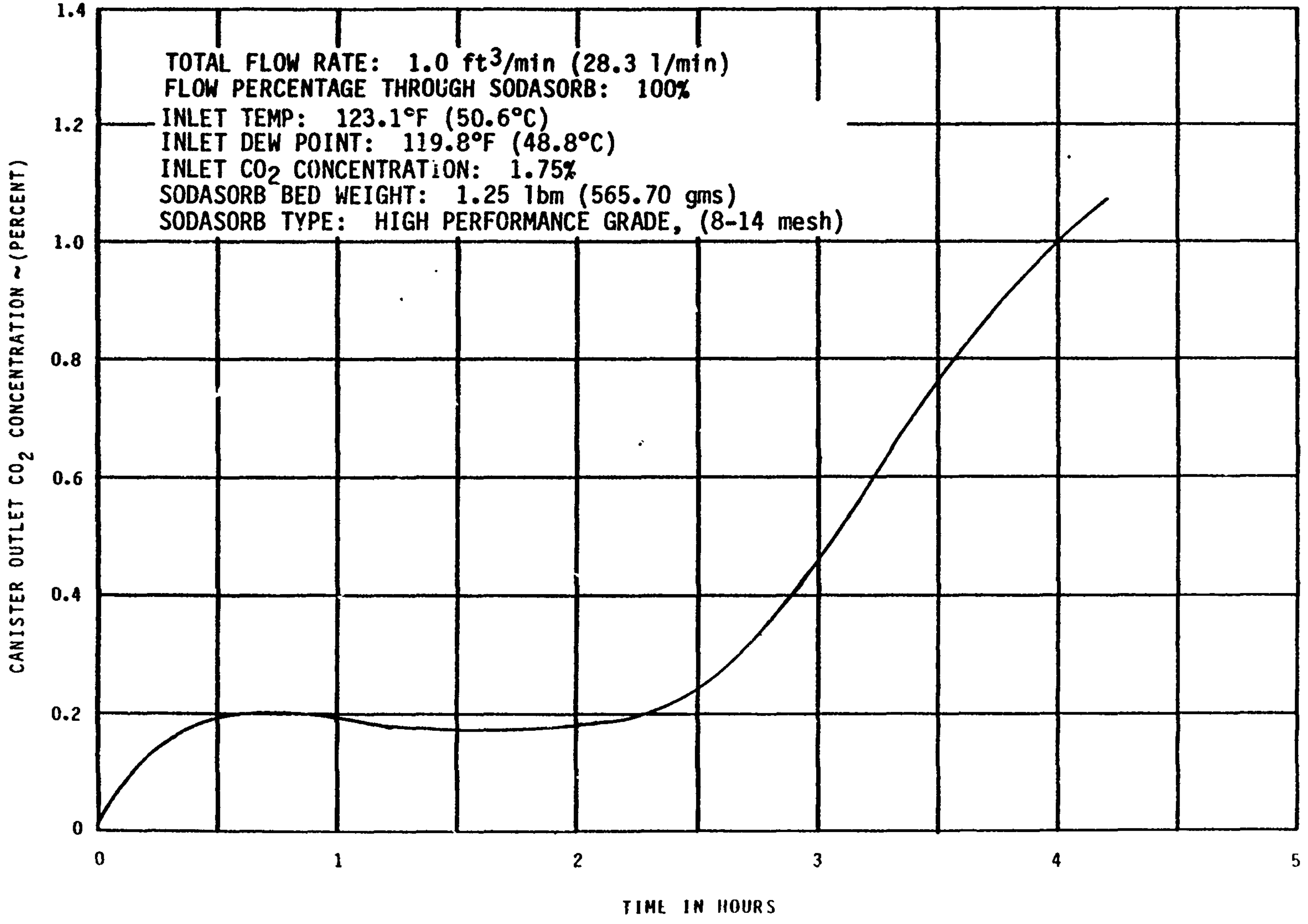
SODASORB PERFORMANCE
TEST L_1



TOTAL FLOW RATE: 1.0 ft^3/min (28.3 l/min)
FLOW PERCENTAGE THROUGH SODASORB: 100%
INLET TEMP: 127.9°F (53.3°C)
INLET DEW POINT: 107.1°F (41.7°C)
INLET CO_2 CONCENTRATION: 3.50%
SODASORB BED WEIGHT: 1.26 lbm (573 gms)
SODASORB TYPE: MEDICAL GRADE, (8-14 mesh)

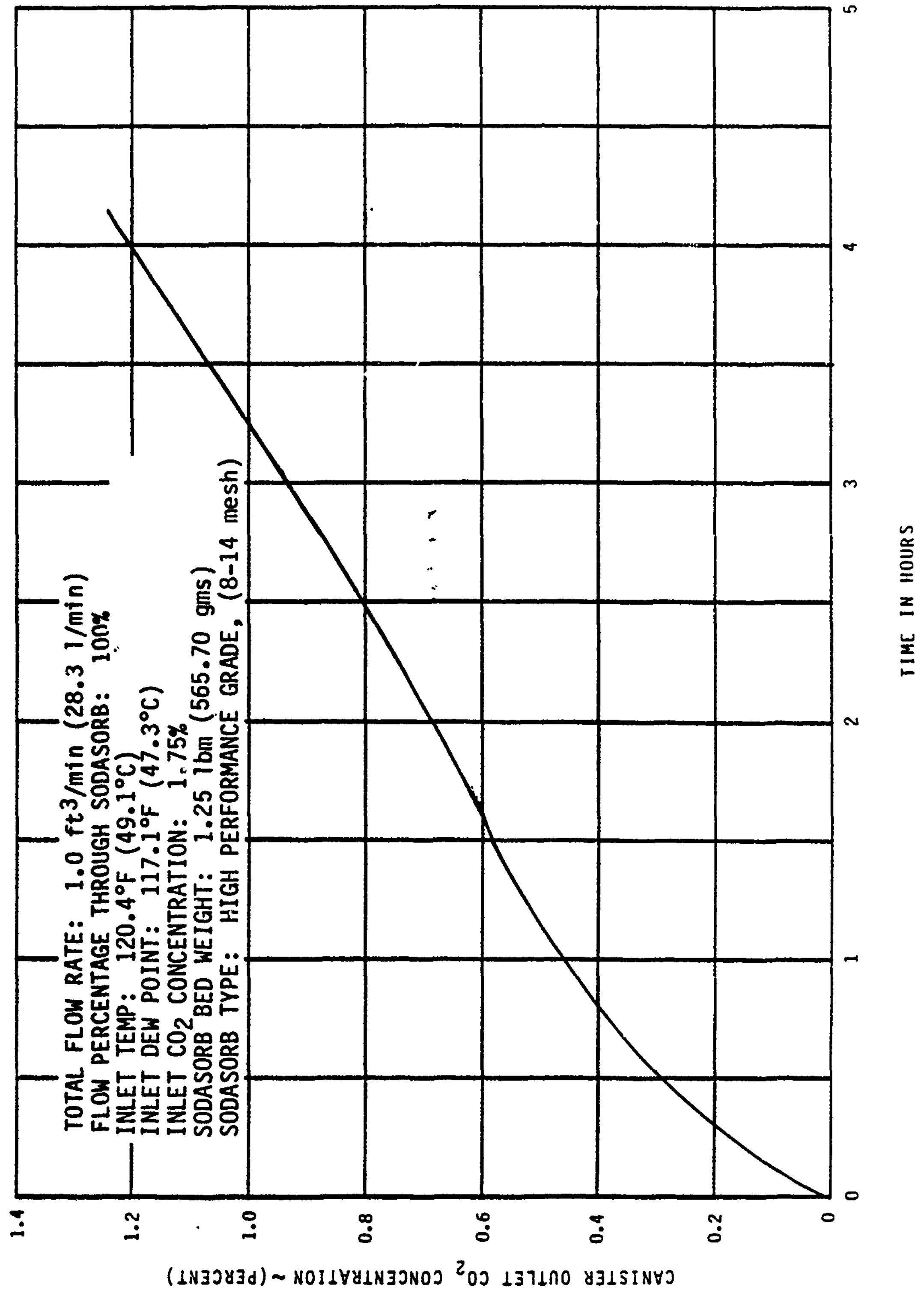
FIGURE 54

SODASORB PERFORMANCE
TEST M



TOTAL FLOW RATE: 1.0 ft^3/min (28.3 l/min)
FLOW PERCENTAGE THROUGH SODASORB: 100%
INLET TEMP: 123.1°F (50.6°C)
INLET DEW POINT: 119.8°F (48.8°C)
INLET CO_2 CONCENTRATION: 1.75%
SODASORB BED WEIGHT: 1.25 lbm (565.70 gms)
SODASORB TYPE: HIGH PERFORMANCE GRADE, (8-14 mesh)

