

INVESTIGATION OF POLYURETHANE FOAM
FOR AIRCRAFT FUEL SYSTEM APPLICATIONS

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AERONAUTICAL SYSTEMS DIVISION
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FOREWORD

This report was prepared by Monsanto Research Corporation, Dayton, Ohio, on Air Force Contract Nr. AF 33(615)-5424, "Investigation of Cellular Packing Material for Application to Aircraft Fuel Systems." Additional contracts under which portions of this work were completed were Nrs. AF 33(615)-1317, AF 33(615)-3277, and AF 33(615)-3880. Work was administered by the ASD Deputy for Limited War, with technical support provided by the Systems Engineering Group and the Air Force Aero Propulsion Laboratory, both of the Research and Technology Division, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio. Project engineers were Messrs. G. W. Gandee of AFAPL and T. O. Reed of SEG. Engineering support was provided by J. R. Fultz and P. C. Linder of AFAPL, and Lt. L. Mahood and D. C. Wight of SEG.

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This technical report has been reviewed and is approved.



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ABSTRACT

The objective of this project was to investigate a low density interconnected, 10 pore to the inch, cellular polyurethane ester foam under extremes of environmental conditions for use as packing material for fuel system applications. A variety of simulated aircraft and environmental tests were conducted which established that the foam and the various hydrocarbon fuels are compatible. Investigated were JP-4, JP-5, Avgas, Type I and III test fluids. JP-4 fuel retention at ambient conditions was measured at 0.95 volume percent, and 1.1 volume percent for Avgas.

Static exposure of the foam and fluids for 28 days at 158°F (110°F for Avgas) and at -65°F causes no significant changes in compression load deflection, tensile strength, or elongation. A simulated field exposure consisting of a cyclic temperature environment (70° to 130°F) and high humidity did not adversely affect the foam. Tumbling tests on foam in fuel at -65°F resulted in slight weight loss due to fragmentation; however, similar testing in the absence of fuel to cushion the foam resulted in appreciable foam fragmentation. Washing action of the fluids removed particulate matter from the matrix of the foam. This washing also extracted a very low percentage of an alkyl phthalate ester from the foam which had a tendency to increase the gum content of the fuel.

The foam material appeared to have no corrosive effects on two aluminum alloys; MIL-C-6529 corrosion preventive oil remained effective and had no detrimental effect on the foam.

The various parameters affecting vent icing in a foam filled tank were studied. Each parameter, including void area, foam condition, inlet air velocity, as well as inlet air and foam temperatures, was systematically varied throughout realistic extremes and vent icing conditions measured. Conditions favoring vent icing were developed as well as tank vent voiding criteria for the foam.

The temperature-pressure relationship across the pressure chamber of the foam filled dynamic flow tester was not significantly affected over the range of fuel velocities and temperatures tested for either JP-4 or Avgas.

Abstract - Cont'd

Foam increased the pressure drop readings across the entire flow range studied with JP-4 causing somewhat greater drop than Avgas, with neither maximum increase considered significant. In these tests the foam was unaffected but tended to filter out system contamination.

Pump down tests were run on a foam filled tank and it was shown that the usable quantity of fuel is dependent on the vertical velocity through the foam. Vertical velocities below 0.50 feet/minute were shown to be essentially unaffected. Low temperatures (-65°F) did not affect fuel transfer rates from a foam filled tank.

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I. INTRODUCTION

The Air Force is considering use of an open-celled polyurethane foam (10 pores/inch) to minimize excessive fuel sloshing during flight. Prior to Air Force acceptance, the physical stability of such a foam in an aircraft fuel tank and the effect on the chemical composition of JP-4 and other fuels stored in contact with the foam must be established. The evaluation methods selected for this program encompassed the practical parameters that might be encountered and as far as possible simulated the most severe ones likely in actual conditions of field operation.

The physical properties of the foam were established and monitored during the program by means of compression load deflection, tensile strength, percentage elongation, and volume change. For chemical stability, infrared measurements of the exposed fuels were used. Foam solubility in the test fluids was also determined by infrared measurement. Extensive physical tests of foam stability under laboratory conditions of extremes of temperature and under mechanical motion (to cause attrition) were made.

To more nearly simulate flight conditions, the effect at fuel tank vents caused by saturated air at various temperatures was explored. To perform these evaluations, extremes of air and foam temperatures and air velocities were observed by passage through 2-foot cubes of foam. Another factor investigated was that of fuel flow through a sizeable plug of foam placed in a loop to determine possible fragmentation and/or hindrance of flow. A further flight factor studied was that of pump-down characteristics at ambient and -65°F conditions. Cavitation and hold-up of fuel caused by rapid pumping from a 117-gallon reservoir with an integral mounted aircraft boost pump were investigated. In all cases, the conditions selected were ambient and extremes encountered during aircraft flight profiles.

II. SUMMARY AND CONCLUSIONS

The foam packing consisted of a network of interconnecting pores by elimination of cell walls to provide a skeletal network. The foam was produced to have 10 pores per inch, to have a density of 2 pounds per cubic foot, and to possess physical properties which permit its handling and usage in either a dry or fuel-wetted condition.

1. EXPOSURE EFFECTS

Fluid retention by the foam was experimentally measured to be 0.95 volume percent with JP-4, 1.1 volume percent with Avgas, and 4.3 volume percent with water. No appreciable changes in compression load deflection, tensile strength, or elongation were noted after exposure to five different hydrocarbon fuels for 28 days at 158°F (110°F for Avgas). Exposure to the test fuels in all cases resulted in removal of trace quantities of soluble alkyl phthalate from the foam resulting in an increase in the gum content of the fuels. This condition is reduced after the initial extraction which results in an insignificant effect to the fuel or foam.

Compression and freezing at low temperatures had minor effects on the foam and should not adversely affect its usage. Exposure at 180°F reduced the foam's compression set and had only slight effect on compression load deflection.

2. STABILITY

Testing of the combination of foam and fuel at low temperatures by either static or slosh conditions did not show any significant changes in the physical properties of the foam. Tumbling of fuel-wetted foam resulted in slight fragmentation of the material and dry tumbling of the foam resulted in a significant deterioration of the material at low temperatures. From these results, it appears that the material must be firmly secured (packed) in the tank to avoid material fragmentation due to movement at low temperatures.

Comparison of the current polyester base material with an experimental polyether base foam revealed that the latter was more resistant to the presence of water or high humidity conditions. (This experimental ether foam of the desired pore size is not available on a production basis.)

3. CONTAMINATION

Evaluation of the foam revealed that there is an adherent contamination entrained or trapped within the matrix of the material. Washing action of the various test fluids tended to remove this contaminant which consisted of foam particles, fibers, metal filings, rust scale and organic char and dust. The foam particles were generally less than 10% of the total recovered contaminant, indicating that most of the contamination within the foam was foreign to the material. Sources of the contaminant are believed to be the processing and handling of the material prior to final usage.

Several techniques were evaluated in an attempt to develop a quantitative method for measuring the particulate contaminant present in the foam. All of these techniques, static fill and drain, slosh/compression, and compression only, appeared to have shortcomings and no final method could be established. Most promising technique was the slosh/drain cycling of a foam sample in a separatory funnel, however, further analysis work will be required before it can be adopted as an acceptable quality control test.

4. CORROSION EFFECTS

The material did not appear to have any corrosive properties in contact with typical aircraft alloys. Although slight corrosion was noted on the test panels in contact with foam, their performance was equal to or better than the control panels without foam. Foam wetted with MIL-C-6529 corrosion preventive oil indicated even less corrosion and the foam was not affected by the oil.

5. ENVIRONMENTAL EFFECTS

A series of cyclic exposure tests (70°F to 135°F) run on the fuel-wetted foam at high humidity conditions resulted in no apparent degradation to foam properties for exposures up to 240 hours. Similar exposures of the foam to a methyl Cellosolve-water mixture (25%), representative of fluid in an aircraft sump, also showed no effect on the foam properties.

Parameters affecting vent icing in a foam filled tank were studied. The observed icing on the foam appeared to be very similar to that noted in a similar type stainless steel flame

arresting screen; however, complete icing or flow restriction was never obtained under any extreme flight conditions. Vent inlet voiding of the foam was shown to eliminate any possibility of complete flow restriction and use criteria for voiding was defined for fuel tank applications. Conditions found which favor vent ice formation include maximum air flow for long durations, saturated air below 25°F, and foam temperature at or below the air temperature to initiate early ice formation. Results also showed that inlet air above 25°F tends to reduce rather than enhance ice formation and once the foam in a tank has been fuel-wetted, it tends to stay wetted regardless of the amount or condition of air imposed on it.

6. FLOW TESTING

Fuel velocities and temperatures achieved in the dynamic flow test did not significantly affect the temperature-pressure drop relationship across the pressure chamber with either JP-4 or Avgas with foam in the chamber. The presence of the foam increased the pressure drop readings across the entire flow range studied, with JP-4 being somewhat higher than Avgas. Maximum increase in pressure drop noted was 3 psi at -75°F and 23 gpm; however, this was considered insignificant. The tests also showed that the foam was essentially unaffected and showed no signs of attrition or deterioration as a result of the various exposures at different flow rates. The foam did, however, tend to act as a filter in that some contamination was collected within the matrix resulting in an increase in weight. No static buildup or discharge could be detected during the various runs.

Pump down tests indicated that the available quantity of fuel that can be transferred from a foam filled tank is dependent upon the vertical velocity of the fuel through the foam. Vertical fuel velocities below 0.50 ft/minute appear to be unaffected by the foam; and no aircraft problems are anticipated because current tank design is such that vertical fuel velocities are generally below this critical value. The percentage of usable fuel that can be transferred appears to be inversely proportional to the pumping rate.

Low temperature had no effect on fuel flow rates and channeling of foam at the bottom of the tank did not change the quantity of fuel transferred.

III. RECOMMENDATIONS

1. Since the extraction of minor levels of alkyl phthalate from the foam can result in an increased gum content of the exposed fuel, attempts should be made to further identify the source of this contaminant and eliminate it from the final foam product.
2. The material should not be allowed to fit loosely in an aircraft tank in order to avoid erosion or fragmentation of the foam at low temperatures.
3. Further studies should be made into the development of a repeatable test procedure for the measurement of particulate contaminant in the foam.
4. Voiding of the foam during tank installation should be maintained in areas such as boost pumps, tank vent outlets, sump areas and any other area of conceivable flow restriction.
5. For maximum utilization of foam around a tank vent, voiding should be restricted to a volume corresponding to a cube with sides three times the inside diameter of the vent.

IV. EXPERIMENTAL DETAILS

1. FOAM PROPERTIES

The polyester foam evaluated was Scott Foam Grade S-103-10-102, Orange, manufactured by Scott Paper Company, Foam Division, Chester, Pennsylvania. Buns of foam 43-1/2" x 81" x 8-1/2" were received and cut to test size. The foam structure consists of a network of interconnected pores, 10 to the inch, by the elimination of cell walls to provide a skeletal network, with an average density of 2 pounds/ft³ (Figure 1).

Test specimens were cut to size with a band saw for compression load deflection and volume change measurements. Tensile strength specimens were cut with a die (Die A, ASTM D 412-62T) from 1/2" thick foam sheets (Figure 2). Compression load deflection specimens with a few noted exceptions were 2" x 2" x 1" and the volume change specimens were 1" cubes. Tensile strength specimens were 6" overall length with 1/2" x 1/2" throat dimensions.

A special series of load vs. compression tests were made at 75°F with 4" foam cubes to establish typical load/compression values. These data are shown in Figure 3.

2. EXPOSURE EFFECTS

2.1 Retention Characteristics

The retention characteristics of the material were determined under a variety of conditions to determine if the presence of the material could adversely affect either the fuel or water separation. The system consisted of an inverted five-gallon glass water bottle with the bottom removed and a valve fitted to the narrow mouth. The system then allowed for a sump area for the collection and drainage of the fuel and water used in these tests. All measurements were made by draining the fluids into graduated containers. Tests were performed at ambient laboratory temperatures (70 ± 5°F) unless otherwise noted.

2.1.1 Fuel Retention

In all testing, the container was filled with dry foam and fluid added. After filling the system, fluid was gravity drained until stream flow ceased. With JP-4, the retention volume was determined to be 0.95% and with Avgas, grade 115/145, the retention volume was 1.1%.

2.1.2 Water Retention

The same procedure was followed using water in place of JP-4. Water retained was 4.3% (by volume). The system was immediately filled with fuel and allowed to stand 16 hours with an additional 1.0% water recovery. The system was drained and dried and the water retention again determined. Water retained was 3.6%. This shows good reproducibility when compared with the initial value of 4.3%. The system was immediately filled with fuel and sloshed four hours by means of a rocker table. At the end of this period, 0.7% more water was recovered from the sump. However, as the system was drained, water began to drop out of the foam as the fuel level lowered. Water recovered during draining was 2.7%, leaving 0.2% not recovered.

The system was drained and dried prior to the next tests.

2.1.3 Sump Migration

The cellular material was removed and the sump area was filled with one quart of a mixture containing 75% (volume) water and 25% ethylene glycol monomethyl ether (methyl Cellosolve). This mixture represents a typical aircraft sump. The foam was replaced and the system filled with JP-4. The interface of the two liquids was marked on the vessel sides. A noticeable mixing and migration between the two phases were immediately apparent. After four hours of sloshing, the water phase was drained and measured. A migration of 2.5% of the water phase into the fuel occurred. The system was drained and dried prior to Sequence C tests.

2.1.4 Icing

The system, with foam in place, was filled with JP-4, placed in a cold box maintained at -20°F , and allowed to reach equilibrium. One pint of water (room temperature) was sprayed into the system as a mist. Spray time totalled about 20 minutes. The system was allowed to stand overnight (approximately 16 hours). No water could be drained from the system. However, ice was visible in the sump and was estimated to amount to 15-20 mls. Ice patches and ice balls were visible throughout the foam.

2.1.5 Summary

Evaluation of the material under the above conditions indicates that the retention characteristics of the foam are not an area of concern. Although water was retained in the fuel/material system, it was removed with the fuel as the system was drained. Migration of the sump water to fuel is not considered sufficient to be a problem. In fact, this slight migration would be beneficial from a microbiological viewpoint, since a methyl Cello-solve-water solution has excellent biocidal properties. Formation of ice in the system at -20°F should not be any problem, since the ice did not fall down to the sump area.

2.2 Fluid Exposure

The effects of accelerated fluid exposure on the foam material and the fluids was studied on a static system.

Unvented five-gallon wide-mouth jars were used to simulate fuel tanks. These fluids conformed to TT-S-735, types I and III and MIL-J-5624, Grade JP-4. Sufficient foam was exposed to each test fluid to provide removal and testing of the material during exposure. Test exposure was at 158°F for 28 days. However, on two occasions the temperature controller malfunctioned and temperature increased to approximately 177°F . Length of exposure at this higher temperature could not be established exactly, but in both cases was believed to have been for less than 12 hours. One set of samples was tested at the end of 7, 14, 21, and 28 days, changing test fluids after each time interval. Material from a second set of samples was tested at the completion of the 28-day period with test fluids not changed for these samples. In addition, a third set of samples exposed to 158°F only (no test fluid present) was tested at the end of 28 days to establish base line data. Both the foam samples and test fluids were analyzed to establish chemical changes resulting from exposure. No change in foam physical properties occurred during the fluid exposures.