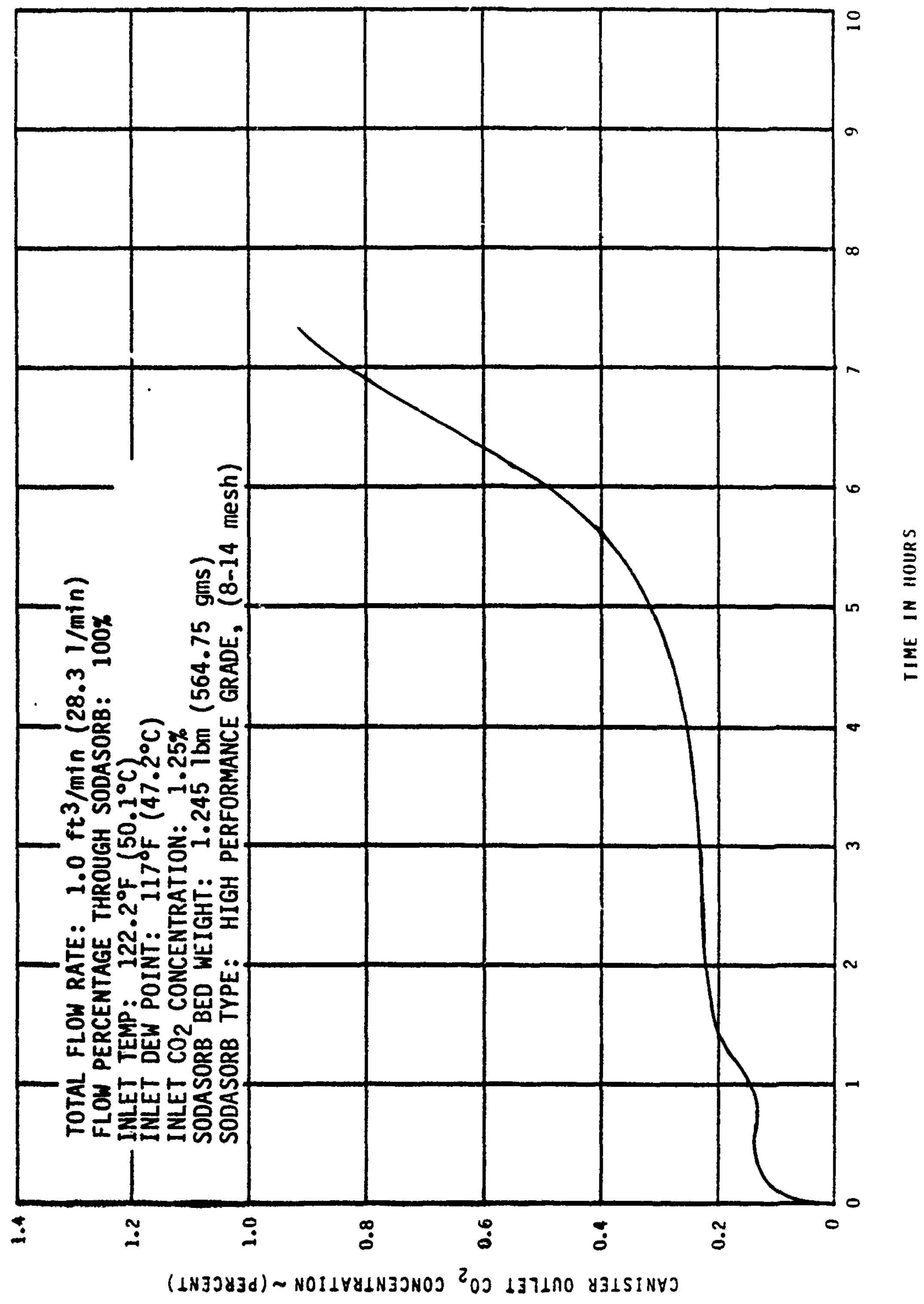
FIGURE 55
SODASORB PERFORMANCE
TEST M1



TOTAL FLOW RATE: 1.0 ft^3/min (28.3 l/min)
FLOW PERCENTAGE THROUGH SODASORB: 100%
INLET TEMP: 120.4°F (49.1°C)
INLET DEW POINT: 117.1°F (47.3°C)
INLET CO_2 CONCENTRATION: 1.75%
SODASORB BED WEIGHT: 1.25 lbm (565.70 gms)
SODASORB TYPE: HIGH PERFORMANCE GRADE, (8-14 mesh)

FIGURE 56

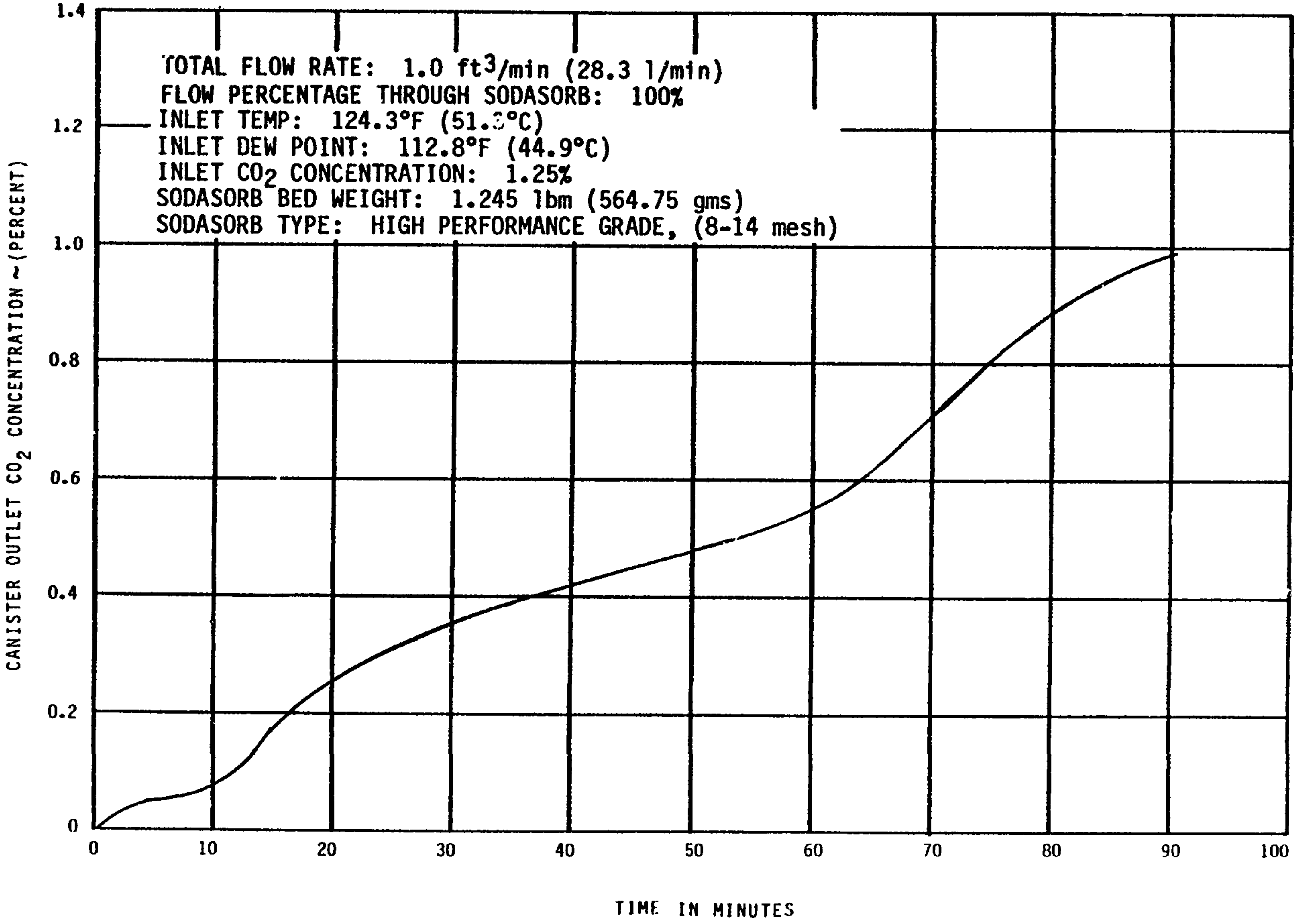
SODASORB PERFORMANCE
TEST N



TOTAL FLOW RATE: 1.0 ft^3/min (28.3 l/min)
FLOW PERCENTAGE THROUGH SODASORB: 100%
INLET TEMP: 122.2°F (50.1°C)
INLET DEW POINT: 117°F (47.2°C)
INLET CO_2 CONCENTRATION: 1.25%
SODASORB BED WEIGHT: 1.245 lbm (564.75 gms)
SODASORB TYPE: HIGH PERFORMANCE GRADE, (8-14 mesh)

FIGURE 57

SODASORB PERFORMANCE
TEST N1



TOTAL FLOW RATE: 1.0 ft^3/min (28.3 l/min)
FLOW PERCENTAGE THROUGH SODASORB: 100%
INLET TEMP: 124.3°F (51.3°C)
INLET DEW POINT: 112.8°F (44.9°C)
INLET CO_2 CONCENTRATION: 1.25%
SODASORB BED WEIGHT: 1.245 lbm (564.75 gms)
SODASORB TYPE: HIGH PERFORMANCE GRADE, (8-14 mesh)