Avgas, grade 115/145, exposure utilized two sets of test specimens. Set 1 utilized Avgas Batch 2, with fluid change at seven-day intervals. Set 2, with Avgas Batch 3, was exposed to the same fluid for the entire exposure. In addition to the test specimens in both sets, additional foam was added to provide an approximate 1:1 volume ratio of foam to fuel. Exposure was made in loosely capped, 5-gallon, wide-mouth glass jars for 28 days

at $110 \pm 5^\circ\text{F}$. Physical properties were the same for both sets of tests and did not vary from the control values. Data indicate that this fluid exposure had no effect on the physical properties of this foam.

The data obtained using five replicate samples in each test are summarized in Table I.

Fluid change during these tests vs. the same fluid for 28 days showed no significant difference in physical properties nor did fuel type result in real differences. In general, these fluid exposures failed to change the foam characteristics.

2.2.1 Foam Analyses

Infrared reflectance techniques (attenuated total reflectance and frustrated multiple internal reflectance) were used to determine changes in the foam after storage in various fluids. Infrared spectra of the treated foam were compared with patterns for "as received" foam and control samples (foams processed under the conditions of the storage experiment, but not immersed in fluid).

In general, there were no significant differences in the spectra. Each pattern was typical of ester-based polyurethanes.

Slight variations in the relative intensities of absorptions ca. 5.78 microns (ester-type carbonyl) and ca. 6.06 microns (urea carbonyl and/or H_2O) occurred.

In all cases, except for the water-treated foam, no particular significance could be attached to the random variations. The intensity of the 6.06 microns absorption for the water-treated foam suggests a slight increase in urea formation.

2.2.1.1 Short-Term Wash and Soak Extractions Scott polyurethane foam (orange) was exposed to JP-4 and Type I fluid to determine whether short-term washes and soaks would remove a significant amount of phthalate prior to aircraft usage.

Foam cylinders 4 inches in diameter and 4-1/2 inches long were cut with the hot-wire apparatus and inserted into a 4-inch diameter metal beaker. The beaker was then filled with test fluid until the foam was just covered and soaked for 15 minutes at room temperature. The fluid was decanted and analyzed for existent gum content and for indications of phthalate. The beaker was immediately refilled with fluid (same foam specimen) and again soaked for 15 minutes. A third immersion was allowed

to stand for 7 days. No appreciable increase in gum content was found in any of the Type I fluids. Gum, however, increased to almost maximum specification limits in JP-4 after 7 days in contact with fluid at room temperature (ca. 75-77°F). No spectral evidence of aliphatic esters of orthophthalic acid was found.

Two additional exposures to Type I fluid at 100°F were made to determine if mildly higher temperature enhanced removal of soluble contaminant. The exposures were for 15 minutes and 1 hour, and were made with the same foam/fluid ratio as before. Foam immersion at 100°F for the short term exposure did not increase soluble contamination removal. The following data show a summary of existent gums after foam exposures.

EXISTENT GUM* CONTENT OF TEST FLUIDS

(After exposure in contact with foam)

	<u>Room Temperature Exposure</u>			<u>100°F Exposure</u>		
	<u>As Received</u>	<u>First 15 Min.</u>	<u>Second 15 Min.</u>	<u>7 Days</u>	<u>15 Min.</u>	<u>60 Min.</u>
JP-4	0.3	2.7	-	6.7	-	-
Type I Fluid	0.0	0.0	0.0	3.9	0.0	0.3

*mg/100 ml fluid

2.2.2 Test Fluid Analyses

2.2.2.1 Jet Fuels Material dissolved by the fluids used in the baths for the foam storage stability tests was characterized by evaporation of a portion of the bath fluid (50 ml) and by subsequent infrared absorption spectrophotometric analyses of the residues (1-10 mg). Fresh fluids were used as controls.

In all cases, a progressive decrease in the amount of residue during the four consecutive 7-day cycles of the fluid exposure tests (replenished fluid) was observed. Most of the residue was obtained during the first 7 days.

The test fluids from cycles in which the foam was maintained in the same bath for 28 days yielded quantities of residue equivalent or slightly greater than that obtained at 7 days, but considerably less than the total cumulative amounts (28 days) from a foam bathed by fluid replenished after 7, 14 and 21 days.

Some variations in the infrared spectra of the residues were observed, but, in general, the residues were mostly the same. The major component was an ester of orthophthalic acid, possibly a C₈ to C₁₂ derivative. The first two 7-day cycles gave a mixture of the orthophthalate and what appeared to be an aliphatic ester, possibly an adipate. After two cycles, little, if any, aliphatic ester was observed.

2.2.2.2 Avgas Fluid Analysis Aliquots (10 ml) of clear fuel were taken from each sample and evaporated at room temperature. The residues were analyzed by infrared spectrophotometry.

Precipitates observed in the 7 and 14-day samples of Batch 2 Fluid were dried at room temperature and analyzed by infrared spectrophotometry and emission spectrography.

Quantities of residue reclaimed from 10 ml of clear fluid were:

<u>Sample</u>	<u>Residue, mg</u>
Batch 2 Fluid	
As received	2.8
7 days	7.4
14 "	5.9
21 "	3.2
28 "	3.3
Batch 3 Fluid	
As received	0.6
28 days	4.4

Materials reclaimed from the original (as received) fluids were mostly long chain aliphatic hydrocarbons with very small amounts (<<5%) of a carbonyl containing material. Residues reclaimed from the other test fluids were mostly C₈ or C₉ aliphatic esters of orthophthalic acid.

Although possibly masked by the orthophthalate, there was no evidence for the presence of low molecular weight polyurethane or derivatives of the isocyanate moiety in the fluids. However,

the residue from the hydrolytic stability test (28 days), though similar to the others, contained additional material which may be hydrolyzed polyurethane. Again, the orthophthalate residue masked the identification of other components.

Samples of the test fluids were examined by atomic absorption analysis to determine if the tetraethyl lead (TEL) content was depleted during storage. No decrease in TEL content could be detected.

Fuel specification tests were also conducted on the various batches of Avgas by the Aerospace Fuels Laboratory (MAOQLA). Test results are shown in Table II. Existent gum was the only property affected by the foam exposure and was significantly higher for the 7-day sample and the fuel used for the entire 28-day exposure.

Precipitates were recovered from the Batch 2 Fluid after 7 and 14 days of storage. Analysis showed these materials to be mostly metal salts of organic acids. Infrared absorption spectra for the major component were very similar to the reference pattern of lead tetraacetate. The qualitative emission spectrographic analysis for the metallic elements was as follows:

- Pb - Major Constituent
- Si - Trace
- Al - Trace
- Fe - Trace
- Cu - Trace
- Mg - Trace
- Na - Trace
- Mn - Trace
- Ag - Trace

While the precipitate is an insoluble lead salt, the fact that the TEL level is not depleted may be attributed to fluid losses to essentially maintain the initial level.

Further to investigate phthalate extraction, samples of the individual foam components were analyzed in an attempt to establish which component was contributing the contaminating material.

Five individual components of Scott Foam, Grade S-103-10-102 (orange) were obtained from the manufacturer for analysis by infrared techniques.

The components were assigned code numbers by the manufacturer to protect proprietary formulation data and these identifications were:

1. TDI 80/20
2. S-149
3. S-513
4. S-3628
5. S-5616

No spectral evidence for the presence of aliphatic esters of ortho phthalic acid was found. However, it would be possible for quantities of phthalates in concentrations of $\leq 1\%$ to be present without detection by normal infrared analyses.

No spectral evidence of aliphatic esters of orthophthalic acid in any of the individual components was found. However, small amounts of the phthalate could be present in component S-149 and be masked by spectra from other constituents.

The concern was that the orthophthalate might cause excessive gum formation. In view of the minor amounts of phthalate found, and the lack of deleterious effect on the JP-4 following long-term storage in contact with foam (Section 2.5.1) it is concluded that these trace amounts were relatively without effect upon the fuel coker ratings and pressure drop.

2.2.2.3 Material Extract Examination

The characterization of the presence of the alkyl orthophthalate, noted in all the fluids, was based on the following absorption bands in the infrared spectra, ca. 3.42, 5.77, 6.24, 6.32, 6.83, 7.24, ca. 7.8, ca. 8.9, 9.33, 9.62, 13.46, and 14.20 microns.

Further to define the amount and type of extractant material, three foams all manufactured by the Scott Paper Company, Foam Division, Chester, Pennsylvania, were tested:

- a. Orange foam - Scott Foam, Grade S-103-10-102.
- b. T-23L - This sample was normal except no pigment was present.
- c. 7-16-1F - This sample contained a different stabilizer and no pigment.

Extractions were performed by soaking the foams in chloroform for progressive 2, 24, and 72-hour periods at 75°F. No agitation was performed. Infrared spectra of deposits after evaporation of the chloroform were recorded after each time period. Fresh chloroform was used for each of the extractions.

The weight losses were:

Orange foam	2.2%
T-23L	2.2%
7-16-1F	2.1%

Progressive extraction was needed to remove an ester of an aliphatic carboxylic acid, probably adipic acid, before the phthalate derivative could be identified. The ester of the aliphatic carboxylic acid was first removed from the foams, while further treatment with chloroform removed mostly the phthalate derivative.

An aliphatic ester of orthophthalic acid, probably di-2-ethylhexylphthalate, was detected in the chloroform extracts of all three foams. The presence of this material was established by infrared spectrophotometry and the identification was supported by NMR data.

Two stabilizing materials supplied by Scott were analyzed to determine if they were the foam components contributing the alkyl orthophthalate esters found in the test fluids after immersion exposure. These materials were examined by infrared analysis and no indication of the orthophthalate was found.

2.3 Freezing Under Compression

Effects of freezing (dry foam) while compressed were investigated by compressing a nominal 4-inch cube of foam to 10% of its normal height and chilling to -65°F. Compression was released after cold soak times of 15, 30, 60, and 90 minutes, and recovery times at -65°F and +77°F determined. Virtually no recovery was obtained at -65°F after 6 hours. Specimen heights were measured at one minute intervals until full recovery was achieved at +77°F. Figure 4 shows the recovery time relationship for expansion at 77°F. Conditioning time was indicated to have slight effect on the time required for complete recovery at 77°F.

To further investigate freezing effects, specimens were compressed as before and chilled to -20°F. Compression was again released after 15, 30, 60, and 90 minutes and recovery times

determined at -20°F . Figure 5 graphically presents these data. Rate of recovery was indicated as affected by conditioning time if the foam is to be expanded at -20°F .

Intermediate data points were obtained at 0°F . A thermocouple was centered in the cube to determine the time required to reach an equilibrium temperature within the cube. Equilibrium at 0°F was reached after chilling for 40 minutes. Cubes were then cold soaked for 60 and 120 minutes before compression was released and expansion allowed at 0°F . Figure 6 presents these data. After three hours the cubes had recovered approximately 50% and expansion was terminated at this point. Although a slight effect of conditioning time is shown, cold soak time after equilibrium temperature is reached does not appear critical.

One other intermediate point was obtained at $+20^{\circ}\text{F}$. Thirty minutes were required to reach equilibrium. The compressed cube was cold soaked 60 minutes after equilibrium was attained. Recovery time is shown in Figure 6.

The effect of compression and foam properties was determined by making compression set tests at 158°F (22 hours) in accordance with ASTM D 1564, Method B. Unexposed foam had sets ranging from 40% to 50%, while test specimens used for the tests at -65°F and -20°F had a set of about 75%. Compression and freezing are indicated to have some effect on the polyester type foam, but should not adversely affect its usage in the intended application.

2.4 Icing Effect

These tests consisted of blowing moist (saturated) air at $75^{\circ} \pm 5^{\circ}\text{F}$ and 0°F through fuel-wet foam samples (4" cubes) maintained at -20°F . Air flow through the foam was for 3 hours although impingement of the moist air on the foam caused visible icing within the foam block. A thermocouple was mounted in the center of the foam sample and the bulk temperature was held to $-20^{\circ} \pm 5^{\circ}\text{F}$. No weight loss occurred from these tests. Compression load deflection values for the foam were not changed by the exposure.

2.5 Temperature Effect

Nominal 4" cubes of the foam were exposed to temperatures of 180°F and -65°F to determine the effect on compression load deflection and compression set properties.

Two foam cubes were placed in an oven at 180°F and allowed to reach an equilibrium temperature. Both cubes were removed from the oven and one was immediately placed in a cold box maintained at -65°F. The second cube was allowed to cool to room temperature (77°F) taking a cooling time of 25 minutes. Compression load deflection and compression set values were obtained for each cube and an unexposed foam cube for comparison.

A fourth cube was compressed to 10% of its normal height for 90 minutes at RT and upon release, % recovery vs. time was established. Figure 7 presents these data. Compression set after 22 hours at 158°F was also determined. In addition, all four cubes were then compressed to 10% of their height for 90 minutes at RT and compression set at RT measured. Compression load deflection and compression set data are given in Table III.

Exposure at 180°F reduced compression set of the foam approximately 50%, showing increased resiliency as a result of the exposure.

Exposure at the two temperature extremes (180°F and -65°F) had little effect on compression load deflection properties.

2.5.1 Long Term Storage of Foam at 130°F

In the early phases of evaluation, a carbon-filled polyurethane Scott foam (10 pore/inch) was considered for use in fuel tanks. Storage stability tests consisted of packing a 55-gallon drum with the foam, covering the foam with JP-4, and storing at 130°F for 10 months. Physical properties of the foam were not significantly affected by the exposure. Properties of the foam before and after exposure were:

	Tensile Strength, psi	% Elongation	Compression Load Deflection, psi	
			25%	50%
Before	32.7	359	0.42	0.53
After	29.5	393	0.37	0.52

Fuel in contact with the foam during storage was examined with the following results:

Existent Gum, mg/100 ml	20.8 (excessive)
Orthophthalate	None (may have been masked)
Fuel Coker*, 300/400°F	Pass - Tube rating 0000011122111 - ΔP Zero

*Performed by University of Dayton Research Institute

Storage at 130°F increased existent gum content of the fuel to an unacceptable level. Maximum gum content specified by the JP-4 specification is 7.0 mg/100 mls. However, this gum content did not adversely affect the fuel coker ratings.

2.6 Abrasion (Slosh) Effect

Abrasion resistance was investigated by sloshing fuel through foam sheets 1/2-inch thick. An exploded view of the slosh tube is shown in Figure 8. Each end was constructed to permit fastening a foam specimen over a sharp edged ridge (1/8-inch wide x 3/8-inch high) by means of a removable retainer ring. The tube was flanged in the center to allow the mounting of a foam specimen through which the fuel flowed during sloshing. The tube was half-filled with filtered (0.45 micron) JP-4 fuel and mounted on a rocker table (15° both ways from axis) so that fuel slosh was lengthwise in the tube. Sloshing was continuous for 195 hours at ambient temperature (75° ± 5°F).

All foam specimens lost weight during the test. Shown below are specimen weight losses and the amount of contamination recovered when the fuel was passed through a 0.8 micron filter. A slight abrasion loss (<1.0%) was indicated by the weight changes of the end foam specimens. Loss of foam through slosh does not appear to be a problem unless sloshing and abrading conditions are quite severe, as in the case where the foam would be loosely packed and allowed to move within a tank. Abrasion appears to produce particles below 0.8 micron in size, as shown by the low amount of solids recovered from the fuel after the test. However, this discrepancy may also be the result of the removal of foam components soluble in JP-4.