FIGURE 58

SODASORB PERFORMANCE
TEST 0

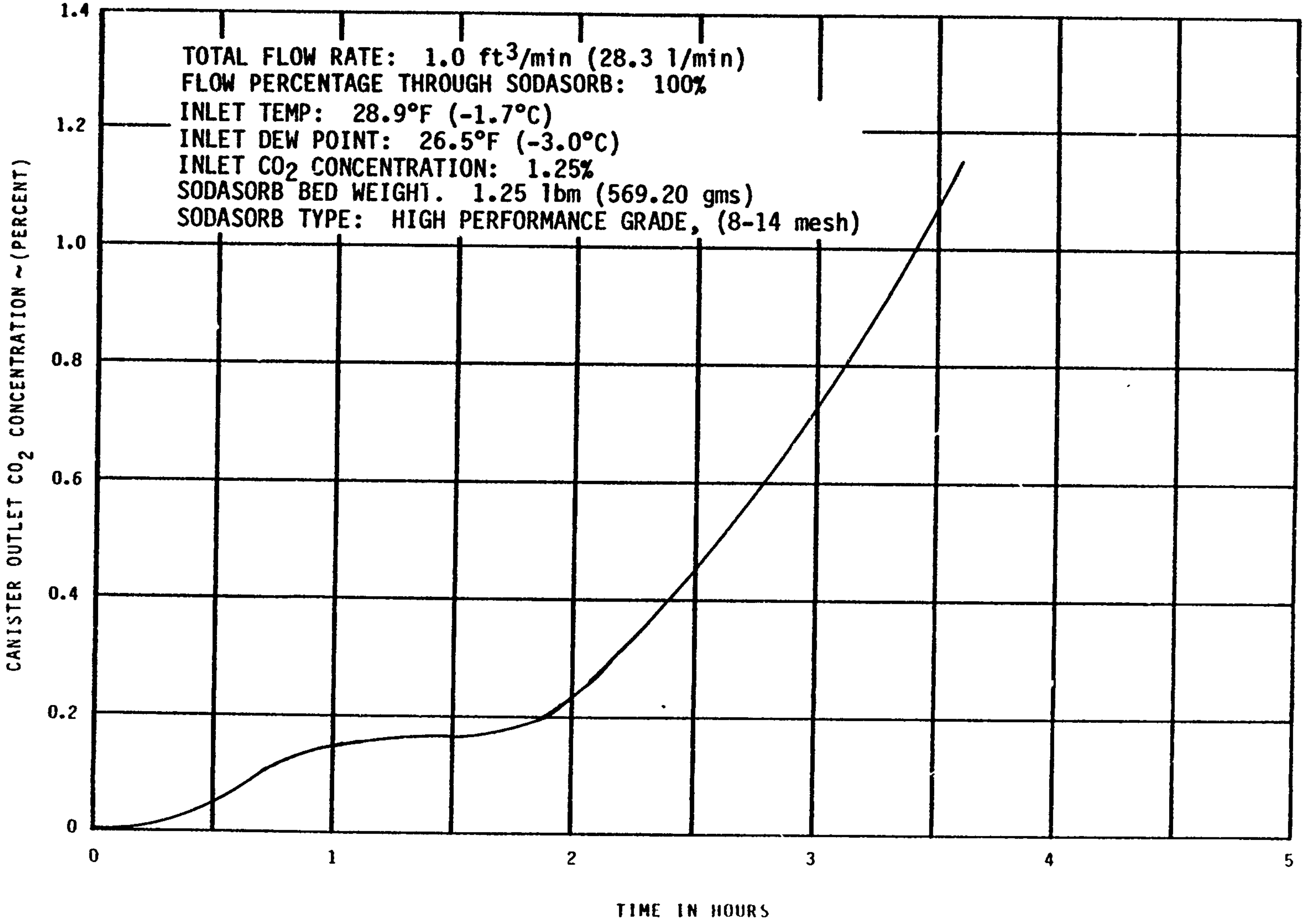


FIGURE 59

SODASORB PERFORMANCE
TEST 0_1

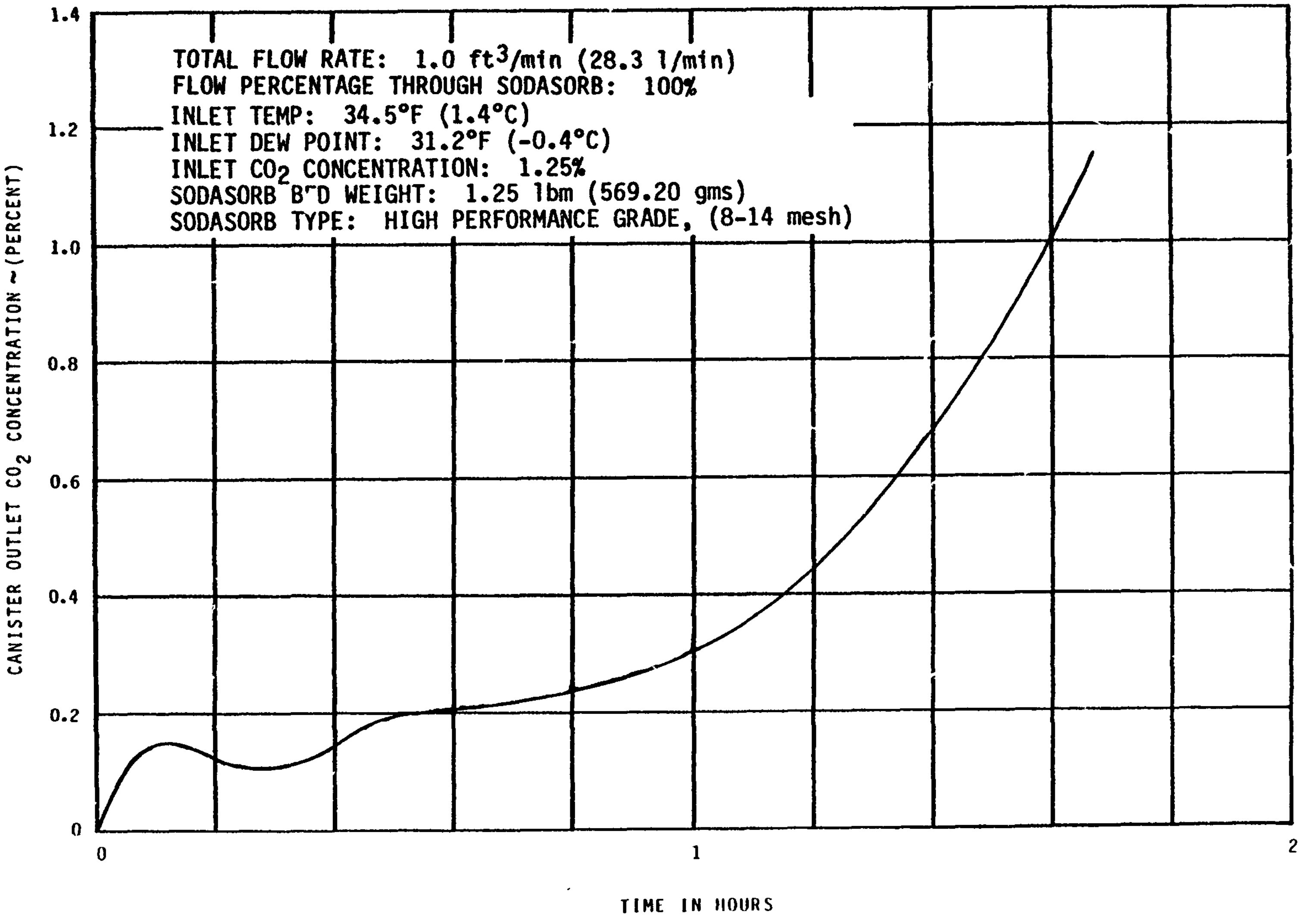
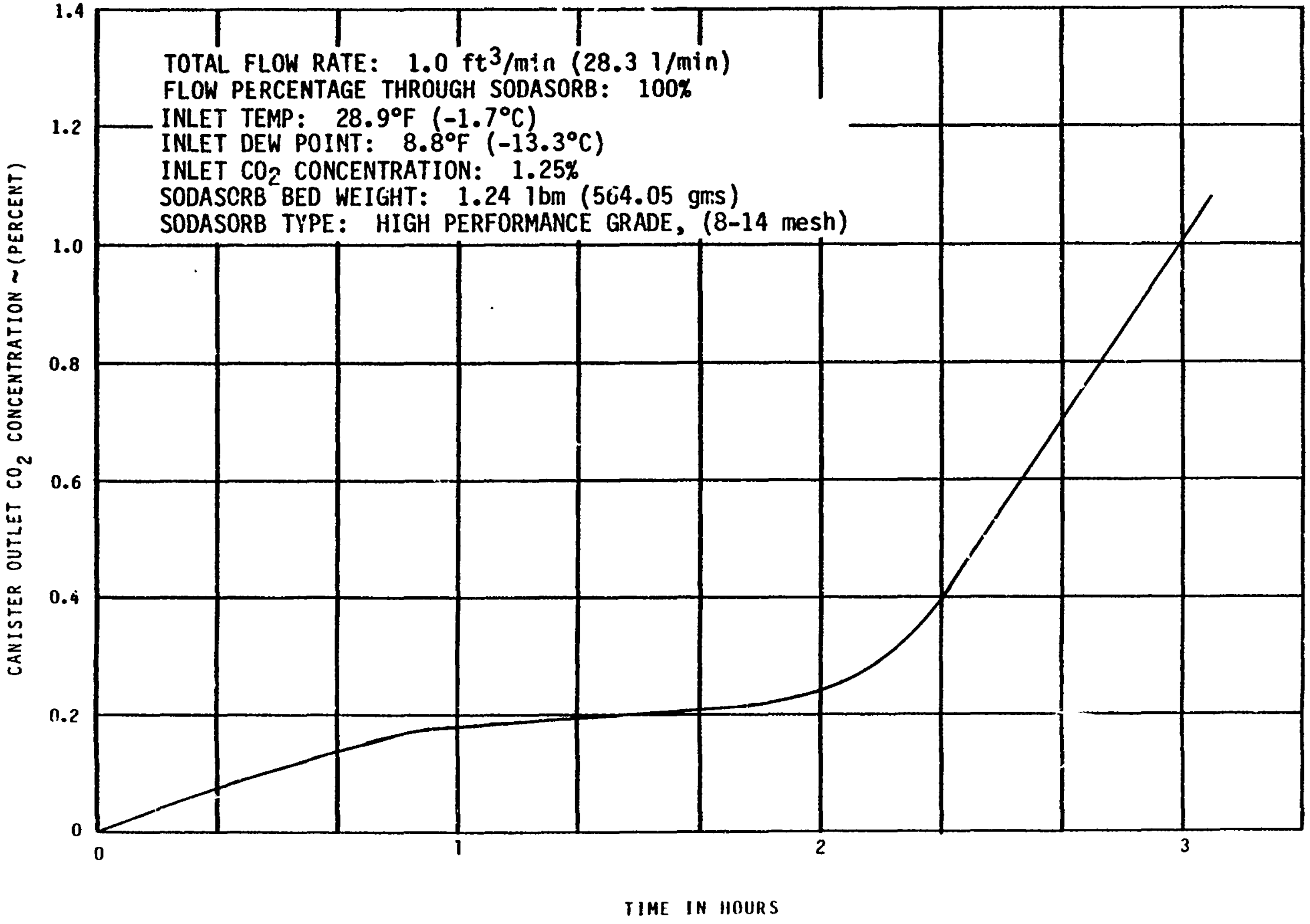