<u>Specimen</u>	<u>Original Weight, g</u>	<u>Loss, mg</u>	<u>% Loss</u>
End			
1	1.9470	13.5	0.7
2	2.0559	17.4	0.9
Center	2.5064	8.8	0.4

Contamination recovered (0.8 micron filter) from the fuel after 195 hours slosh was 2.4 mg.

3. STABILITY

3.1 Hydrolytic Stability

The hydrolytic stability of the current polyester type (orange) foam was compared to an experimental polyether type (white) foam. These materials were immersed in water and stored at $160^{\circ} \pm 2^{\circ}\text{F}$ continuously for 28 days. It should be noted that oven malfunction increased the temperature twice to 177°F . During exposure the polyester foam changed from its original orange color to a light brown. The water was also discolored brown. Physical properties of the polyester foam were significantly changed, and the properties of the experimental polyether foam were affected to a smaller degree.

	Before Exposure		After 28 Days ($160^{\circ} \pm 2^{\circ}\text{F}$)	
	<u>Orange</u>	<u>White</u>	<u>Orange</u>	<u>White</u>
Compression Load				
Deflection, psi				
25%	0.30	0.34	0.14	0.28
50%	0.39	0.42	0.17	0.33
Tensile Strength, psi	22.6	15.7	8.3	12.4
% Elongation	327	136	144	143

Infrared analysis of the foams indicated a slight increase in urea formation (see section 2.2.1).

Other specimens of the two types of foams were exposed at 160°F and 100% RH, with the results shown in Table IV. As before, the polyester type of foam was affected to a greater extent than the polyether foam, whose properties remained essentially unchanged after exposure for 28 days.

3.2 Low Temperature Stability

The effects of a low temperature environment on the foam, either in a dry or wet condition was determined. Cubes of 2-1/2" to the edge as well as pre-cut tensile test specimens were immersed in fuel

(1 to 1 ratio) and equilibrated at -65°F . However, at this temperature the foam is stiff and therefore physical property changes of the foam were made at room temperature following this exposure.

3.2.1 Static and Slosh Exposure

Data from the static exposure as shown in Table V did not indicate any significant physical property change. However, data from the slosh exposure, 2 hours at -65°F , showed slight changes in tensile strength and percent elongation when exposed to Type I and Type III fluids, but this variation is probably within test repeatability resulting from the variation in test specimens.

3.2.2 Tumble Tests

Physical property specimens were immersed in Avgas, Types I and III fluids and JP-4, cooled to -65°F and with JP-5 at -40°F , and tumbled for 72 hours. No significant change in tensile strength, % elongation, or compression load deflection values resulted from these exposures.

Tumbling tests in the fuels showed little change in properties, though indications are that JP-4 caused somewhat greater fragmentation (-65°F) than the others. Tumbling tests at -65°F also showed the same general fragmentation as the slosh test, Avgas causing least effect. However, dry tumbling of the foam at -65°F resulted in significant material deterioration. In these tests, 86% of material weight was lost due to the abrasion and tumbling.

3.2.3 Particulate Contamination

Specimens (2-1/2" foam cubes) were immersed in 900 mls of the fluids (previously filtered through a $0.45\ \mu$ filter), cooled to -65°F , or to -40°F for JP-5, and tumbled for 72 hours. After the tumbling period the specimen container was removed from the cold box, allowed to return to room temperature, and the fluid passed through a $0.8\ \mu$ filter to recover solid particles resulting from the tumbling action.

Other contamination specimens were immersed in the test fluids, cooled to test temperature and sloshed for 2 hours. Solid particles were recovered by passing the fluid through a $0.8\ \mu$ filter at room temperature. Initial Avgas filtrations attempted with cold fuel produced an apparent contamination level of $1444\ \text{mg}/\text{ft}^3$ of foam.

Examination of the filters indicated that much of this material was the blue dye used in the fuel. When the Avgas was allowed to warm to room temperature before filtration, the contamination level was reduced to the level of contamination found in the other test fluids. All subsequent filtrations were made at room temperature.

In general (see Table VI), contamination resulting from slosh (or tumbling) when immersed in fluid is not considered excessive. However, it is imperative that the foam not be loosely installed in a fuel tank and allowed to tumble at low temperatures while in the brittle state. This was very clearly demonstrated when a dry foam cube was tumbled 72 hours at -65°F with a resultant 85.6% weight loss. Under no circumstances should this foam be exposed to abrading or eroding conditions at -65°F .

4. PARTICULATE CONTAMINANTS

Contaminants found in the fuels stored in contact with foam may be soluble (section 2.2) or may be solids. The manufacturing process is aimed at removing small residual particles, but no specification had been established by the vendor, nor had a control test procedure been developed. Furthermore, no data were available to demonstrate abrasion resistance under foam usage conditions. This section includes the experimental data secured in attempting control test development, describes a microscope technic used to examine particulate matter for differentiation and particle size distribution, and cites the examination of solid contaminants from a number of sources.

4.1 Particulate Contamination Removal with JP-4

A method was desired for determining the removal of insoluble contaminants from Scott Foam S-103-10-102 (orange). Three procedures were tested consecutively on the same foam specimen to determine the most effective.

4.1.1 "Fill-and-Drain" Procedure

Three and one-half gallons of JP-4 were filtered twice through $0.45\ \mu$ Millipore filters (HAWG 04700) and stored in a clean 5-gallon glass bottle which had been precleaned and well-rinsed with filtered ($0.45\ \mu$ filter) petroleum ether.

The foam chamber consisted of an inverted 5-gallon glass bottle with the bottom cut off. It was cleaned and well-rinsed with filtered (0.45 μ filter) petroleum ether. A rubber stopper with a glass tube and stopcock closed the mouth of the bottle.

All other equipment (filter-holders, funnels, delivery tubes, and receiving filter-flasks) were scrupulously cleaned and rinsed with filtered (0.45 μ filter) petroleum ether.

A 1-quart sample of fuel was gravity-fed from the reservoir to a tared 0.8 μ Millipore filter (AAWG 04700). The filtered fuel was returned to the reservoir.

To determine blank values, a volume (3.17 gal.) of JP-4 roughly equal to the volume of the foam sample was gravity-fed to the foam chamber. Through the bottom stopcock a 1-quart sample was removed and set aside. A second 1-quart sample was filtered through a tared 0.8 μ Millipore filter, then a 1-gallon sample was filtered through a second tared 0.8 μ Millipore filter. Finally the balance of the fuel in the foam chamber was filtered through a third tared 0.8 μ Millipore filter, adding also the first quart previously set aside. The three filters were rinsed three times with filtered petroleum ether, dried at 224°F for 10 minutes, and reweighed. All filtrates were returned to the reservoir.

The foam sample previously saw- or hot wire-cut to fit snugly in the foam chamber was then put in place, and 3.17 gallons of fuel from the reservoir were added to just cover the foam. A set of samples were taken exactly as was done for the blank. This fill-and-drain procedure was repeated three more times, each time drawing three filtered samples: the second quart, the gallon, and the balance. However, to prove the filtering efficiency and the cleanliness of the fuel returned to the reservoir, a quart sample was drawn from the reservoir before passing the fuel into the foam chamber.

4.1.2 Slosh Procedure

After refilling the foam chamber, the chamber was rocked (platform rocker) for five minutes before drawing out any fuel. Then, while still rocking (a total of 40 minutes) the usual quart, gallon, and balance samples were taken, the filters were treated as indicated above, and the filtered fuel was returned to the reservoir. This rocking procedure was done twice, and at the end of the second run, the foam was removed from the chamber,

and the chamber sides were rinsed down several times with filtered fuel, filtering the washings through the same filter used to filter the balance of the fuel.

4.1.3 Compression Procedure

The foam was then placed in a clean, well-rinsed (petroleum ether) stainless steel beaker. The same volume of fuel as had been previously used (3.17 gal.) was gravity-fed to the beaker. With a clean aluminum plunger consisting of a perforated 10-inch disc with a long rod handle, the foam was compressed to minimum volume and then allowed to return to its normal shape. This action was repeated 12 times, after which the regular quart, gallon, and balance samples were drawn out and filtered, and the filters were rinsed, dried, and weighed. The filtrates were returned to the reservoir, and the compression procedure was repeated. At the end of the second run, the foam was removed from the container, and the container sides were rinsed several times with filtered fuel, filtering the washings through the second balance filter.

Table VII shows the weight in milligrams (uncorrected for the blank) of contaminant found for each sample taken, the total weight (blank-corrected) of contaminant extracted by 3.17 gal. of fuel, the total weight (blank-corrected) of contaminant extracted per gallon of fuel, and the total weight (blank-corrected) of contaminant per cubic foot of foam.

To check the compression procedure, a fresh 6-inch cube was submitted to the procedure, pressure being applied on three faces of the cube for each trial. Results were significantly different from those reported in Table VII.

<u>Cycle No.</u>	<u>Extracted Contamination (mg)</u>	<u>Wt. Contamination per Cu.Ft. of Foam (mg)</u>
1	13.6	108
2	2.6	21
3	<u>2.8</u>	<u>22</u>
Total	19.0	151

The "fill-and-drain" method of washing out contaminants proved ineffective. When a sloshing action was incorporated in the system, the weight of extracted contaminants per cubic foot of foam rose eightfold. Compression and expansion of the foam while

immersed in JP-4 resulted in a fivefold increase in weight of contaminants removed. No appreciable difference was found between saw-cut samples and hot wire-cut samples. Submission of a 6-inch cube of fresh foam to the compression procedure showed 3 to 4 times the contamination of the larger foam sample taken through the three procedures. No good explanation exists, except for possibly greater mechanical effect on the small cube.

4.2 Particulate Contamination Removal with Avgas

The same "fill-and-drain", slosh, and compression procedures were used as with JP-4, using instead prefiltered aviation gasoline. Table VIII shows these data. In general, the "fill-and-drain" procedure removed least contaminant. The sloshing procedure showed no real difference between JP-4 and Avgas in particulate contamination removal. However, Avgas removed twice as much total contaminant as JP-4 by the compression procedure.

The data from these two approaches indicated that if a control procedure was desired, another procedure must be sought.

4.3 Particulate Contamination Removal by Compression-Expansion

Since the previous methods for contaminant removal had proved somewhat doubtful, tedious, and not necessarily reproducible, another approach to a control procedure was tested.

A foam cube 5 in. on each side was placed in a well-cleaned, 3-liter stainless steel beaker. One liter of filtered (0.45μ) JP-4 fuel was added, and with a clean aluminum plunger consisting of a perforated 6-inch disc with a long rod handle, the foam was compressed to minimum volume and then allowed to return to its normal shape. This action was repeated 12 times on each face of the cube. The fuel was filtered through tared 0.8μ Millipore filters after every cycle on each face. After the last filtration the beaker was rinsed carefully with clean petroleum ether and the rinsings were added to the last filter. The filters were dried and reweighed. Results varied from 910 mg/ft^3 to $1,945 \text{ mg/ft}^3$ (Table IX).

The reproducibility of this method appears to leave much to be desired, whether from variation in sample constitution or procedure. The amount of contaminant solids is 20 to 50 times that of the series testing (fill-and-drain, etc) of JP-4. It may well be that this much more rigorous treatment results in fragmentation of retained non-foam constituent not affected by the comparatively gentle treatments.

4.4 Particulate Contamination Removal by Water and Sloshing

Vigorous agitation of JP-4 in a separatory funnel in the presence of the foam causes evidence of static charge and potential hazard in glassware. Hence this system was not believed to be a satisfactory one for control purposes. As a substitute it was decided to use an aqueous medium with the hope that this might remove particulate contaminant similarly to JP-4.

A 4-liter separatory funnel was modified to allow insertion of a foam cube 5 inches on each side. Two liters of prefiltered (0.45 μ) water containing 0.2% (vol.) of Triton X-100[®] (Rohm & Haas) were added, and the whole sloshed vigorously to force the liquid through the foam. The water was then filtered through a 0.8 μ Millipore filter. The filter was dried for 10 minutes on a hot plate with a surface temperature of 300°F. Six extractions were made on each foam cube. See Table X for results.

To establish the loss in weight of the Millipore filters upon heating at 300°F for 10 minutes, four tared filters were thus treated showing a weight loss of 1.4, 1.6, 1.3, 1.2 mg, with an average value of 1.4 mg. This figure was added to the values shown in Table X.

Based upon these data, it appears that this procedure may offer safety while removing loose contaminant similarly to hydrocarbon fuels.

4.5 Particulate Contamination from Various Foam Buns

Previous studies of insoluble contamination contained in Scott Foam S-103-10-102 (orange) were made with foam specimens cut from the same bun. This section presents data obtained from seven different buns to determine typical amounts of solid contamination that can be expected to "fall-out" in a fuel system.

A 4-liter separatory funnel was modified to allow insertion of a foam cube 4 inches on each side. Two liters of prefiltered (0.45 μ) water containing 0.2 vol. % of Triton X-100[®] (Rohm & Haas) were added, and the whole sloshed to force the liquid through the foam. Sloshing was accomplished by inverting the separatory funnel 180° and then returning the funnel to its original upright position. This was done ten times/test cycle. The water was then filtered through a 0.8 μ filter, dried for 10 minutes on a hot plate with a surface temperature of 300°F, and weighed to determine the amount of recovered contamination. Corrections were made for weight loss of the filters alone. Six extractions (cycles) were made on each foam cube.

Previous studies used 5-inch foam cubes, while these studies were made using 4-inch foam cubes supplied by the Air Force. All data were converted to mg contamination/ft³ of foam and are directly comparable. Table XI tabulates these results.

Contamination extractions from the 4-inch cubes taken from seven different buns supplied by the Air Force gave total contaminations ranging from 116 to 429 mg/ft³ of foam. Previous contamination levels obtained with three foam cubes (5-inch) from the same bun ranged from 279 to 322 mg/ft³ of foam. It is obvious from these data that no "hard and fast" rule of thumb for contamination level can be formulated. However, in all cases but one the contamination levels were below 350 mg/ft³ of foam. This may be a significant trend and perhaps a maximum contamination level might be set at that value if additional tests verified the value as realistic.

Another test was made to determine the approximate amount of foam particles found in the contamination extracted in the above manner. The contamination from a 5-inch foam cube was microscopically examined to establish particle distribution and estimate the percentage of foam particles present. The total number of contamination particles recovered was found to contain approximately 4.3% foam particles. The observed foam particles were fairly evenly distributed over the three particle ranges defined. Table XII presents particle distribution data.

Contamination may be expected to vary considerably with each individual bun. Of seven buns tested, the range was from 116.1 to 429.3 milligrams and with one exception the contamination fell between 116.1 and 267.3 mg.

4.6 Contaminants on Millipore Filters

One factor affecting the acceptance of a foam baffling system is the degree of contamination it introduces into fuel. Therefore, a series of contaminants on sets of Millipore filters was submitted by the Systems Engineering Group for microscopic analysis.

The apparatus used was an American Optical Model 8QLS0 microscope with a number 735 lamp set up to provide oblique epi-illumination. The examinations were made at X100.

The two most heavily loaded samples could not be examined in the "as received" condition, therefore, a representative sample was scraped onto another filter, and redispersed. The less heavily

loaded samples were then examined "as received" and the entire filter surface inspected. Although the contaminants for all the filters fell into the same classes, for the purpose of this report each filter is described separately.