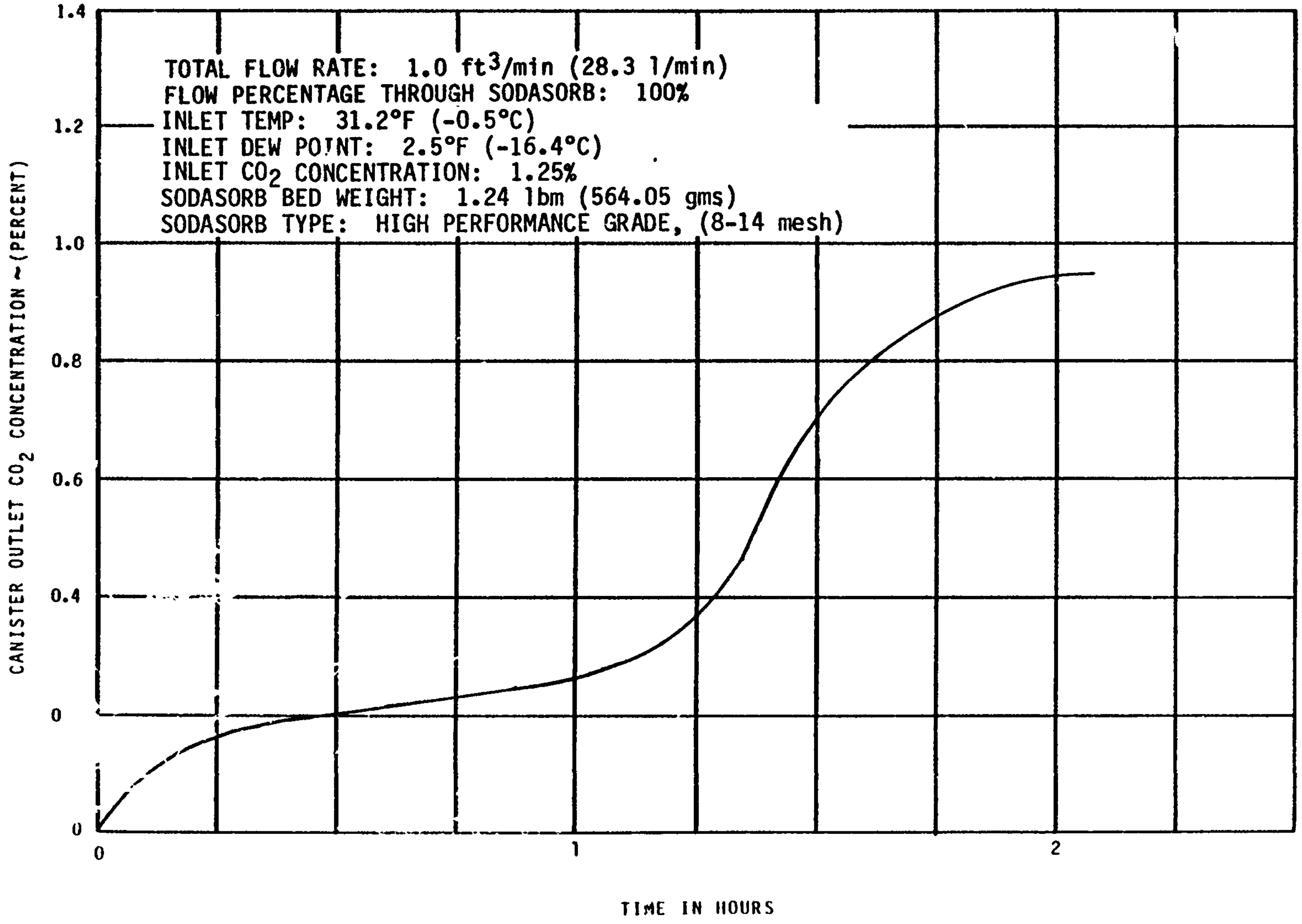
FIGURE 60

SODASORB PERFORMANCE
TEST P



TOTAL FLOW RATE: 1.0 ft^3/min (28.3 l/min)
FLOW PERCENTAGE THROUGH SODASORB: 100%
INLET TEMP: 28.9°F (-1.7°C)
INLET DEW POINT: 8.8°F (-13.3°C)
INLET CO_2 CONCENTRATION: 1.25%
SODASORB BED WEIGHT: 1.24 lbm (564.05 gms)
SODASORB TYPE: HIGH PERFORMANCE GRADE, (8-14 mesh)

FIGURE 61
SODASORB PERFORMANCE
TEST P1



TOTAL FLOW RATE: 1.0 ft^3/min (28.3 l/min)
FLOW PERCENTAGE THROUGH SODASORB: 100%
INLET TEMP: 31.2°F (-0.5°C)
INLET DEW POINT: 2.5°F (-16.4°C)
INLET CO_2 CONCENTRATION: 1.25%
SODASORB BED WEIGHT: 1.24 lbm (564.05 gms)
SODASORB TYPE: HIGH PERFORMANCE GRADE, (8-14 mesh)