Monsanto Research Corporation (MRC) Sample - First Filtration, Fuel Slosed, Wire Cut Foam, Residual

The contamination on this sample consisted of pieces of foam, fibers (both cotton or paper and man-made), rust scale, metal filings, metal shot (most probably solder), siliceous dust, miscellaneous particles consisting of possible soot, charred organic material and a few paint flakes.

MRC Sample - First Filtration, Saw Cut, Compressed 6" Foam Cube

The contamination on this filter consisted of pieces of foam, fibers (both cotton or paper and man-made), rust scale, metal filings, metal shot (solder), siliceous dust, soot and possibly charred organic material.

Wright-Patterson 6" Cube - First Wash

The contamination on this filter consisted of pieces of foam, fibers (both cotton or paper and man-made), metal filings, rust scale, metal shot (solder), siliceous dust, soot and possibly organic char.

Wright-Patterson 6" Cube - Second Wash

The contamination on this filter was identical with that of the first wash sample, except that the concentration of foam particles and fibers was lower, and they were smaller in size.

West Coast No. 54 Filter Wash

The contaminants on this filter were foam particles, fibers (both cotton or paper and man-made), metal filings, rust scale, metal shot (solder), siliceous dust, soot, organic char, and some yellow spheres which appeared to be paint (possibly from a spraying operation, or they could be flux).

West Coast No. 66 Filter Wash

This sample was essentially the same as No. 54.

West Coast No. 51 Sump Sample

The contamination on this filter and the following sample was different from the previous ones. The particles were much smaller and an absence or a very low concentration of fibers and siliceous material was noted. The contamination consisted of metal filings, rust scale, yellow spheres, soot, fibers, siliceous dust (low concentration), and small pieces of foam.

West Coast No. 63 Sump Sample

The contamination on this filter consisted of metal filings, siliceous dust (low concentration), soot, and small pieces of foam of low concentration.

It is apparent from the above observations that the contamination was essentially the same for all of the filters and differed mostly in concentration of individual materials. The greatest difference was in the sump samples which consisted mostly of metal particles, soot and organic char, and had low concentrations of fibers and small foam particles. The highest concentration of fibers was seen in the filter wash samples, and the lowest concentration of siliceous dusts was in the sump samples. A summary of the contamination is tabulated in Table XIII.

4.6.1 Particle Distribution

Particle distribution by size was determined for the West Coast samples. The counts were made directly on the two sump samples and followed ARP Procedure No. 598. For the two filter wash samples, the concentration of material on the filter was too high to count, therefore, a portion was removed and dispersed with filtered petroleum ether and refiltered with a series of new filters on which the particle count was then made, following the same procedures used for the sump samples.

The counts obtained and particle distributions follow:

	<u>Size (μ)</u>	<u>Particles Counted</u>	<u>Distribution (%)</u>
West Coast No. 51	50	4001	99.73
Sump Sample	50-100	6	0.15
	100	5	0.12
West Coast No. 66	50	3666	99.87
Sump Sample	50-100	3	0.08
	100	2	0.05
West Coast No. 54	50	3108	95.1
Filter Wash	50-100	114	3.49
	100	46	1.41
West Coast No. 66	50	1312	91.6
Filter Wash	50-100	77	5.37
	100	44	3.07

Particle distribution by size also shows the differences in composition of the contamination between the filter wash and the sump samples. The majority of material which is greater than 50 μ in size was either pieces of foam or fibers.

4.6.2 Ash of West Coast Filter Wash Samples

Contamination of each of the West Coast Filter Wash Samples Nos. 54 and 66 was ashed. The samples were found to consist of the following:

<u>Sample No.</u>	<u>Weight %</u>	
	<u>Inorganic</u>	<u>Organic</u>
54	45.2	54.8
66	47.4	52.6

Emission analysis of each sample is tabulated in Table XIV and shows the inorganic ash as essentially identical in both cases.

4.6.3 Summary

With the exception of the two sump samples, the contaminants on the filters were of the same general types and sizes. This contamination consisted mostly of fibers, rust, metal filings, metal shot, siliceous dust, soot and organic char and pieces of foam. Sump samples were mostly rust, metal filings, and soot.

The particle size breakdown for the West Coast samples exemplified the absence of fibrous and foam material. A very low (less than 1%) concentration of material above 50 μ was found in the sump samples. Most of the fibrous and foam material fell in the >50 μ range and was <10% of the total particles found.

4.7 25-Hour Slosh Test (WPAFB)

4.7.1 Type III Fluids

Two specimens of Type III Fluid (TT-S-735, Type III, 70% isooctane-30% toluene) were analyzed and the filters from the two systems examined.

Analysis of the test fluids indicated the following compositions:

	Volume %	
	<u>Isooctane</u>	<u>Toluene</u>
Type III Fluid - From 25-hour slosh test conducted by the Air Force	64.1	35.9
Type III Fluid - Supplied for MRC test program	71.5	28.5

The test fluids were analyzed chromatographically. There was no indication of foam material on either filter, suggesting no attrition.

4.7.2 Filters

Filters from a WPAFB test and one from the West Coast were examined to identify the contaminant components, and spectral data were compared with data obtained from a specimen of Scott foam (black).

Analytical methods used were emission, X-ray diffraction, infrared absorption, and attenuated total reflectance.

4.7.2.1 Filter #12 from WPAFB Test The material retained on the filter was a mixture of inorganic and organic material. Although specific characterizations could not be made, the following observations were evident from the spectral data:

- (a) There appeared to be less inorganic than organic material.
- (b) Inorganic components were noncrystalline, except for a small amount of elemental lead.
- (c) Some Si-O- groups were present.
- (d) Emission analysis is presented in Table XV.
- (e) The organic portion of the sample was composed of a small amount of carbonyl-containing material, probably as an ester of a fatty acid (infrared adsorption at 1748 cm^{-1}), and a relatively large amount of an ethylene oxide adduct (infrared bands ca. 1250 cm^{-1} and 1100 cm^{-1}). Due to interferences from water and the inorganic materials, the nature of the ethylene oxide adducts could not be established with certainty. However, some possibilities are:
 - Alkylphenol-ethylene oxide adducts (most probable).
 - Saponification products of ester-ethylene oxide adducts.
 - Long chain alcohol-ethylene oxide adducts.
 - Ethoxylated monoalkylamides.
- (f) The infrared pattern was very similar (including the small ester carbonyl) to the patterns obtained for the diethyl ether extracts of nonionic materials from liquid detergents (sulfonates, etc.). These nonionic materials are usually one or more of the ethylene oxide adducts listed above.

4.7.2.2 Filter #15 from West Coast Test There was more inorganic material found on this filter than on #12. Metallic particles were visually observed that could well have been solder particles formed during tank fabrication. Emission analyses were obtained for both the powder and metallic particles.

Observations were as follows:

- (a) The inorganic material was noncrystalline except for small amounts of lead (significantly more than found on filter #12) and an unidentified material indicated by two weak lines (X-ray diffraction) which were coincident with strong lines for elemental Ni (or Fe) and Cu (or Zn).

- (b) Emission analyses are tabulated in Table XV.
- (c) Some Si-O- groups were indicated as well as the presence of aliphatic hydrocarbon. In addition, the possibility of the ionized carboxyl of a metal salt of a fatty acid was indicated. A more specific characterization would require separation of components and removal of water.

4.7.2.3 Scott Foam (Black) The material was a polyurethane of a polyester type. There was no spectral evidence of the presence of this material in the deposits on either filter.

4.8 HH-3E Helicopter Filters

Four pleated filters removed from the fuel systems of two HH-3E helicopters were examined for residue from contact with open-celled polyurethane foam. These filters were all dated 8 July 1966, and were identified as follows:

<u>No.</u>	<u>Aircraft No.</u>	<u>Location</u>	<u>A/C Time (hrs)</u>	<u>Solids in Fuel Sample (mg/gal.)</u>
1	64-14229	Left	407.5	1.42
2	64-14229	Right	407.5	2.84
3	64-14232	Left	422.6	1.42
4	64-14232	Right	422.6	1.89

The filters were opened up and the contamination washed from them with filtered petroleum ether and then recovered on 0.45 μ Millipore filters. The entire Millipore filter surface was then examined and the particles identified (Table XVI).

Particle distribution by size was determined. Since the Millipore filter concentration was too high, a representative portion was removed, dispersed in filtered petroleum ether, refiltered, and a particle count made. These data are shown in Table XVII.

The particle distribution by size shows very little difference in contamination compositions with the exception of No. 4 which had a smaller ratio of large particles. Although the majority of foam particles was greater than 50 μ in size, some of the metal filings and most of the fibers and composite material were larger than the foam particles.

An increase in concentration of particles sized $>50 \mu$ was found with these filters over the previous samples. However, this increase is due to a higher concentration of fibers of the type present in the filters, and not from the polyurethane foam. It is estimated that the recovered foam particles represented less than 0.1% of the total particles observed.

Table XVI shows that the recovered particulate contamination was comprised of 46% to 48% inorganic material and 52% to 54% organic matter.

Emission analysis indicated the composition of the inorganic ash to be that shown in Table XVIII.

5. CORROSION EFFECTS

The corrosive effects of the foam on 7075 and 6061 alloys, both bare and Alodine treated, were established by placing foam in contact with the metal surfaces (single test panel per test) at $100^{\circ} \pm 5^{\circ}\text{F}$ at 100% RH over a 28-day period. The metal surfaces were inspected after 7, 14, 21, and 28 days for visual corrosion. In addition, a second set of foam specimens was first soaked in MIL-C-6529, corrosion preventative oil, and tested in a like manner. Foam samples were also immersed in the oil for 7 days at $75^{\circ} \pm 5^{\circ}\text{F}$ to determine if the oil was detrimental to the foam.

A tabulation of corrosion observations is presented in Table XIX. Foam contacting the metal surfaces did not accelerate corrosion.

Foam immersion in corrosion-preventative oil for 7 days at 75°F did not affect its physical or chemical properties.

6. ENVIRONMENTAL EFFECTS

6.1 Cyclic Environmental Tests

An attempt was made to simulate the temperature and humidity extremes associated with an operational fuel system environment so that the effect of these conditions on the foam could be studied. To simulate these constant environmental changes a cyclic type test environment was used which included a total of 20 cycles under the following conditions:

Humidity 70-90% entire test

Temperatures 70°F gradually increasing to 135°F over a 3-hour period. 135°F maintained for 6 hours. 135°F gradually decreasing to 70°F over a 3-hour period.

Time Cycle 12 hours

Test containers consisted of five gallon wide-mouth glass jars, vented to the atmosphere through a 1-inch diameter hole in the lid. Each of the two test jars was packed with foam and the foam was wetted with JP-6 fuel. The low vapor pressure JP-6 fuel was used in preference to JP-4 because of the reduced explosion hazard at elevated temperatures.

The one test container contained a solution of 75% water (volume) and 25% methyl Cellosolve (one pint of solution per two gallons of tank capacity) with a small overlay of JP-6. The second jar contained only fuel-wetted foam and was used as a control to establish base line data for comparison to the methyl Cellosolve-water exposed foam. Foam specimens from the control container were tested for physical property data initially and after cycles 8 and 20. Foam samples exposed to the methyl Cellosolve-water container were tested after cycles 2, 4, 8, 14, and 20. Physical property data determined included compression load deflection, tensile strength, percentage elongation (ASTM D 1564-64T), and volume change (Beckman air comparison pycnometer Model 930). Chemical changes to the foam were investigated by means of the infrared frustrated multiple internal reflection technique. No appreciable changes could be detected as shown by the data in section 2.2.2.

A summary of the physical property data is shown in Table XX.

No significant changes in foam properties resulted from the exposure. However, considerable variation in elongation was noted in the test fluid sample after cycle 8, but this was considered to be within the test repeatability.

6.2 Vent Icing Tests

A series of icing tests were run to study the factors associated with icing at a tank inlet containing foam. Primary objective was to determine the conditions conducive to icing which could prevent the successful venting of a fuel tank during aircraft

maneuvers under normal or maximum descent conditions. Basically five parameters were studied including inlet foam void area, foam condition (wet versus dry), inlet air velocity, inlet air temperature, and inlet foam temperature. During the tests these parameters were varied systematically and the most critical combinations tested. In certain cases extreme conditions were set for several parameters (air velocity, inlet void area, foam condition) whereas others were varied over a wide range (inlet foam and inlet air temperature). At all times the inlet air stream was maintained at maximum moisture content (100% relative humidity) to enhance the probability of ice formation. Measurements were made during each run on such parameters as: visible inlet ice formation on foam, inlet pressure differential, inlet air temperature and moisture, and resulting response temperatures at various points throughout the foam in the test tank.

The test set-up for this study is shown in Figure 9. Air from a large-capacity Joy compressor passes through a rotameter, a twin-bed desiccant drier (not pictured), and through a dry ice-isopropanol cooling bath in an insulated drum. A parallel flow of ambient temperature air passes through a water spray humidity chamber, then into a mixing chamber where it is blended with the cooled air in proper proportion to control temperature and dew point of the blend. The air then passes into either of two 2' cubical test boxes which are packed with cellular foam except for an inlet plenum measuring 6" x 6" x 6". One side of each insulated, wooden test box was a removable 1/4" Plexiglas sheet to permit observation and/or photographing of ice formation.

The following parameters were set for initial investigation:

Test Run No.	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>
Inlet Air Velocity, fps	3-5	20	3-5	3-5	20
Inlet Air Temp., °F	40	40	32	20	20
Initial Foam Temp., °F	0	0	32	-65	-65

Preliminary runs were made according to these parameters to test the equipment and to determine whether further changes in operating conditions were required. Two changes were made to permit greater control of operating conditions: (1) a separate temperature conditioning line to chill the foam in either test box was installed, permitting independent adjustment of air and test foam temperatures prior to a run; and (2) a larger inlet line for wet,

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warm air was installed to facilitate moisture saturation of the air flowing into the test boxes. Test results were recorded and tabulated for 22 runs. An additional 12 runs were conducted, but results were not recorded because shakedown tests were being made, or desired test conditions were not achieved. Tests covered the parameter envelope set forth below:

<u>Parameter</u>	<u>Conditions</u>
Air Velocity	Between 0-50 ft/sec
Air Temperature	Ranging from -30°F to 135°F
Foam Temperature	Ranging from -65°F to 0°F
Foam Condition	Fuel wetted
Inlet Vent Configuration	1 (plus others)
Minimum Air Flow Time	1 minute
Air Moisture Saturation	Record

These conditions were in fact exceeded in most cases, since runs were conducted with air temperatures ranging from -65°F to 135°F and foam temperatures, -65°F to 135°F. Moreover, it became apparent that much more than one minute of operating time was necessary for a good test, and run lengths varied from 9 to 84 minutes. Each run was continued until operating conditions had stabilized and no further change in icing conditions took place. Two of the runs recorded were made with dry foam in the test cubicle, and all others using foam wetted with JP-5 fuel. Practice showed that there was no observable difference in test results which could be attributed to the use of dry or fuel-wetted foam. However, it was noted that the fuel-wetted foam tended to stay wetted throughout a number of runs, regardless of temperature or air velocity imposed. The remaining runs were conducted using this wetted foam condition. This is considered representative of the foam condition found in a foam-filled tank once it has been fuel-wetted for the first time.