FIGURE 62
SODASORB PERFORMANCE
TEST Q

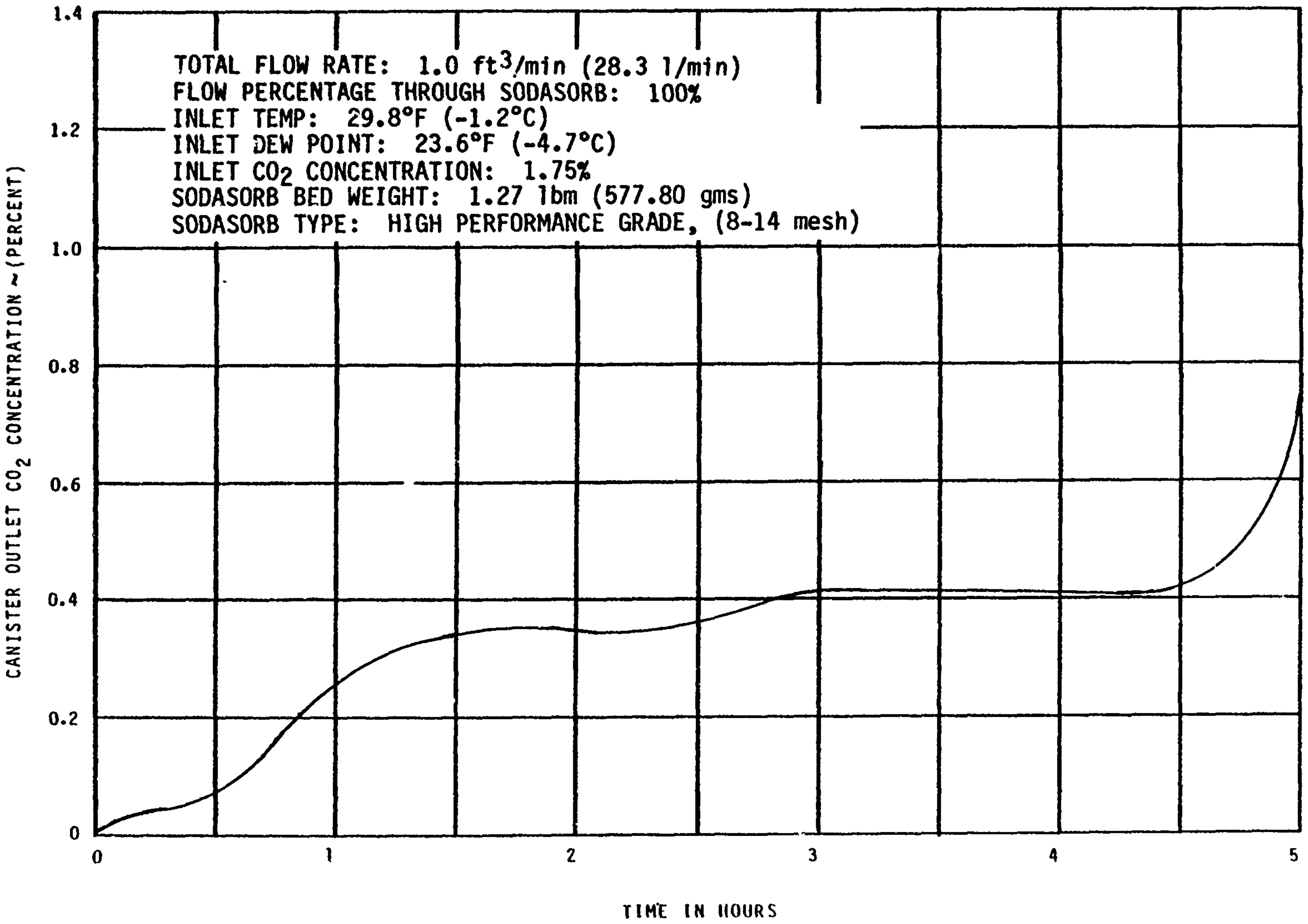


FIGURE 63

SODASORB PERFORMANCE

TEST R

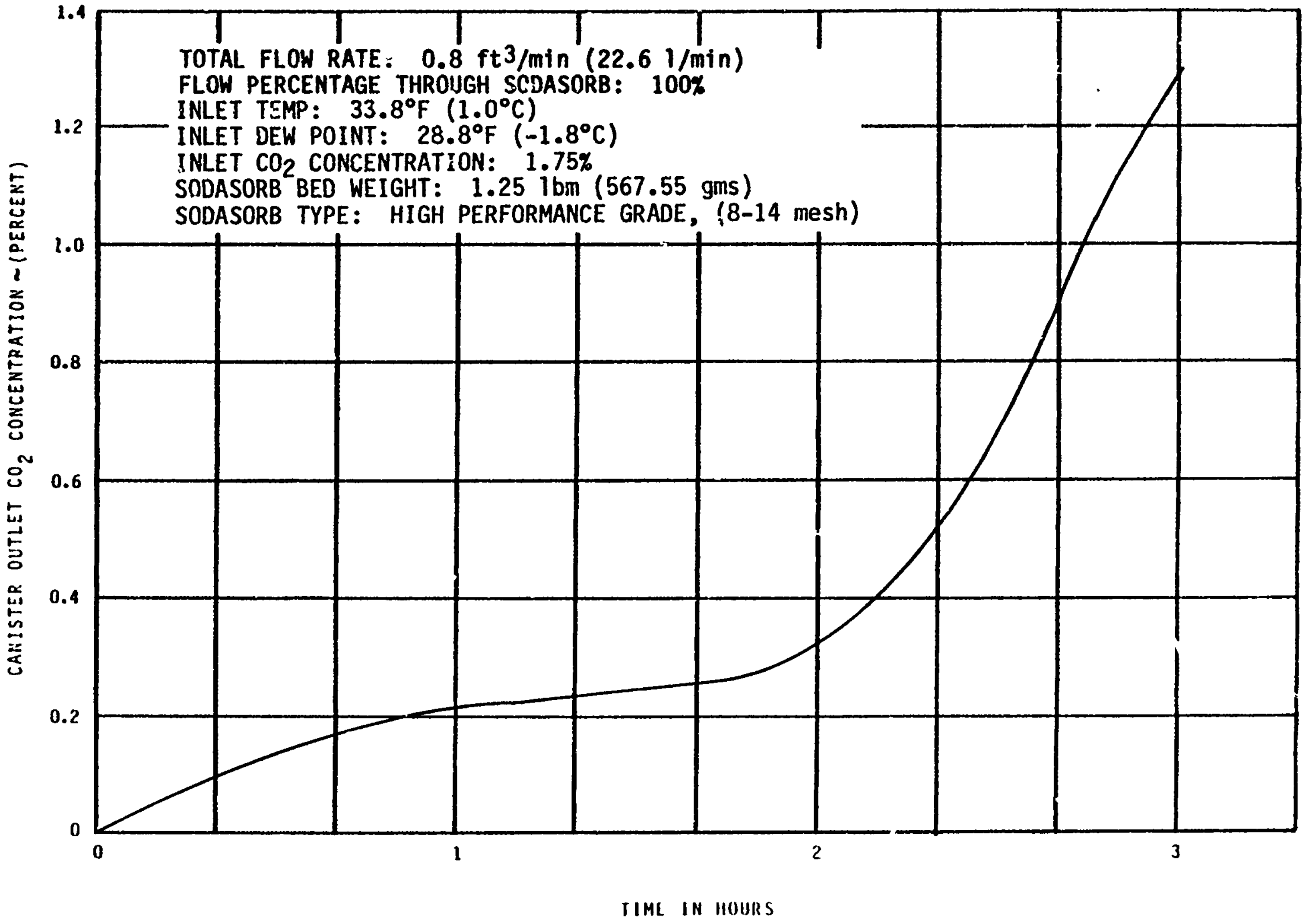
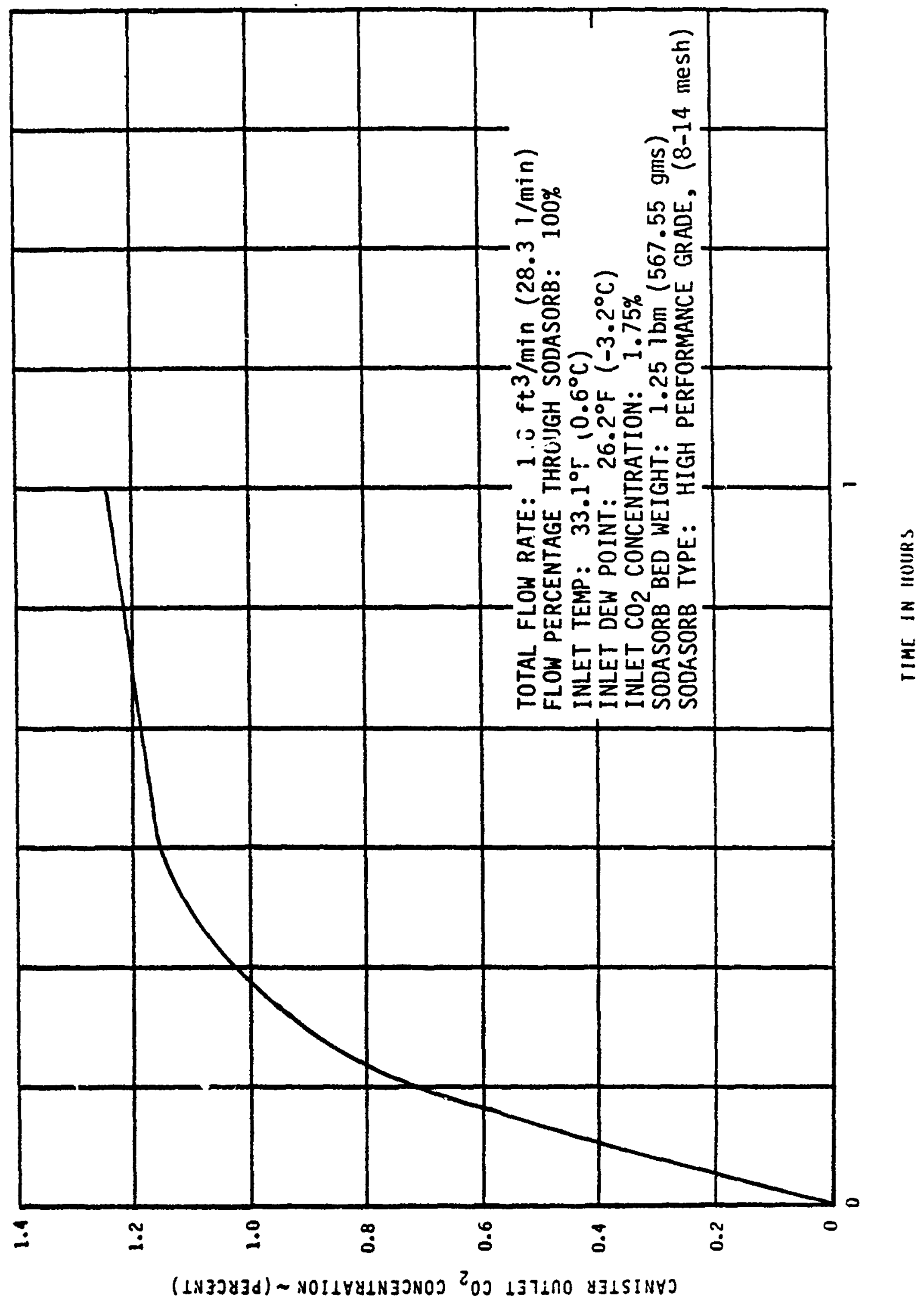


FIGURE 64
SODASORB PERFORMANCE
TEST R_1



TOTAL FLOW RATE: 1.0 ft^3/min (28.3 l/min)
FLOW PERCENTAGE THROUGH SODASORB: 100%
INLET TEMP: 33.1°F (0.6°C)
INLET DEW POINT: 26.2°F (-3.2°C)
INLET CO_2 CONCENTRATION: 1.75%
SODASORB BED WEIGHT: 1.25 lbm (567.55 gms)
SODASORB TYPE: HIGH PERFORMANCE GRADE, (8-14 mesh)