All runs were conducted using the same flow configuration in the 2-foot cubical test boxes (entering through a 2" pipe inlet at one corner of the cube and exiting through a 2" pipe outlet at the opposite corner of the cube). The Plexiglas top on the test box permitted visual observation of the inlet area. Ice formed on the observation window while the box was below freezing temperature was easily removed by pouring a layer of water on the outside surface. Runs 9, 11, and 12 were made with the test

box completely filled with foam and packed firmly against the 2" inlet. All other runs utilized a 6" cubical void space at the inlet corner of the cube, with inlet air flow normal to and centered on one face of the 6" foam wall. Runs 13 through 21 included a 1" square, stainless steel, 20 mesh screen placed 1" in front of and parallel to the foam surface on which the air flow impinged. This setup was utilized in order to provide a comparison of foam ice formation versus metallic screen icing.

Test results for the 22 runs are shown in Table XXI. Response of temperatures in the foam system was highly dependent on the rate of air flow. At inlet air velocities below 10 ft/sec. it became difficult to stabilize the inlet air temperature at a specific value because of ambient effects. Consequently icing effects, when observed, were more pronounced using higher air inlet flows. The effect of air velocity on the tests can be appreciated by comparing flow rates in the inlet line and the test cube (assuming 4 square-foot cross-sectional area in the cube, which is an approximation ignoring foam volume and variations in flow pattern):

<u>Velocity in 2" Inlet Line</u>	<u>Volumetric Flow</u>	<u>Velocity in 2' Test Cube</u>
50 ft/sec	1.16 ft ³ /sec	0.29 ft/sec
20	0.466	0.12
6	0.140	0.035
1	0.023	0.006

At lower air flow rates the mass flow of air carries insufficient moisture to produce observable icing conditions. Nevertheless, since the low flow condition is obtained for aircraft fuel tank vents under some flight conditions, tests at 6 ft/sec vent flow for periods up to 24 minutes were run. However, no critical icing buildup was noted. Air inlet velocity also affected the time lag response of the four thermocouples placed in either test cube. Thermocouple #6 (embedded in the foam 6" behind the air impingement surface) responded at all flows instantly to variations in air inlet temperature. The initial response of Thermocouples #7, 8, 9 (embedded 6" from blind corners of the test cubes) varied from 8 to 10 minutes for an inlet flow rate of 6 ft/sec to less than 1 minute for a 50 ft/sec flow rate. Apparently the lower flow tends to cut through the foam cube directly to the outlet, and increasing the flow increases turbulence and eddy flow in contact with the #7, 8, 9 thermocouples. This heat transfer effect is reinforced by the greater mass of air passing any point in the test cube at higher flow rates.

Although ice developed on the foam in various amounts during 7 of the 19 runs with the 6" cubical void at the air inlet, no appreciable hindrance to flow was observed in these cases. Pressure at the inlet was monitored using a 36" water manometer, and indicated less than 1.0" positive water pressure in each of the 19 runs with the exception of #13. The inlet pressure in that instance rose rapidly from 0.3" to 1.2" when the air flow was increased from 20 to 50 ft/sec, and a "snowstorm" of ice particles appeared in the inlet void. The ice was probably dislodged from the inlet pipe walls when the air flow was increased suddenly. In Run #13, the ice deposits then melted rapidly and cube inlet pressure returned to the original value.

During Runs #9, 11, and 12 the approach was varied by packing the 6" inlet void with foam and passing cold, saturated air into the cube for an extended period of time. During Run #9 no significant pressure developed at the inlet manometer after passing saturated, 20°F air at 20 to 50 ft/sec through the cube for 71 minutes. Run #11 utilized saturated, -30°F air at 50 ft/sec for 84 minutes during which time the inlet pressure rose from 0.5" to 13.0" H₂O. The pressure increase was rapid after foam temperature near the air inlet reached -30°F, rising from 0.6" to 13.0" H₂O in 30 minutes. At completion of the run we found a 1/4" thick frost plug in the inlet pipe against the face of the foam (see Figure 10). Run #12 produced similar results, again utilizing -30°F saturated air at 50 ft/sec inlet velocity and again developing significant pressure only after the adjacent foam temperature reached -30°F. In this instance the inlet pressure rose from 0.55" to 31.0" H₂O in 82 minutes, and the foam cube against the inlet pipe (which had been precut to permit examination) had ice penetration to about 2" in depth. These results indicate that it is probably advisable to provide an entrance void in the foam at the tank vent in order to preclude any conceivable blockage due to ice, although results for Runs #11 and #12 were obtained only after a rather extended period of operation.

During operations with the 6" cubical void at the cube inlet, frost was visible on the walls of the 2" inlet pipe during each run which actually produced icing on the foam. No accumulation formed on any occasion which threatened to block or restrict air flow to the test cube, with the exception of Run #13 in which frost sloughed off the internal pipe surfaces when air flow was increased abruptly. In a like manner, the stainless screen and foam impingement surface were compared in each run in which ice formation was observed. There was no preferential formation of ice on either the screen or foam; ice appeared on or disappeared from the two materials at about the same time. Figure 11 shows the ice on both screen and foam at the 10-minute mark of Run #13.

The conditions favoring ice formation in the test cube void faces are:

- (a) Maximum air flow (maximum of 50 ft/sec inlet velocity achieved in this series of tests) for long durations.
- (b) Saturated air below 25°F.
- (c) Foam temperature at or below the air temperature to initiate early ice formation.

Air temperatures at any level above 25°F produced melting rather than any formation of ice, regardless of initial foam temperature. Operating with air in the 20-25°F range favors ice formation, since the moisture content of the air is maximum (see psychometric data in Figure 12). Maximizing air flow rate also results in a greater mass of water vapor in contact with the foam surface and enhances deposition of ice crystals. Nevertheless, it should be emphasized that in the testing envelope explored, no significant ice buildup on surfaces of the void developed even after extended periods of air flow. These tests utilized air saturated with water vapor. It is possible that, unless an aircraft encounters combinations of atmosphere-tank conditions beyond those outlined in Table XVI, no significant icing will occur in the vent area of a foam-filled fuel tank containing a 6" cubical void at the inlet.

7. FLOW TESTING

7.1 Dynamic Flow

Another factor to be investigated was that of dynamic fuel flow through the foam, to simulate fuel passage into a fuel tank and for engine supply. Pumping temperatures selected were 32°F, -30°F, and -65°F at 6, 15, and 23 gallons per minute. This test was designed to show restriction in flow, icing of the foam, and degree of foam erosion.

The facilities for this portion of the project are shown in Figure 13. The equipment is essentially a flow loop of chilled fuel through a 6-inch diameter by 2-foot long section of foam packed Pyrex pipe (visible below the rotameter). The foam section can be bypassed while test fuel is being chilled by circulation through the dry ice-isopropanol bath prior to a test run. Foam performance during the test was monitored by pressure drop, internal bed temperature, and visual examination.

Shakedown runs of the dynamic flow facilities were completed, and the following parameters, both with and without foam packed in the Pyrex test chamber, were investigated.

Fuel pumping temperature: Ambient, 32°F, -30°F, -65°F
Fuel pumping rate: 23, 15, 6 gallons per minute
Test chamber: 6-inch ID x 24-inch Pyrex pipe

Higher flow rates were contemplated, dependent upon the ability to secure a suitable capacity pump within the time limits for the program. Unfortunately, the pump procurement delivery exceeded the program completion date.

A schematic flow diagram of the test rig appears in Figure 14. An initial series of runs using JP-4 as the pumped fluid was made with the test chamber empty. The temperature and flow parameters examined were:

<u>JP-4 Temperatures, °F</u>	<u>JP-4 Flow Rates, gpm</u>
90 (ambient)	23, 15, 6.2
32	23.8, 15, 6.2
-45	24.5, 15, 6.2
-75	23, 15, 6.2

The first flow rate listed in each case is the maximum obtainable from the pumping system, coincident with temperature control at the level shown. Flow rates for each test run were set at 55% of rotameter scale (23 gpm), or maximum; 35% (15 gpm); and 15% (6.2 gpm). Temperature of the flowstream was controlled by adjustment of the flow by-passing the cooling coil. Test results were recorded when identical temperatures were indicated by a thermocouple mounted in the test chamber over a fifteen-minute period, showing that a steady state had been reached. In the case of the ambient temperature runs, energy input to the fluid from the Blackmer pump caused a slow, steady rise in temperature, and the mean temperature (between readings 5-6° apart) was taken for a fifteen-minute observation period.

No temperature effect due to line friction could be observed in any of the test runs conducted, which was to be expected, considering the fluid velocities involved.

Pumping Rate	Linear Velocity	
	In 3/4" Inlet Line	In 6" Test Chamber
6.2 gpm (15%)	3.73 ft/sec.	0.0706 ft/sec.
15 gpm (35%)	9.00 ft/sec.	0.170 ft/sec.
23 gpm (55%)	13.80 ft/sec.	0.261 ft/sec.

Pressure drop readings across the test chamber are shown along the solid lines in Figure 15, in which it is apparent that fluid temperature had no significant effect on pressure drop across the empty test chamber. Pressure gauges on all dynamic flow tests were read to the nearest 1/2 psi, which proved sufficient to satisfy the test objectives. The data scatter is attributable to the difficulty in reading small differences in pressure drop, and shows that under the observation conditions no significant pattern emerges.

The second series of test runs involved pumping at similar temperatures and flow rates with foam installed in the test chamber. Figure 16 shows the cylindrical foam stack being placed in the Pyrex test chamber. The foam was cut about 10% oversize in diameter to provide slight compression during exposure to test conditions. In addition, the foam was carefully weighed before installation in the test chamber. The system was again operated at four specified temperature levels and at flow rates of maximum obtainable, 35% of scale, and 15% of scale. Pressure drop readings from the second series of test runs are shown along the dashed lines in Figure 15. Presence of the foam raised test chamber pressure drop to a somewhat higher level, but again no significant effect of fluid temperature on the pressure differentials could be found.

The foam was removed from the test chamber, drained of residual fuel, and dried overnight at 140°F. The foam stack weighed 417.6 grams, as opposed to the 414.7 grams it weighed when originally placed in the test chamber. When some fine particles were observed on the foam surface, the foam was shaken vigorously, and enough particles were dislodged to reduce the final observed weight to 416.4 grams, a net gain over the testing period of 0.41%. Even though the foam is relatively coarse, these findings indicate that it tends to act as a filter bed to remove suspended materials in the system. The particles removed from the foam consisted entirely of pipe scale and rust, probably dislodged by thermal shock during temperature variations, since the pumping system was cleaned thoroughly prior to charging JP-4 for testing. It is probable that the remaining foam weight gain is attributable to particles still held within the foam structure.

In its final state the foam was slightly darkened from its initial bright orange color, but showed no signs of attrition or change in any other characteristics.

At this point the system was drained, flushed completely with Avgas, and recharged with Avgas. After the same foam stack was replaced in the test chamber, Avgas pumping test runs were conducted at -30°F and -65°F . Test results (Figure 17) indicate a slightly lower pressure drop than for JP-4 at each flow rate, a function of the lower Avgas viscosity, and there was no observable effect of temperature on pressure differentials.

Fuels used in the three series of test runs were in "as-received" condition. No attempt was made to dry the fuels before testing, and no water addition was made. The pumping system was operated with a laminated-type flame arrestor on the fuel surge tank, permitting passage of water vapor in or out of the system. No water fraction was observed in the test chamber or in fuel drained from the system, and no visible ice formation occurred in the test chamber during any of the runs. The piping system was thoroughly grounded; no static buildup or discharge could be detected during the test runs.

Thirty dynamic flow tests were made. Test fuels (JP-4 and Avgas) in "as-received" condition were pumped through the test chamber at inlet line velocities ranging up to 13.8 ft/sec. and test chamber superficial velocities up to 0.261 ft/sec. Fuel temperatures during the tests were controlled at 90°F to -75°F . No significant change in pressure drop readings across the foam test chamber was observed with change in fuel temperature, and no degradation of the foam, which was compressed slightly in the test chamber, was apparent from visual observation and foam weight checks. The foam however acted as a filter bed, removing suspended foreign particles from the flow system.

It is concluded that at the velocities and temperatures achieved during the dynamic flow tests changes in temperature level do not significantly affect the pressure drop across the test chamber when pumping JP-4 or Avgas. Presence of Scott S-103-10-102 foam in the test chamber raises pressure drop readings across the entire flow range but does not make a significant change in the temperature-pressure drop relationship.

7.2 Pump Down Tests

A simulated fuel tank, equipped with an actual aircraft boost pump, was fabricated to study the effects of the foam on the fuel transfer rates. These tests were conducted with JP-4 fuel

at both ambient and low temperatures. Equipment utilized is shown in Figures 18 and 19 and a description of equipment is as follows:

Tank - Galvanized, 117 gallon capacity, fitted with lid. A 1" pump discharge line shown in Figure 19 was increased in diameter to 1-1/2" in order to approach maximum pump capacity more closely. Horizontal cross-sectional area of the empty pump-down tank was 8.14 ft²; with the foam in place occupying about 3% of total volume: the net cross-sectional area was 7.90 ft².

Pump - Integral sump-mounted aircraft booster pump - Hydro-Aire Model AY V/L 60-0933.

Velocity Measurement - Turbine flow - Pottermeter.

Mass Fuel Measurement - Calibrated reservoir mounted external to equipment.

Temperature - Thermocouple monitors in tank.

Shakedown tests were made without the foam to establish the rig capabilities and to assure that test measurement instrumentation was satisfactory. Tank was then packed with foam and check out conducted at ambient temperature for a base line comparison. Initial runs at -65°F with JP-4 fuel were sufficient to indicate that low temperature did not affect pump-out performance and therefore, remaining tests were run at ambient conditions.

The presence of foam in the pump-down tank did not limit the output rate of the pump, which reached a maximum of approximately 41,500 lb JP-4/hour with and without foam in the tank. However, the foam did limit the total amount of fuel transferred at maximum pump output. This holdup effect is illustrated by data in Table XXII, which was used to prepare Figure 20. Essentially all the usable fuel is recovered from the tank (Note: Some fuel is held up in the structure due to wetting action) at pumping rates up to 10,000 lb/hr, which in this tank corresponds to a vertical drop in fuel level of 0.44 foot per minute. The percentage of fuel recovered then drops roughly in inverse proportion to the pumping rate to 87.2% of total at the maximum pump output of 41,500 lb/hr, equivalent to a 1.81 feet per minute drop in the fuel level.

The degree of hindrance to fuel flow in the horizontal direction was studied. In order to evaluate this effect on pump performance, tests were run with and without foam in the tank, first

with the tank in its customary horizontal position, and second, with the end opposite the pump raised 2" or 2.5° from horizontal. Table XXIII indicates that tilting the tank to this degree had no appreciable effect on fuel transferred. Further tests with the lower section of foam removed from the tank did not appreciably change the fuel transfer rates.

The critical parameter in the pump-down tests appears to be the vertical velocity of the fuel through a given cross-sectional tank area. Fuel transfer rate has been expressed in terms of vertical velocity in Figure 20, the drop in fuel level therefore being applicable for use in tank systems of different geometry.

V. APPENDIX

1. Tables I through XXIII
2. Figures 1 through 20
3. Evaluation of Baffle Material - University of Dayton
Research Institute
4. Microbiological Compatibility Tests on Polyester
Urethane Foam - University of Dayton Research Institute

Table I

FLUID EXPOSURE

158°F for JP-4, etc., and 110°F for Avgas.