FIGURE 65
SODASORB PERFORMANCE
TEST S

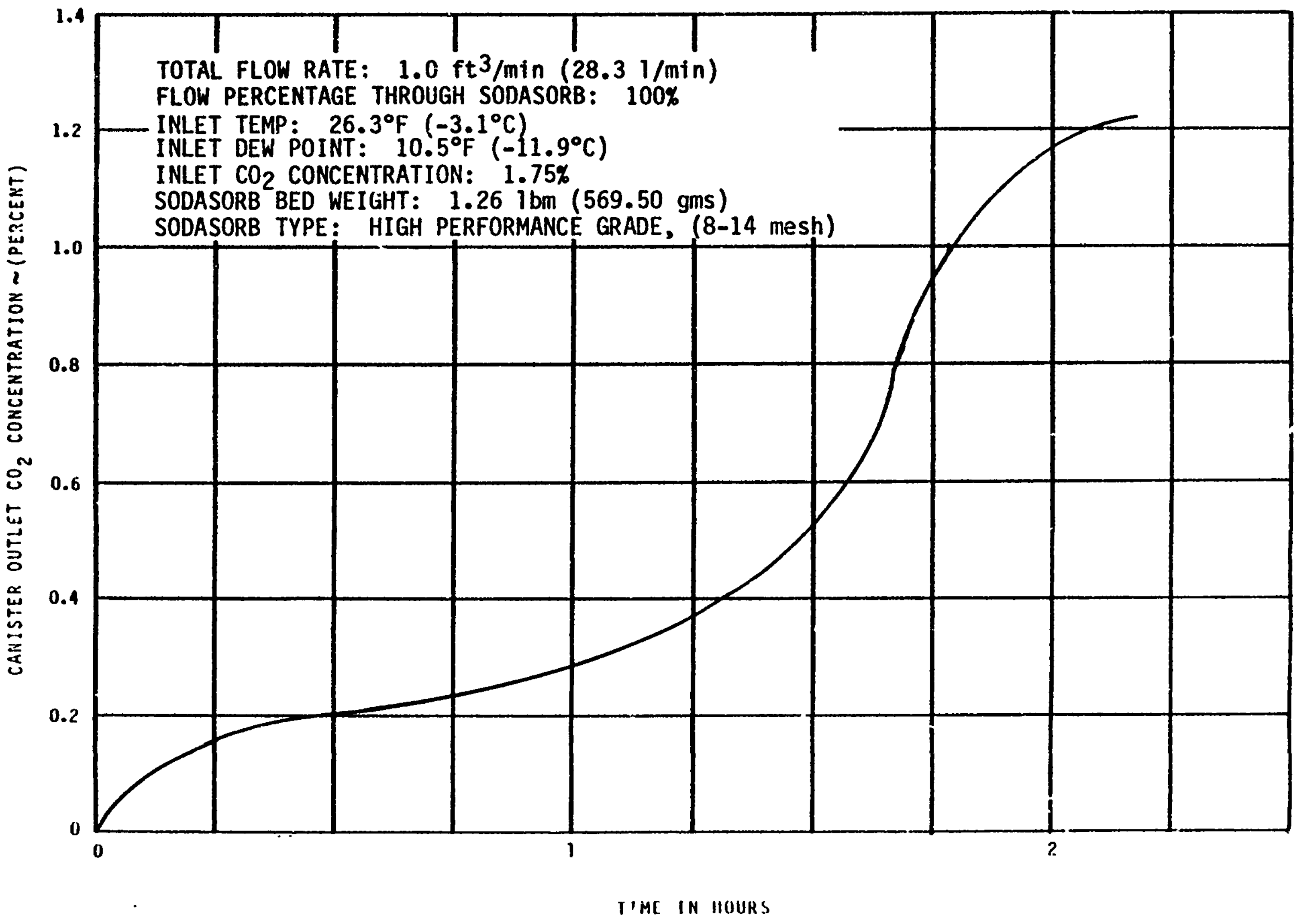
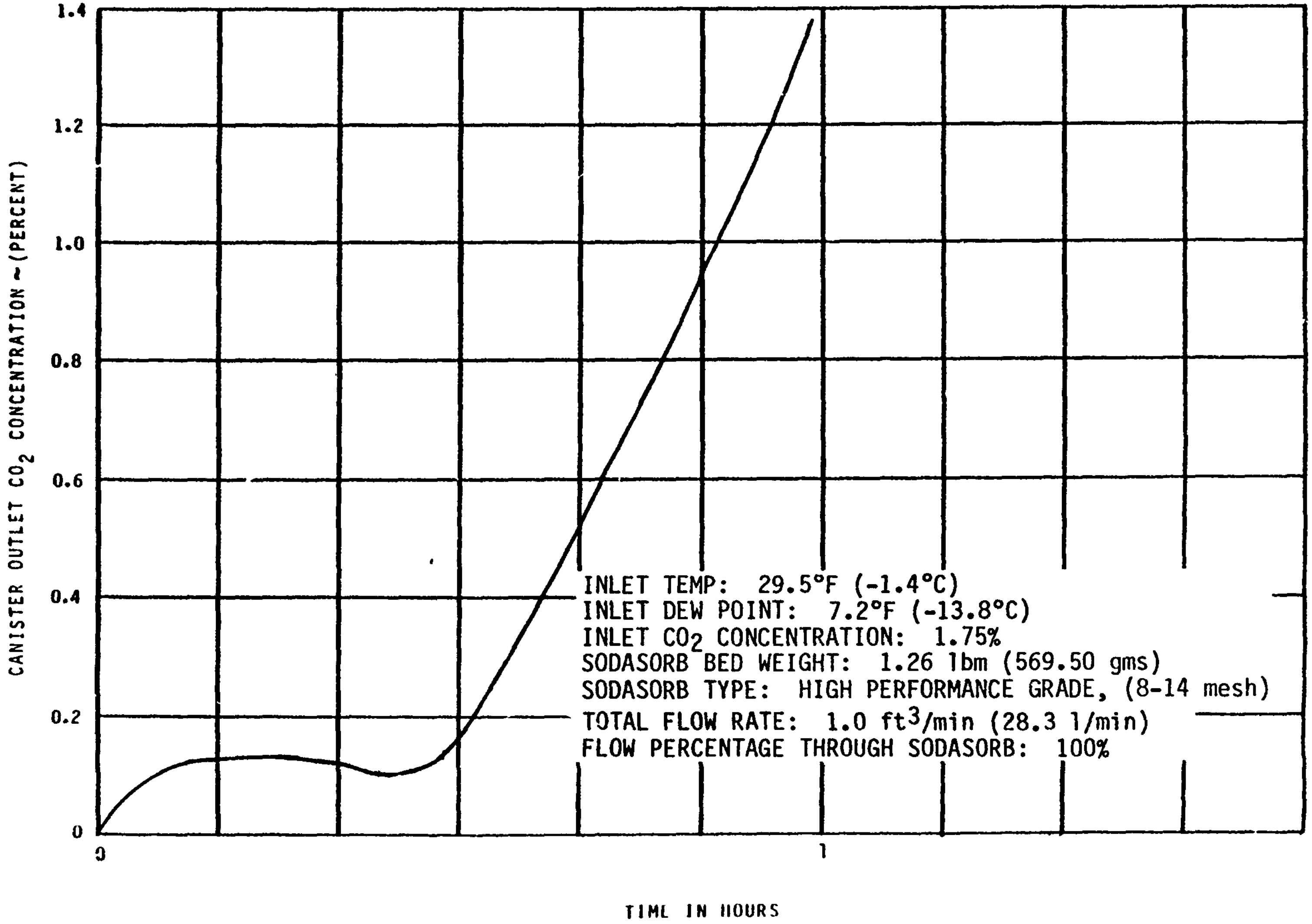


FIGURE 66

SODASORB PERFORMANCE
TEST S1



INLET TEMP: 29.5°F (-1.4°C)
INLET DEW POINT: 7.2°F (-13.8°C)
INLET CO_2 CONCENTRATION: 1.75%
SODASORB BED WEIGHT: 1.26 lbm (569.50 gms)
SODASORB TYPE: HIGH PERFORMANCE GRADE, (8-14 mesh)
TOTAL FLOW RATE: 1.0 ft^3/min (28.3 l/min)
FLOW PERCENTAGE THROUGH SODASORB: 100%