Compression Load Deflection, psi	Days Exposure						Same Fluid Entire 28 Days
	Fluid Changed Each 7 Days						
	As Rec'd	7	14	21	28		
<u>25%</u>							
Control	0.30	--	--	--	--	--	0.36
JP-4	0.30	0.25	0.25	0.31	0.29	--	0.34
Type I Fluid	0.30	0.29	0.26	0.33	0.37	--	0.35
Type III Fluid	0.30	0.29	0.23	0.30	0.31	--	0.28
Control	0.33	--	--	--	--	--	--
Avgas 2	0.33	--	--	--	0.36	--	--
Avgas 3	0.33	--	--	--	--	--	0.34
<u>50%</u>							
Control	0.39	--	--	--	--	--	0.45
JP-4	0.39	0.35	0.33	0.39	0.40	--	0.41
Type I Fluid	0.39	0.40	0.35	0.42	0.45	--	0.46
Type III Fluid	0.39	0.39	0.30	0.41	0.40	--	0.40
Control	0.41	--	--	--	--	--	--
Avgas 2	0.41	--	--	--	0.45	--	--
Avgas 3	0.41	--	--	--	--	--	0.44
<u>Tensile Strength, psi</u>							
Control	22.6	--	--	--	--	--	22.7
JP-4	22.6	21.3	21.0	25.3	21.2	--	21.9
Type I Fluid	22.6	26.6	24.4	23.2	23.3	--	24.7
Type III Fluid	22.6	21.4	16.3*	18.2*	21.9	--	24.7
Control	18.6	--	--	--	--	--	--
Avgas 2	18.6	--	--	--	20.0	--	--
Avgas 3	18.6	--	--	--	--	--	20.4

Table I - Cont'd

Elongation, %	As Rec'd.	Days Exposure				Same Fluid Entire 28 Days
		Fluid Changed Each 7 Days				
		7	14	21	28	
Control	327	--	--	--	--	314
JP-4	327	282*	322	335	322	355
Type I Fluid	327	309	332	284*	308	289*
Type III Fluid	327	280*	270*	276*	311	334
Control	290	--	--	--	--	--
Avgas 2	290	--	--	--	297	--
Avgas 3	290	--	--	--	--	297
<u>Volume Change, %</u>						
Control	--	None	None	None	None	None
JP-4	--	"	"	"	"	"
Type I Fluid	--	"	"	"	"	"
Type III Fluid	--	"	"	"	"	"
<u>Foam Color</u>						
Control	Bright Orange	NC**	NC	NC	NC	NC
JP-4	"	Lt. Orange	Same	Lt. Orange- Brown	Same	Same
Type I Fluid	"	"	Same	Same	Same	Same
Type III Fluid	"	Lt. Yellow- Orange	Same	Same	Same	Same

*Probably result of test repeatability and specimen variation.

**No change.

Table II

FUEL SPECIFICATION TESTS*
MIL-G-5572C, Grade 115/145

	Batch 1	Batch 2			Batch 3					
		Can 2	As Rec'd	7 Days	14 Days	21 Days	28 Days	As Rec'd	28 Days	
Laboratory Test Number*	1963	1964	2871	2873	2874	2875	2876	1965	2872	2877
Gravity, °API	68.6	68.4	67.4	67.4	67.6	67.4	67.5	68.8		67.5
Existent Gum, mg/100 ml	0.2	0.4	1.2	9.6	3.2	2.2	2.2	0.6	1.0	8.0
Aniline Point, °F	150.3	149.0	149.5	149.0	149.0	149.0	149.0	147.0		146.0
Aniline Gravity Constant	10311	10192	10076	10072	10043	10058		10114		9855
Aromatics, %	5.0	6.0	5.8	6.4	6.5	5.6		8.0		8.5
Olefins, %			0.9	0.9	0.6	1.0				0.8
Knock Rating								Lean 117.3 Rich 146.6		Lean 119.2 Rich 147.2
Total Solids, mg/gal.	1.6	3.2	0.4	0.4	0.4	0.4	0.4	1.2		0.8
Fibrous Material/Qt.			Trace	Trace	Trace	Trace	Trace			Trace
Visible Free Water, ml/gal.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0
Tetraethyllead, ml/gal.			4.54	4.67	4.67	4.75	4.66		4.42	4.61
Distillation, °F										
IBP										337
10%										352
20%										355
50%										364
90%										380
E.Pt.										422
Rec., %										99.0
Res., %										1.0
Loss, %										1.0

Table III

SUMMARY OF TEMPERATURE EFFECT RESULTS

<u>Foam Exposure</u>	<u>Compression Load Deflection, psi</u> <u>25%</u>	<u>Compression Load Deflection, psi</u> <u>50%</u>	<u>Compression Set, %</u> <u>22 hrs @ 158°F</u>	<u>Compression Set, %</u> <u>90 min @ RT Only</u>
(1) Unexposed	0.35	0.44	51.3 44.4	5.7
(2) 180°F/RT	0.35	0.50	26.0	1.5
(3) 180°F/-65°F	0.33	0.41	26.8	2.9
(4) Unexposed foam compressed to 10% normal height for 90 minutes @ RT			44.4	7.1

Above samples compressed to 10% normal height for 90 minutes at RT and allowed to recover.

Table IV

HYDROLYTIC DEGRADATION

(160°F, 100% R.H.)

	Control		After 7 Days		After 28 Days	
	<u>Orange*</u>	<u>White*</u>	<u>Orange</u>	<u>White</u>	<u>Orange</u>	<u>White</u>
Compression Load						
Deflection, psi						
25%	0.30	0.34	0.27	0.32	0.20	0.35
50%	0.39	0.42	0.37	0.40	0.28	0.41
Tensile Strength, psi	22.6	15.7	19.1	16.1	8.9	14.6
% Elongation	327	136	307	152	212	136

*Orange - Polyester
 White - Polyether

Table V

MATERIAL STABILITY DATA

<u>Exposure Media</u>	<u>Tensile Strength, psi</u>	<u>% Elongation</u>	<u>Compression Load Deflection, psi</u>	
			<u>25%</u>	<u>50%</u>
<u>Static Test - Fuel-Wet @ -65°F</u>				
Controls	18.6	290	0.30	0.39
AvGas	17.5	266	0.36	0.43
Type I Fluid	17.2	272	0.35	0.46
Type III Fluid	16.0	252	0.38	0.47
JP-4	16.3	264	0.36	0.45
JP-5***	17.5	292	0.34	0.43
<u>Static Test - Immersion @ -65°F</u>				
Controls	18.6	290	0.30	0.39
AvGas	17.0	277	0.36	0.45
Type I Fluid	16.6	282	0.34	0.42
Type III Fluid	17.3	277	0.35	0.43
JP-4	18.0	270	0.34	0.41
JP-5***	17.2	289	0.31	0.39
<u>Slosh Test* @ -65°F</u>				
Control	18.6	290	0.30	0.39
AvGas	18.7	292	0.34	0.44
Type I Fluid	14.7**	242	0.35	0.45
Type III Fluid	14.7**	248	0.35	0.44
JP-4	16.6	247	0.34	0.42
JP-5***	17.3	266	0.35	0.42

*Cooled to -65°F then sloshed 2 hours.

**Probably the result of test repeatability and specimen variation.

***-40°F

Table V - Cont'd

MATERIAL STABILITY DATA

<u>Exposure Media</u>	<u>Tumble Test* @ -65°F</u>			
	<u>Tensile Strength, psi</u>	<u>% Elongation</u>	<u>Compression Load Deflection, psi</u>	
			<u>25%</u>	<u>50%</u>
Controls	18.6	290	0.33	0.41
Avgas	17.5	269	0.32	0.41
Type I Fluid	16.9	268	0.33	0.44
Type III Fluid	16.9	265	0.36	0.45
JP-4	16.3	247	0.31	0.39
JP-5**	17.3	284	0.32	0.39

*Cooled to -65°F then tumbled 72 hours.

**Cooled to -40°F then tumbled 72 hours.

Table VI

PARTICULATE CONTAMINATION DATA

<u>Exposure Media</u>	<u>mg/ft³ Foam</u>	<u>mg/gal. Fuel</u>	<u>mg/ft³ Foam</u>	<u>mg/gal. Fuel</u>	<u>Previous Work</u>
		<u>Slosh Test^a @ -65°F</u>			
Avgas	133.3	5.1	19.5		2.8
Type I Fluid	133.3	5.1	--		--
Type III Fluid	111.1	4.2	--		--
JP-4	188.9	7.2	21.0		3.3
JP-5	155.5				
		<u>Slosh Test^a @ -40°F</u>			
		5.9			
JP-4	166.7			21.0	3.3
		<u>Slosh Test^a @ R.T.</u>			
		6.3			
		<u>Tumble Test @ -65°F^b</u>			
Avgas	77.8	2.9			
Type I Fluid	111.1	5.7			
Type III Fluid	144.4	5.5			
JP-4	144.4	5.5			
JP-5 ^c	266.6	9.3			
Dry Foam Only	85.6% by weight lost by 2-1/2" cube. Particles produced generally >1500 μ in size.				

^aCooled to test temperature then sloshed 2 hours.

^bCooled to -65°F then tumbled 72 hours.

^c-40°F.

Table VII

WEIGHT (MG) OF PARTICULATE CONTAMINATION

JP-4 volume - 3.17 gal. Foam volume - saw-cut 0.49 ft³; wire cut 0.45 ft³.

Treatment	Mg of Undissolved Solids										Total per Cu.Ft. of Foam				
	In One Quart		In One Gallon		In Balance of Fuel		In Total Volume		Total per Gal. of Fuel						
	Saw	Wire	Saw	Wire	Saw	Wire	Saw	Wire	Saw	Wire					
Reservoir blank #1	0.2														
Initial blank (before foam addition)	0.2	0.0	0.8	0.1	1.0	0.8	2.0	0.9	0.63	0.28	4	2			
Fill and drain #1	0.3	0.1	0.7	0.1	2.0	1.1	1.0	0.4	0.32	0.13	2	1			
Reservoir blank #2	0.0														
Fill and drain #2	0.4	0.1	0.5	0.0	1.4	1.1	0.3	0.3	0.09	0.10	1	1			
Reservoir blank #3	0.2														
Fill and drain #3	0.1	0.0	0.4	0.1	0.6	0.6	(-0.9)	(-0.2)	-	-	-	-			
Reservoir blank #4	0.1														
Fill and drain #4	0.1	0.3	0.1	0.1	0.2	1.0	(-1.6)	0.5	-	0.16	-	1			
Total extracted by fill and drain													3	3	
Slosh #1	0.7	0.5	1.7	1.0	10.0	5.8	10.4	6.4	3.28	2.0	21	14			
Slosh #2	0.0	0.3	0.7	0.7	3.4	4.8	2.1	4.9	0.66	1.6	4	9			
Total extracted by sloshing													25	23	
Compression #1	0.1	0.3	0.3	0.8	5.3	2.7	3.7	2.9	1.2	0.92	8	6			
Compression #2	0.0	0.4	0.1	0.4	4.9	4.3	3.0	4.2	0.95	1.3	6	9			
Total extracted by sloshing													14	15	
Total Weight Extracted													42	41	

Table VIII

WEIGHT (MG) OF PARTICULATE CONTAMINANTS EXTRACTED WITH
AVIATION GAS

<u>Treatment</u>	<u>mg of Undissolved Solids</u>				<u>Total</u> <u>per</u> <u>Gal.</u> <u>Fuel</u>	<u>Total</u> <u>per Cu.</u> <u>ft. of</u> <u>of Foam</u>
	<u>In one</u> <u>Quart</u>	<u>In One</u> <u>Gallon</u>	<u>In</u> <u>Balance</u> <u>of Fuel</u>	<u>In</u> <u>Total</u> <u>Volume</u>		
Blank	0.1	0.1	0.0	0.2		
Fill and Drain #1	0.2	0.2	1.0	1.2	0.4	2.7
Fill and Drain #2	0.2	0.5	1.0	1.5	0.5	3.3
Fill and drain #3	0.7	0.4	2.0	2.9	0.9	6.4
Fill and drain #4	(-0.2)	(-0.3)	0.2	(-0.3)	—	—
Total extracted by fill and drain					1.8	12.4
Slosh #1	0.7	2.5	5.8	8.8	2.8	19.5
Slosh #2	0.1	0.1	4.3	4.3	<u>1.4</u>	<u>9.6</u>
Total extracted by sloshing					4.2	29.1
Compression #1	0.0	(-0.1)	0.9	0.8	0.3	1.8
Compression #2	0.0	0.1	18.6	18.7	<u>5.9</u>	<u>41.5</u>
Total extracted by sloshing					<u>6.2</u>	<u>43.3</u>
Total Weight Extracted					12.2	84.8

Table IX

WEIGHT OF PARTICULATE CONTAMINANTS EXTRACTED WITH JP-4
Compression-Expansion

Trial No.	Wt. of Foam, g	mg of Undissolved Solids						Total per Cu.Ft. of Foam	
		Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5	Cycle 6		
1	62.640	22.7	22.1	20.7	20.2	17.3	8.7	111.7	1,545
2	61.820	15.1	0.4	4.1	12.8	21.0	12.3	65.7	910
3	62.270	20.6	8.1	20.6	11.9	9.8	5.9	76.9	1,060
4	63.860	34.9	24.5	23.3	15.6	27.9	14.5	140.7	1,945
5	61.150	12.9	18.2	9.0	11.6	9.1	13.9	74.7	1,005

Table X

WEIGHT (MG) OF PARTICULATE CONTAMINANTS EXTRACTED WITH WATER

<u>Trial No.</u>	<u>Wt. of Foam</u>	<u>Extr. #1</u>	<u>Extr. #2</u>	<u>Extr. #3</u>	<u>Extr. #4</u>	<u>Extr. #5</u>	<u>Extr. #6</u>	<u>Total</u>	<u>Total per Cu.Ft. of Foam</u>
Blank		0.0	0.0					0.0	
1	62.465	7.9	4.3	4.2	2.8	2.5	1.6	23.3	322
2	61.975	8.2	3.8	2.9	2.8	2.7	2.0	22.4	310
3	62.215	5.1	4.9	3.5	2.6	2.3	1.8	20.2	279

Table XI

CUMULATIVE WEIGHT (MG) OF SOLID CONTAMINANTS EXTRACTED

	Extraction					
	1	2	3	4	5	6
<u>Bun</u> (4-inch cubes)						
24	132.3	205.2	259.2	326.7	372.6	429.3
32	70.2	118.2	126.9	162.0	175.5	213.3
28	91.8	118.8	121.5	132.3	156.6	175.5
5	81.0	113.4	121.5	124.2	124.2	124.2
11	59.4	78.3	89.1	94.5	97.2	116.1
14	83.7	143.1	159.3	213.3	226.8	234.9
20	99.9	148.5	186.3	213.3	226.8	267.3
<u>Previous Work</u> (5-inch cubes)						
1	109.2	168.6	226.6	265.3	299.9	322
2	113.3	165.8	205.9	244.6	281.9	309.5
3	70.4	138.2	186.5	222.5	254.3	279

Table XII

PARTICLE DISTRIBUTION DATA (5-INCH CUBE)

<u>Particle Size, μ</u>	<u>Total Particles Counted</u>	<u>Foam Particles Counted</u>	<u>Particle Size Distribution, %</u>	<u>Foam Particles, %</u>
<50	2169	31	90.5	1.3
50-100	149	48	6.2	2.0
>100	79	23	3.3	1.0
Total	2397	102	100.0	4.3

Table XIII

SUMMARY OF PARTICULATE CONTAMINANTS

Contaminant	MRC		WPAFB		West Coast			
	Compression 1st Filtration	Sloshed 1st Filtration	No. 63		No. 54 Filter Wash	No. 66 Filter Wash	No. 51 Sump	No. 63 Sump
			1st Wash	2nd Wash				
Foam	X	X	X	X	X	X	*	*
Cotton or Paper Fibers	X	X	X	X	X	X	*	*
Man-Made Fibers	X	X	X	X	X	X		
Rust Scale	X	X	X	X	X	X	X	
Metal Fillings	X	X	X	X	X	X	X	X
Metal Shot (Solder)	X	X	X	X	X	X		
Siliceous Dust	X	X	X	X	X	X	*	*
Soot & Organic Char	X	X	X	X	X	X	X	X
Paint								
Flakes		X						
Spheres					X	X		X
Glass				X				

*Very little of these materials present in the samples.

Table XIV

EMISSION ANALYSIS

<u>Sample 54</u>	<u>Sample 66</u>
Si - 20%	Si - 20%
Al - 20%	Al - 20%
Fe - 10%	Fe - 10%
Pb - 10%	Pb - 10%
Zn - 5.0%	Zn - 5.0%
Ca - 3.0%	Ca - 3.0%
Mg - 2.0%	Mg - 2.0%
Na - 1.0%	Na - 1.0%
Ti - 1.0%	Ti - 1.0%
Cr - 0.6%	Cr - 0.6%
Cu - 0.6%	Cu - 0.6%
Cd - 0.3%	Cd - 0.8%
Ni - 0.1%	Ni - 0.1%
Mn - 0.3%	Mn - 0.3%
Sn - 0.08%	Sn - 0.06%
Mo - 0.02%	Mo - 0.02%
Zr - 0.01%	Zr - 0.01%
V - 0.007%	V - 0.007%
Ag - 0.003%	Ag - 0.003%

Table XV

EMISSION ANALYSES

Powder from Filter #12 (WPAFB Test)		Powder from Filter #15 (West Coast Test)
Al - Major Constituent) Low	Pb - Major Constituent
Si - Major Constituent		Al - Major Constituent
Zn - Minor Constituent		Si - Major Constituent Low
Ca - Minor Constituent		Ca - Major Constituent
*Fe - Minor Constituent		*Fe - Minor Constituent
Pb - Minor Constituent		Zn - 1.0%
Na - 1.0%		Mg - 0.6%
Cr - 0.8%		Na - 0.6%
Cd - 0.8%		Ti - 0.6%
Mg - 0.6%		Cu - 0.2%
Ti - 0.5%		Cr - 0.1%
Sn - 0.3%		Mn - <0.1%
Cu - 0.2%		Sn - <0.1%
Mn - <0.1%		Cd - <0.1%
Mo - <0.1%		Ni - <<0.1%
Ni - <<0.1%		Mo - <<0.1%
Zr - <<0.1%		Zr - <<0.1%
Ag - <<0.1%		Ag - <<0.1%

Metallics from Filter #15
(West Coast Test)

Fe - Major Constituent
 Pb - Major Constituent
 Zn - Minor Constituent
 Si - Minor Constituent
 Mn - 0.5%
 Al - 0.3%
 Ni - 0.1%
 Cr - <0.1%
 Ti - <0.1%
 Mg - <0.1%
 Cu - <0.1%
 Mo - <<0.1%
 Zr - <<0.1%
 Co - <<0.1%

*The iron content is lower in the powder from Filter #12 sample than from Filter #15.

The aluminum and silicon concentrations are the same in both powdered samples.

Table XVI

SUMMARY OF CONTAMINANTS ON HELICOPTER FILTERS

Contaminant	Sample Number			
	1	2	3	4
Foam	x	x	x	x
Fibers, Cotton	x	x	x	x
" , Filter	x	x	x	x
" , Manmade	x	x	x	x
Rust scale	x	x	x	x
Metal filings	x	x	x	x
Metal shot		x		x
Siliceous dust	x	x	x	x
Organic char	x	x	x	x
Paint flakes	x	x	x	x
Paint spheres	x			x
Insect parts		x		x
Composite laminate	x	x	x	x
Hair, animal		x		
Miscellaneous dust	x	x	x	x
Miscellaneous surface coatings	x	x	x	x
Miscellaneous resinous material		x	x	x
Total contaminant recovered, mg	160.0	80.7	79.2	108.9
% Inorganic	48.0	47.5	46.3	48.3
% Organic	52.0	52.0	53.7	51.7

Table XVII

HELICOPTER FILTER PARTICLE SIZE DISTRIBUTION

<u>Sample No.</u>	<u>Size (μ)</u>	<u>Particles Counted</u>	<u>Distribution (%)</u>
1	<50	1767	87.4
	50-100	176	8.7
	>100	80	3.9
2	<50	886	86.7
	50-100	70	7.0
	>100	63	6.3
3	<50	1313	93.5
	50-100	60	4.2
	>100	33	2.3
4	<50	2635	98.0
	50-100	32	1.2
	>100	26	0.8

Table XVIII

EMISSION ANALYSIS OF ASH FROM FUEL FILTER RESIDUES

	Wt.-%			
	<u>#1</u>	<u>#2</u>	<u>#3</u>	<u>#4</u>
Si	20	20	20	20
Fe	10	10	20	20
Al	20	10	10	8.0
Cd	5.0	3.0	1.0	5.0
Zn	3.0	2.0	5.0	8.0
Mg	2.0	2.0	3.0	2.0
Ca	0.7	5.0	0.7	0.8
Na	1.0	1.0	1.0	1.0
Pb	1.0	0.2	0.8	0.8
Ti	0.3	0.3	0.5	0.3
Cu	0.4	0.7	0.4	0.4
Mo	0.1	0.6	0.1	0.2
Cr	0.2	0.2	0.3	0.3
Ni	0.1	0.07	0.1	0.07
Mn	0.2	0.2	0.3	0.3
Sn	0.1	0.02	0.04	0.04
Zr	0.05	0.06	0.1	0.05
V	0.08	0.08	0.08	0.08
Ag	0.005	0.0002	0.002	0.0008

Table XIX

CORROSION OBSERVATIONS

	Days at 100°F, 100% RH				
	<u>0</u>	<u>7</u>	<u>14</u>	<u>21</u>	<u>28</u>
<u>Control Panels</u>					
Bare 7075	(1)	(2)	(2)	(2)	(2)
Bare 6061	(1)	(2)	(2)	(2)	(2)
Alodine 7075	(1)	(1)	(1)	(1)	(1)
Alodine 6061	(1)	(1)	(1)	(1)	(1)
<u>Dry Foam Specimens</u>					
Bare 7075	(1)	(1)	(2)	(2)	(3)
Bare 6061	(1)	(1)	(1)	(2)	(2)
Alodine 7075	(1)	(1)	(1)	(1)	(1)
Alodine 6061	(1)	(1)	(1)	(1)	(1)
<u>MIL-C-6529 Soaked Foam</u>					
Bare 7075	(1)	(1)	(1)	(2)	(2)
Bare 6061	(1)	(1)	(1)	(2)	(2)
Alodine 7075	(1)	(1)	(1)	(1)	(1)
Alodine 6061	(1)	(1)	(1)	(1)	(1)

- (1) Free of corrosion
(2) Several small pits
(3) Pitting and stains

Table XX

SIMULATED FIELD ENVIRONMENT

	As Rec'd	Exposure Cycles									
		2		4		8		14		20	
		Test Fluid	Test Fluid	Test Fluid	Test Fluid	Control Fluid	Test Fluid	Control Fluid	Test Fluid	Control Fluid	Test Fluid
Compression Load Deflection, psi		0.30	0.29	0.31	0.31	0.30	0.29	0.30	0.37	0.31	
25%		0.39	0.38	0.40	0.40	0.39	0.30	0.40	0.43	0.41	
50%											
Tensile Strength, psi	22.6					24.8	19.0*		26.6	30.3*	
Elongation, %	327					348	287*		349	356	

*Probably result of test repeatability and specimen variation.

Test Conditions

Humidity 70-90% entire test
 Temperatures 70°F gradually increasing to 135°F over a 3-hour period
 135°F maintained for 6 hours
 135°F gradually decreasing to 70°F over a 3-hour period
 Time/Cycle 12 hours

Table XXI

SUMMARY OF VENT ICING TEST RUNS

Test Run No.	Air Flow, PPS	Air Temp, °F	Dew Point, °F	Foam Temp, °F	N or S Test Cube	Dry or Wetted Foam	Test Duration, Min.	Test Results and Conclusions
1	20	40	42	0	N	W	10	No visible ice formation or increase in inlet pressure during run.
2	20	20	8	-50	N	W	10	Ditto
3	6	20	17	-50	S	D	10	Slight icing on foam prior to run. This decreased during run. No inlet pressure increase.
4	20	20	19	-65	N	W	10	Ditto
5	6	20	20	-65	N	W	10	Slight icing on foam prior to run. Ice "cobwebs" formed, then disappeared after 9 minutes.
6	25	20	3	0	N	W	10	No visible ice formation or increase in inlet pressure during run.
6A	20	10	3	-5	N	W	9	Ditto
7	21	32	26	-40	N	W	12	Slight icing on foam prior to run. This increased momentarily, then disappeared as foam temperature rose past 25°F.
8	5	30	36	-40	N	W	10	Ditto
9	20 + 50	20	20	20	S	D	71	Foam mounted flush to cube inlet. No increase in inlet pressure during run.
10	10	30	20	-20	N	W	10	No visible ice formation or increase in inlet pressure during run.
11	50	-30	-10	40	N	W	84	Foam mounted flush to cube inlet. Inlet pressure rose rapidly after 1 hr, 15 min. of run (to 13.0" H ₂ O). Foam surface at inlet filled completely with 1/4" thick frost layer.
12	50	-30	-8	-30	N	W	82	Foam mounted flush to cube inlet. Inlet pressure rose rapidly after 1 hr, 20 min. of run (to 31.0" H ₂ O). Ice penetration of 2" into foam block mounted at inlet.
13*	20 + 50	-20 + +30		0	N	W	30	-----
14	50	20	21	-40	N	W	27	Chilled foam with cold, dry air and then turned on full, wet air flow. Ice formed on foam at once, then gradually disappeared. No increase in inlet pressure during run.
15	40	20	10	-30	N	W	30	Chilled foam with cold, dry air and then opened wet air valve about 1/2. Increased to full wet air flow after 6 minutes. No visible ice formation or increase in inlet pressure.
16	50	-60	-54	-60	N	W	80	No visible ice formation or increase in inlet pressure during run.
17	5	-55	-21	-65	N	W	10	Slight icing on foam prior to run. No significant change in icing during run, and no increase in inlet pressure. Minimum air temperature obtained at the low flow rate was -55°F.
18	1	-	15	-65	N	W	49	Heavy icing on foam prior to run. No significant change in icing or inlet pressure during run. Air temperature was not controllable at 1 ft./sec. Rose rapidly from -65° and leveled at +20°F.
19	20 + 50	-65	-20	32	N	W	58	Reached minimum air temperature of -10°F at 20 ft./sec. Increased flow to 50 ft./sec after 10 min. Ice formed immediately and remained to end of run. No increase in inlet pressure during run.
20	6	135	-	-65	N	W	17	Air heated by steam addition. Light icing in box before run. This melted immediately, since inlet temperature jumped to 26°F within one minute after start of run.
21	6 + 50	-60	-	135	N	W	24	Foam heated with steam flow, leaving free moisture visible on foam prior to run. Air flow of 6 ft./sec insufficient to drop inlet temperature. Raised flow to 50 ft./sec at 7 min. mark and had immediate icing. Droplets on foam and Plexiglas froze, but inlet pressure did not change. Icing remained constant to end of run.

*First run with stainless screen mounted in front of foam. Immediate ice formation (on both screen and foam) upon admitting -20°F air to cold foam. Drop in flow rate indicated ice blockage in cooling coil, and moist air was admitted directly from compressor after 16 minutes. An immediate "snowstorm" resulted, causing momentary rise in inlet pressure from 0.3" to 1.2" H₂O. Ice then melted out rapidly and inlet pressure returned to lower value.

Test Cube Configuration: 1. Flow in test cube entered at one corner, exited at opposite corner.
2. 1" square stainless steel screen placed normal to flow, 1" in front of foam impingement face on Runs 13 - 21.

Table XXII

PUMP-DOWN TESTING

<u>Run No.</u>	<u>Date</u>	<u>Foam in Tank</u>	<u>Pumping Temp. (°F)</u>	<u>Pump Time (sec)</u>	<u>Fuel Flow (lb/hr)</u>	<u>Pump Discharge Pressure (psig)</u>	<u>Total Fuel Flow (lbs)</u>	<u>% of Tank Contents</u>
1	8-25-66	No	-65	65	41,500	23	745	100
2	8-25-66	No	-69	84	32,500	23	745	100
3	8-30-66	Yes	-64	49	41,500	22	560	87.2
4	8-31-66	Yes	Amb.	229	10,000	24	640	99.5
5	8-31-66	Yes	Amb.	206	11,500	24	660	99.5
6	8-31-66	Yes	Amb.	111	20,000	23	615	94.3
7	8-31-66	Yes	Amb.	80	27,000	22	600	92.2
8	8-31-66	Yes	Amb.	62	34,000	21	590	93.4
9	8-31-66	Yes	Amb.	50	40,000	20	555	86.2
10	9-20-66	Yes	Amb.	572	4,000	24	650	100
11	9-20-66	Yes	Amb.	382	6,000	24	650	100
12	9-20-66	Yes	Amb.	286	8,000	24	650	100
13	10-66	Yes	Amb.	554	4,300	23.5	662	100
14	10-66	Yes	Amb.	334	7,100	23.5	659	100
15	10-66	Yes	Amb.	246	9,600	23.0	656	100
16	10-66	Yes	Amb.	206	11,250	22.5	644	99.5
17	10-66	Yes	Amb.	192	12,100	22.5	645	99.5
18	10-66	Yes	Amb.	91.5	24,250	22.0	616	94.3

Table XXIII

EFFECT OF TILTING PUMP-DOWN TANKA. TANK HORIZONTAL (9-19-66)

<u>Time (sec)</u>	<u>Pump Discharge Pressure (psi)</u>	<u>Flow Instrument Reading</u>	<u>Increase in Fuel Reservoir Level (in.)</u>
0	23	13.7	-
30	23	13.7	-
60	22-1/2	13.7	-
90	22-1/2	13.6	-
120	22-1/2	13.6	-
150	22-1/2	13.5	-
183	-	-	15-5/8

B. TANK INCLINED (Elevated 2" at end opposite pump;
2° 30' from horizontal)

<u>Time (sec)</u>	<u>Pump Discharge Pressure (psi)</u>	<u>Flow Instrument Reading</u>	<u>Increase in Fuel Reservoir Level (in.)</u>
0	23	13.8	-
60	23	13.7	-
120	23	13.7	-
180	23	13.6	-
188	-	-	15-5/8