FIGURE 67

SODASORB PERFORMANCE
TEST T

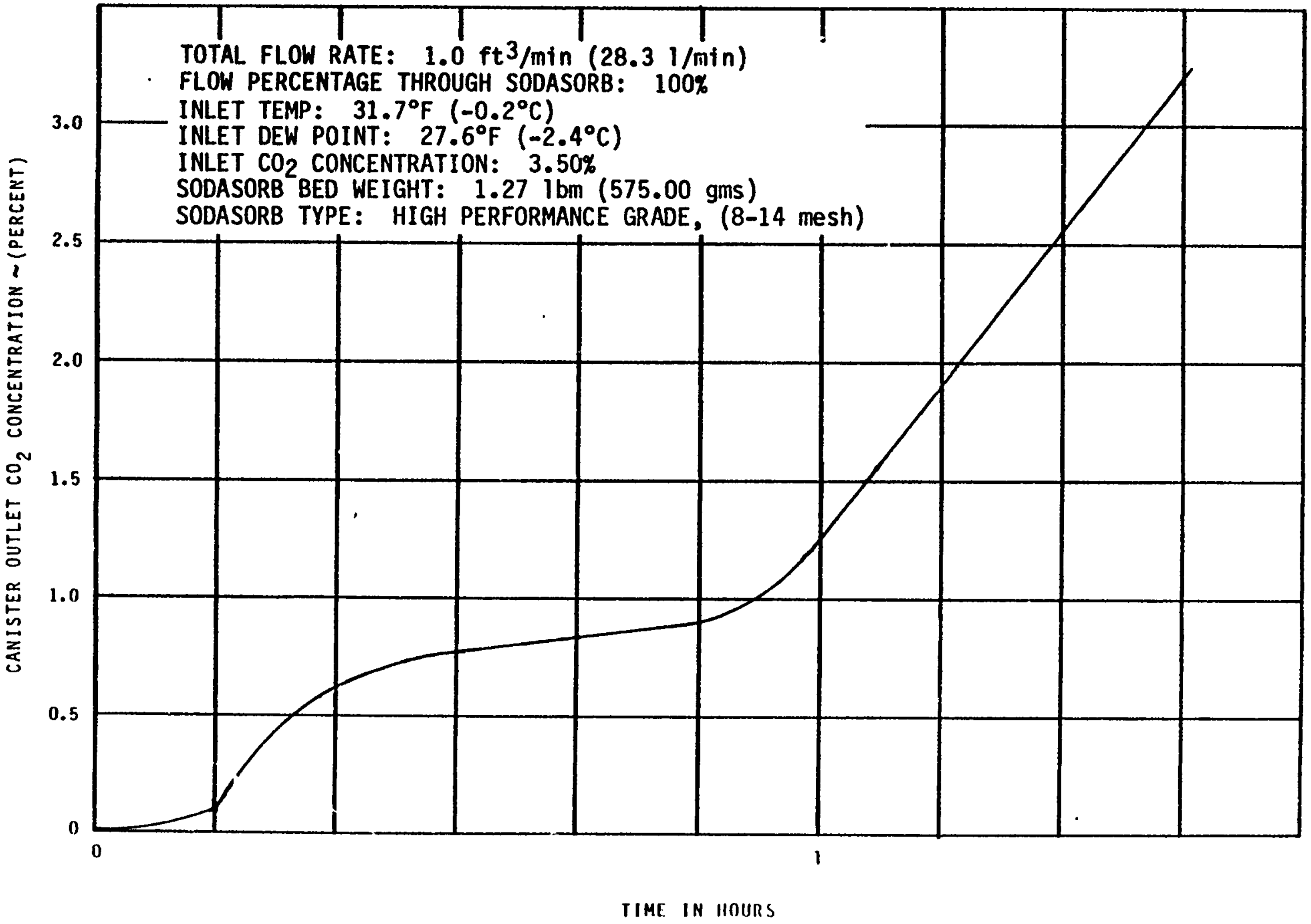


FIGURE 68
SODASORB PERFORMANCE
TEST T_1

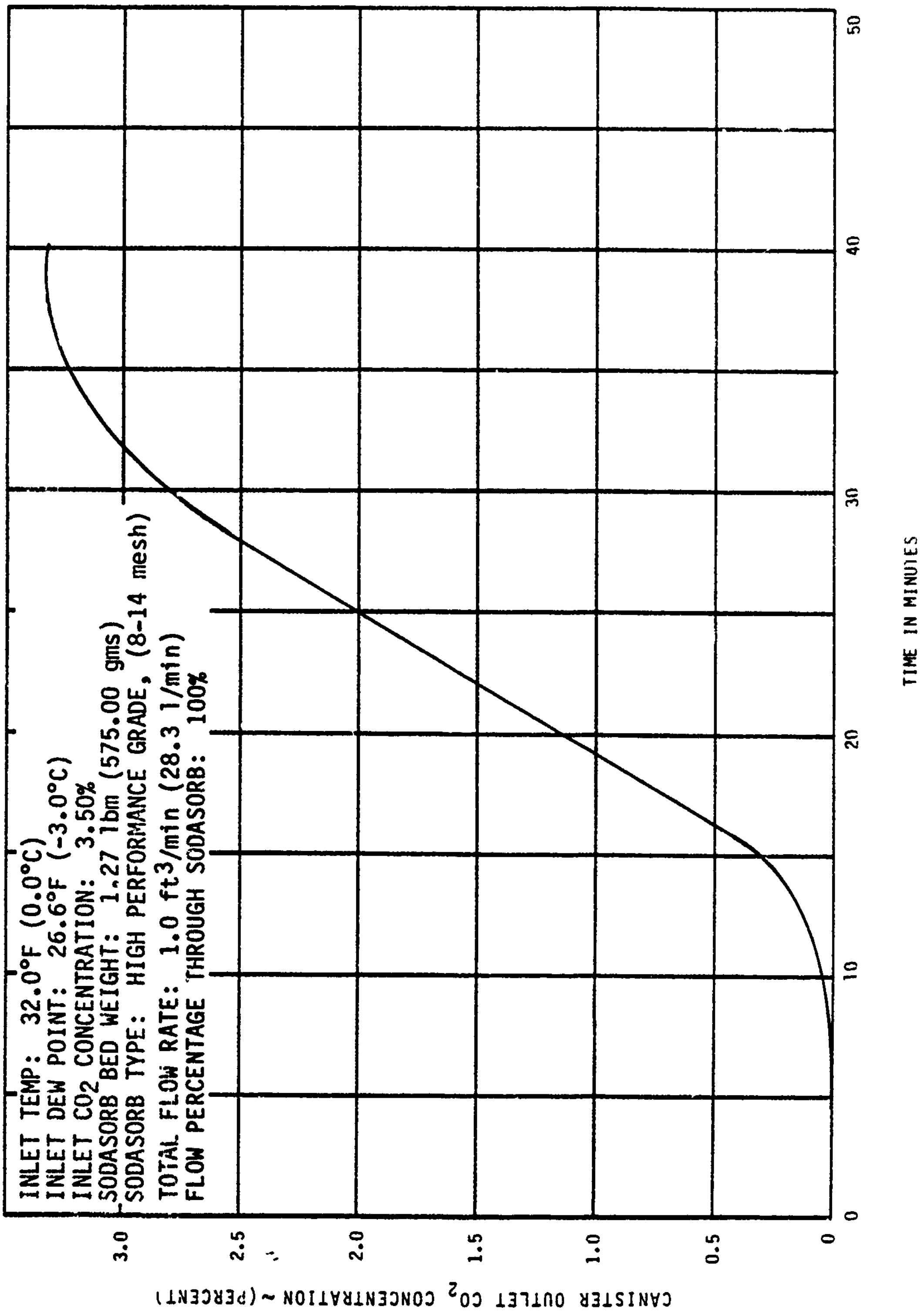
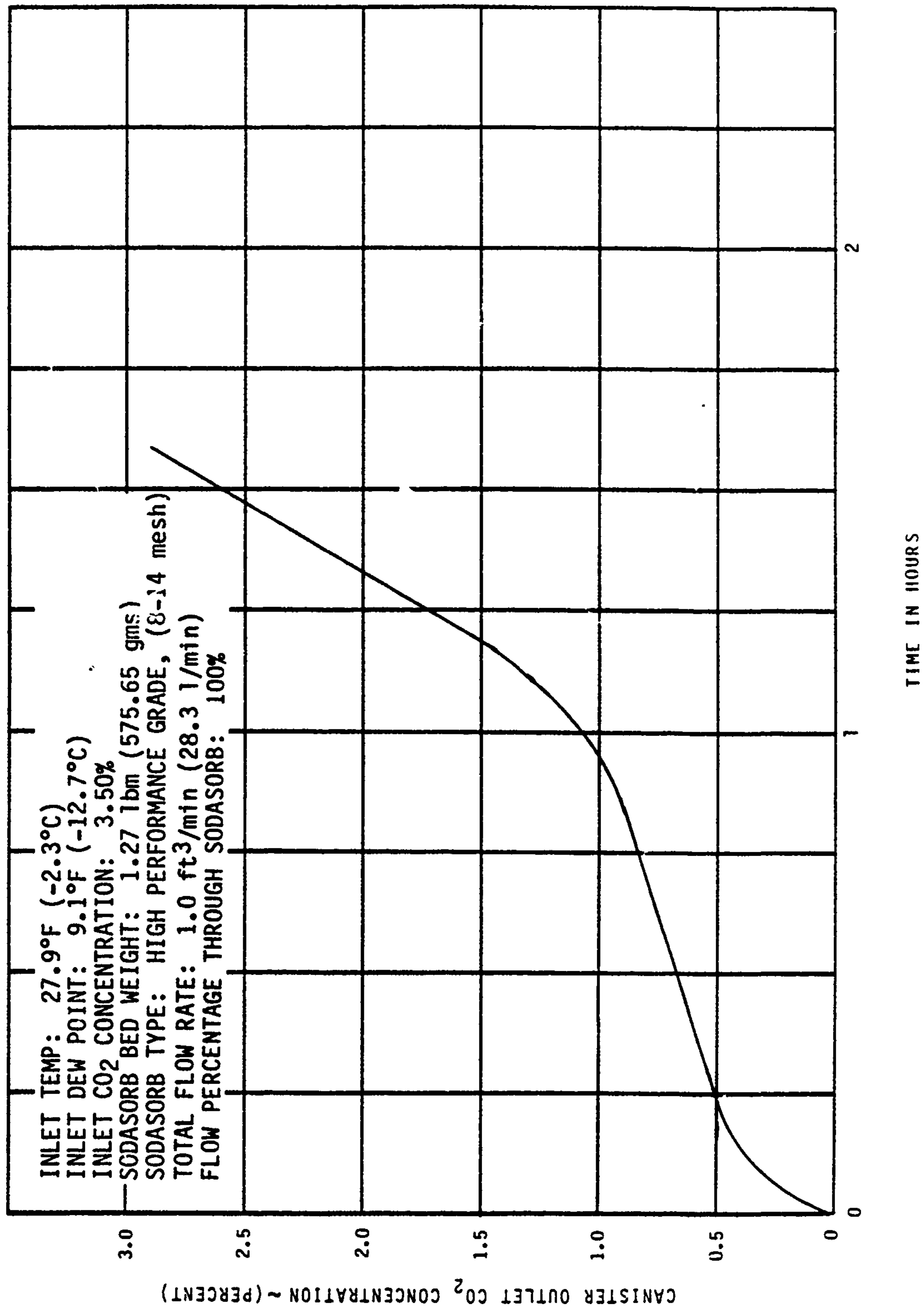

INLET TEMP: 32.0°F (0.0°C)
INLET DEW POINT: 26.6°F (-3.0°C)
INLET CO_2 CONCENTRATION: 3.50%
SODASORB BED WEIGHT: 1.27 lbm (575.00 gms)
SODASORB TYPE: HIGH PERFORMANCE GRADE, (8-14 mesh)
TOTAL FLOW RATE: 1.0 ft^3/min (28.3 l/min)
FLOW PERCENTAGE THROUGH SODASORB: 100%

FIGURE 69
SODASORB PERFORMANCE
TEST U



INLET TEMP: 27.9°F (-2.3°C)
INLET DEW POINT: 9.1°F (-12.7°C)
INLET CO_2 CONCENTRATION: 3.50%
SODASORB BED WEIGHT: 1.27 lbm (575.65 gms)
SODASORB TYPE: HIGH PERFORMANCE GRADE, (8-14 mesh)
TOTAL FLOW RATE: 1.0 ft^3/min (28.3 l/min)
FLOW PERCENTAGE THROUGH SODASORB: 100%

FIGURE 70

SODASORB PERFORMANCE
TEST U1

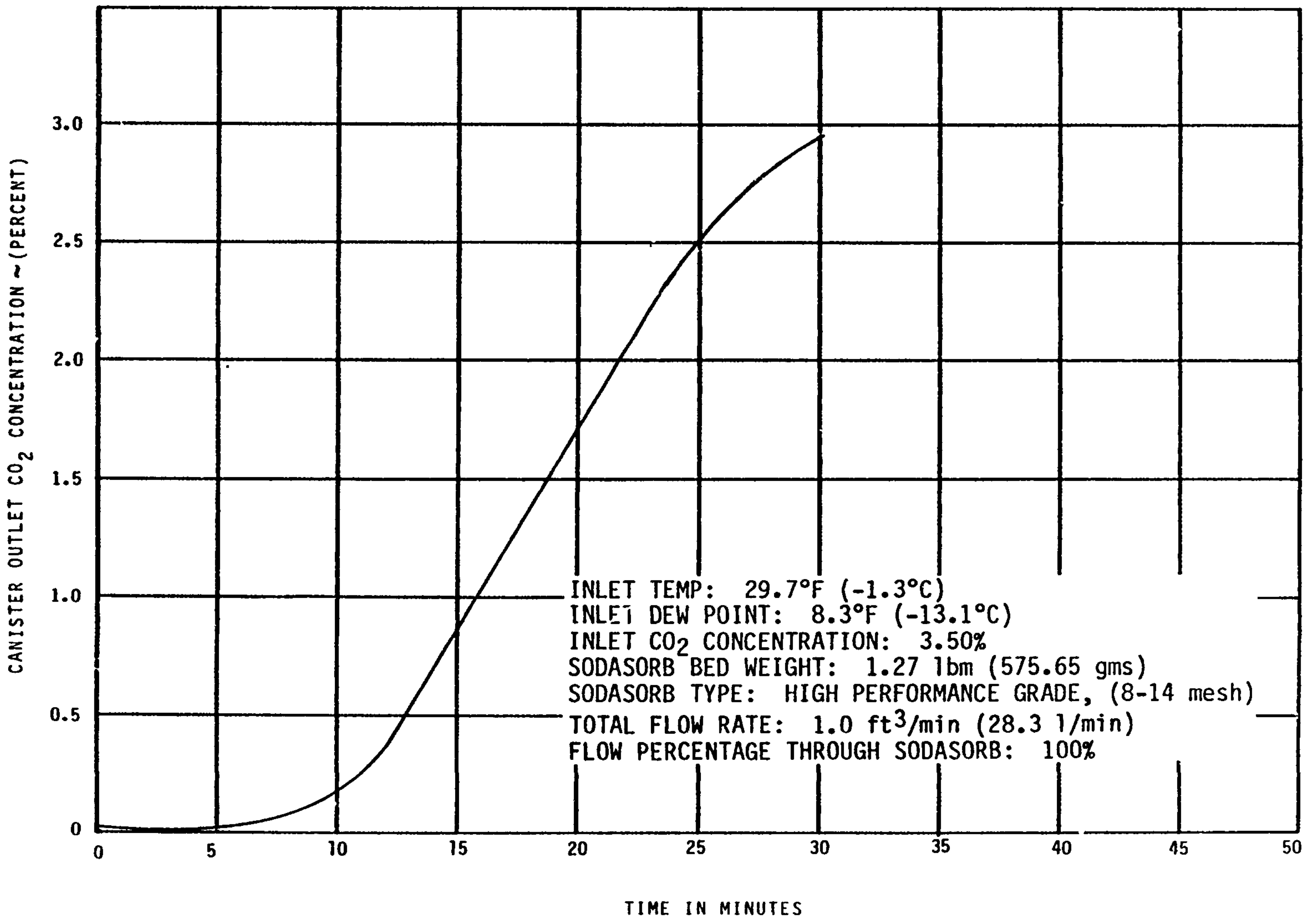
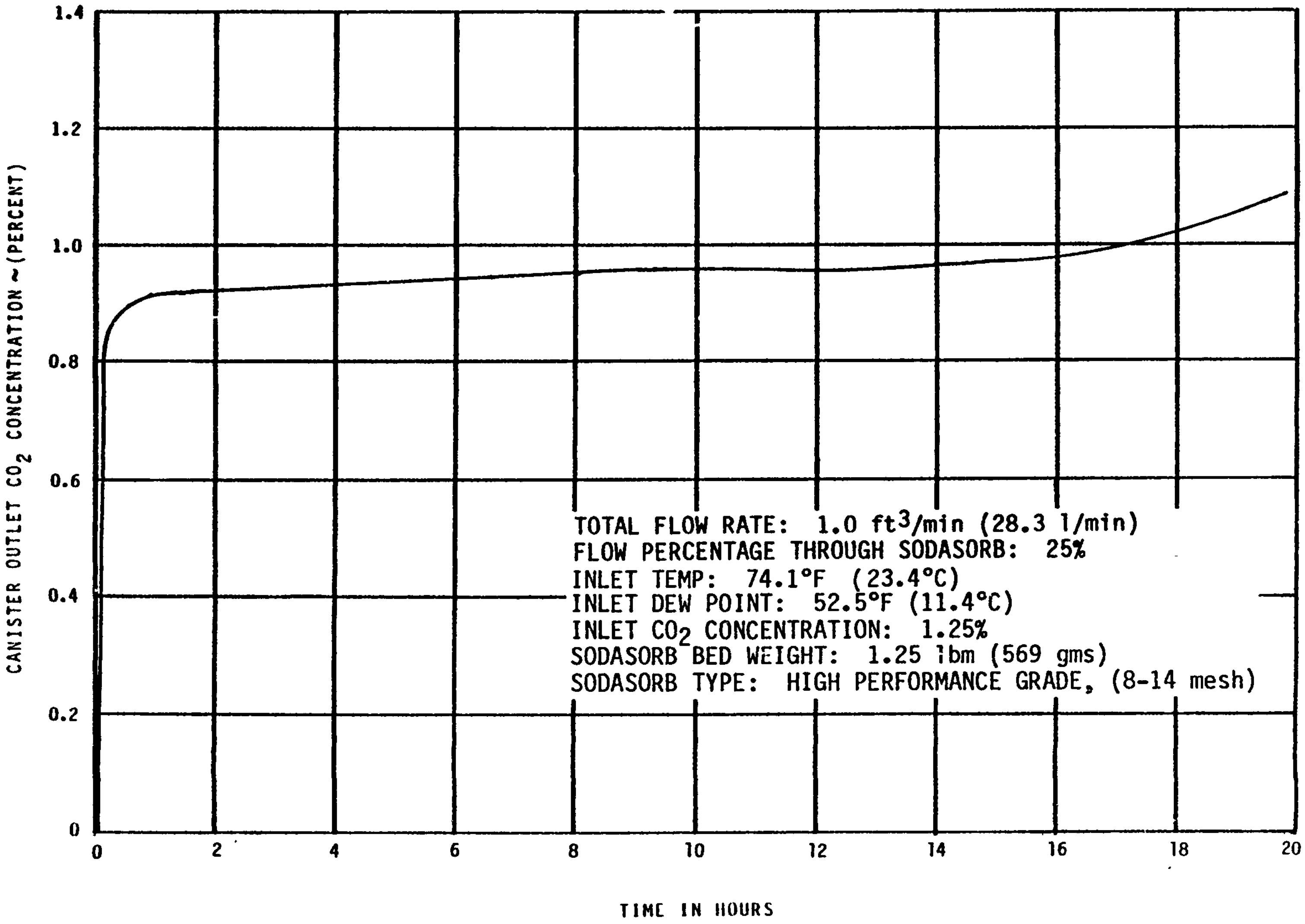


FIGURE 71

SODASORB PERFORMANCE
TEST V



TOTAL FLOW RATE: 1.0 ft^3/min (28.3 l/min)
FLOW PERCENTAGE THROUGH SODASORB: 25%
INLET TEMP: 74.1°F (23.4°C)
INLET DEW POINT: 52.5°F (11.4°C)
INLET CO_2 CONCENTRATION: 1.25%
SODASORB BED WEIGHT: 1.25 lbm (569 gms)
SODASORB TYPE: HIGH PERFORMANCE GRADE, (8-14 mesh)

Appendix A

Letter from the National Institute for Occupational Safety and Health, NIOSH, Concerning Review of the Preliminary Phase Test Results

DEPARTMENT OF HEALTH & HUMAN SERVICES

SVHSER 8918
Public Health Service

Centers for Disease Control
National Institute for Occupational
Safety and Health - ALOSH
944 Chestnut Ridge Road
Morgantown, WV 26505

August 1, 1983

Mr. Art Colling
United Technologies
Hamilton Standard
Windsor Locks, Connecticut 06096

Reference: Your letter of July 1, 1983

Dear Mr. Colling:

I have read and reviewed the "Preliminary Phase Test and Feasibility Design Report" and "Test Specification for the Feasibility Evaluation of a Reusable Contaminant Filter Canister for Use as an Oxygen Breathing Apparatus Trainer".

Your test rig set up is similar in concept to the test set up used by NIOSH in testing air purifying canisters against carbon monoxide. Your test specifications are about the same as NIOSH's and in some cases even more stringent. Overall, your test program is very good.

Sincerely yours,

Christopher Coffey

Christopher Coffey
Supervisory Chemist
Air Purifying Respirator Section
Testing and Certification Branch
Division of Safety Research