C. TANK INCLINED WITH VARYING PUMP RATE (1-5/8" in 30";
3° 6' from horizontal) (October 1966)

<u>Pump-Down Time (sec)</u>	<u>Pump Discharge Pressure (psi)</u>	<u>Flow (lb/hr)</u>	<u>Total Fuel Pumped (lbs)</u>
588	23.5	4,000	653
287	23.0	8,200	653
215	23.0	10,800	645
196	23.0	11,900	648

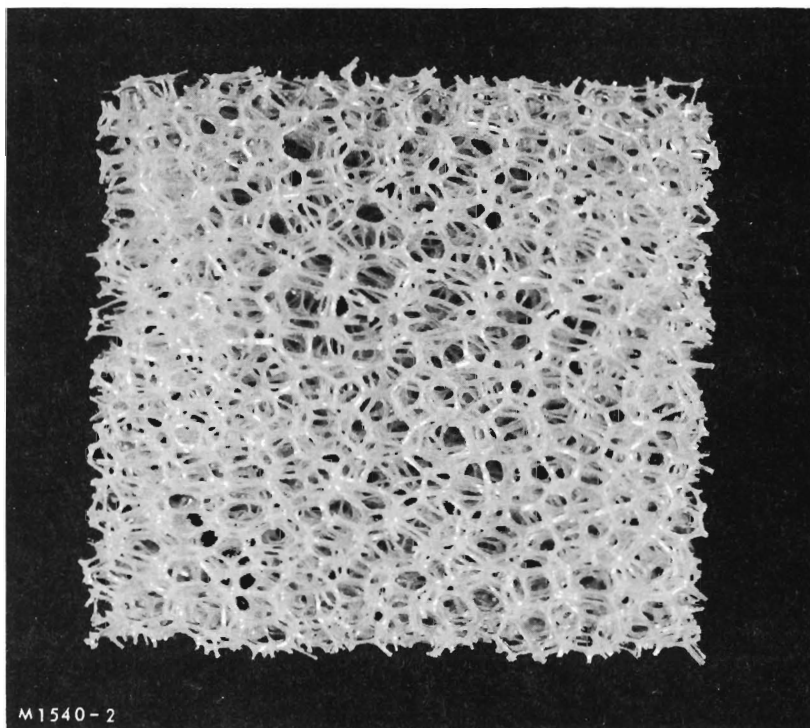
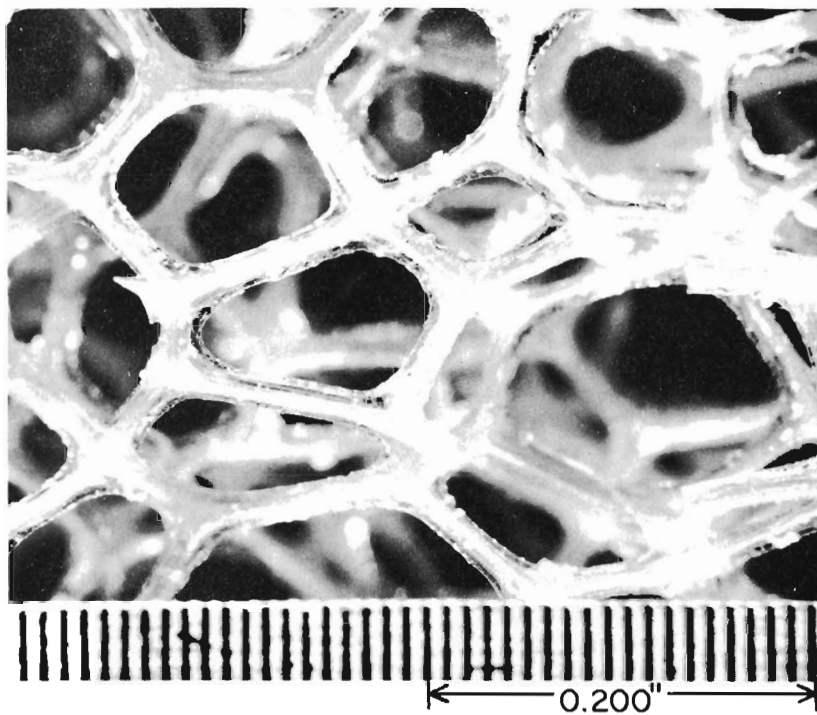


Figure 1. Foam Pore Structure.

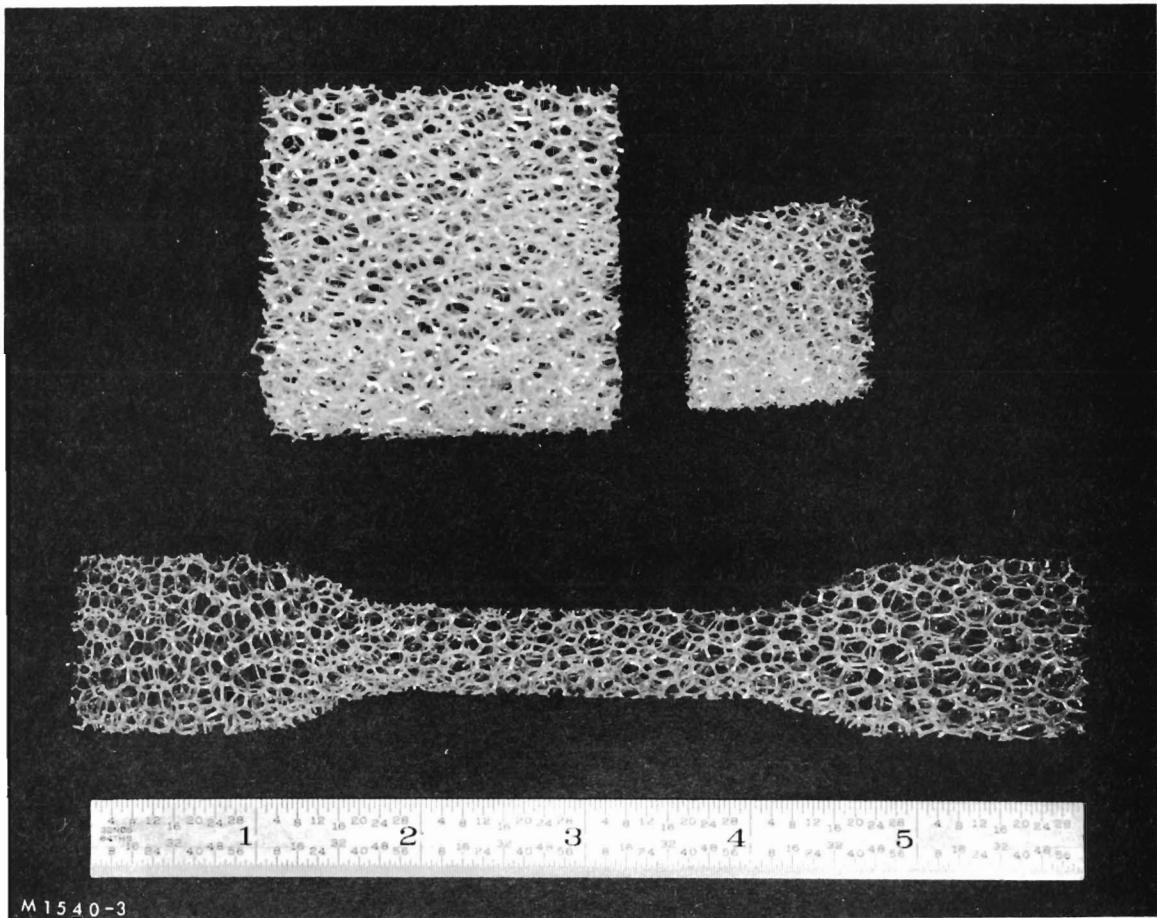


Figure 2. Test Specimens.

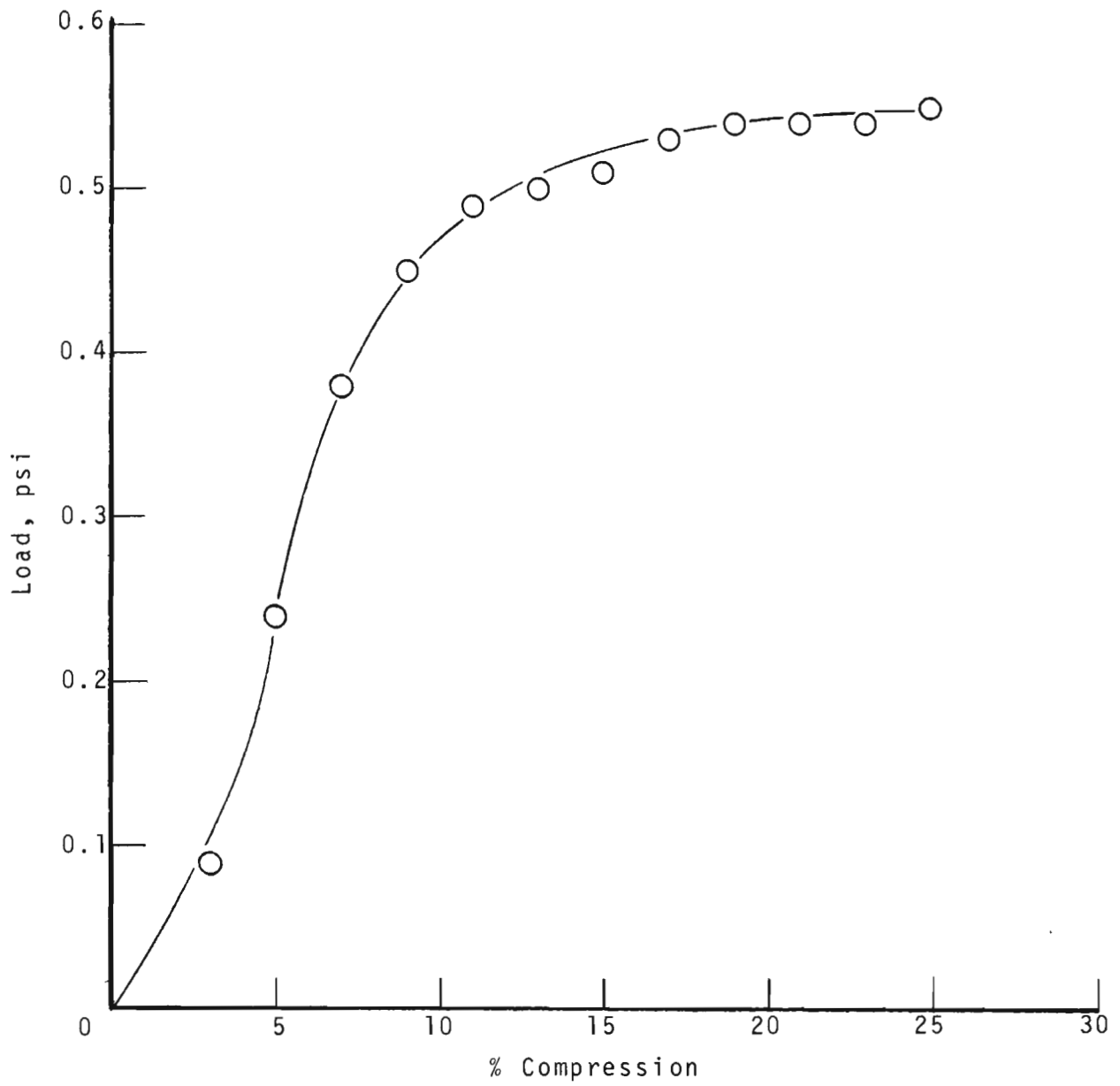


Figure 3. Load vs. Compression - 4" Cube at 75°F.

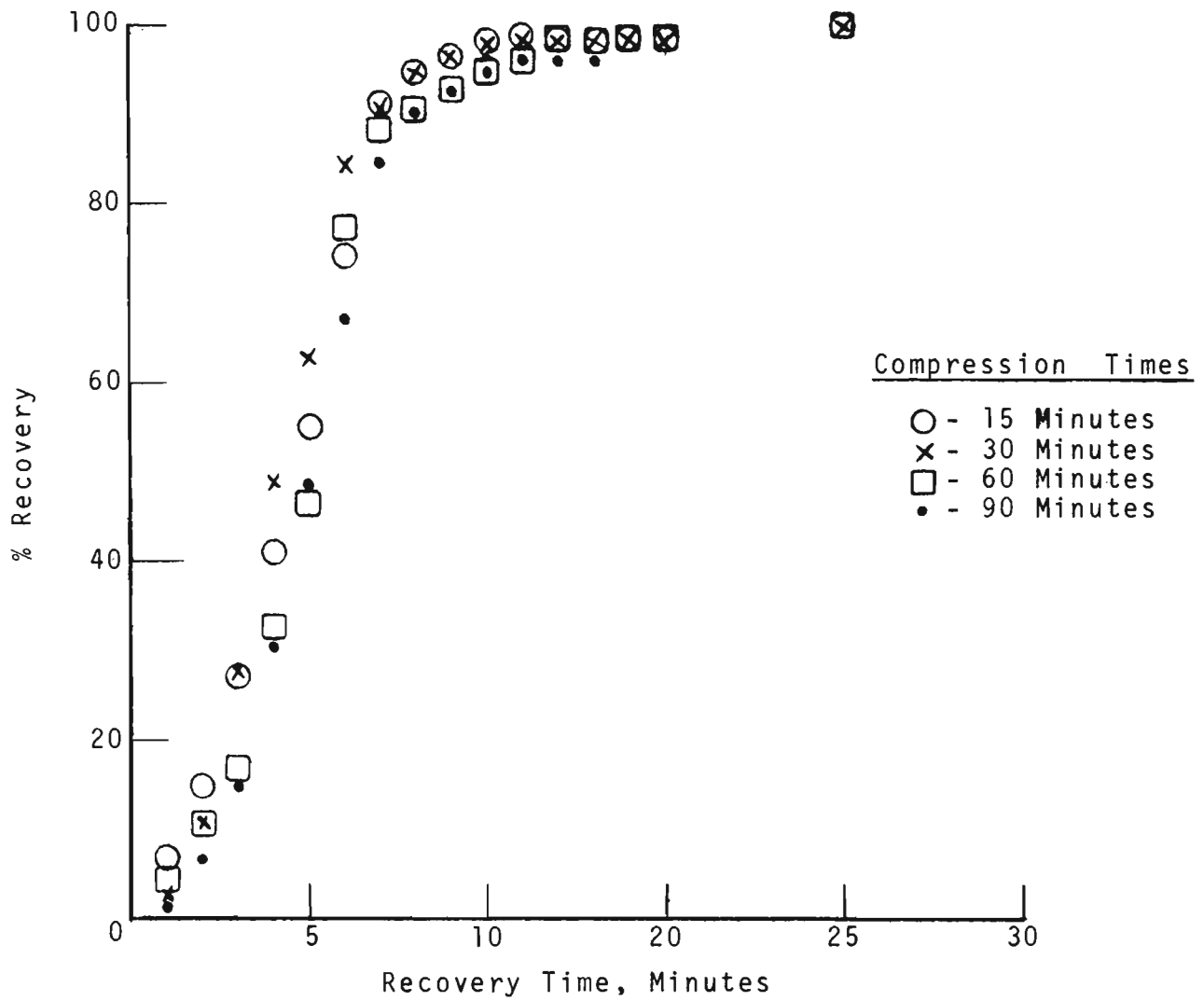


Figure 4. Foam Recovery at 77°F.

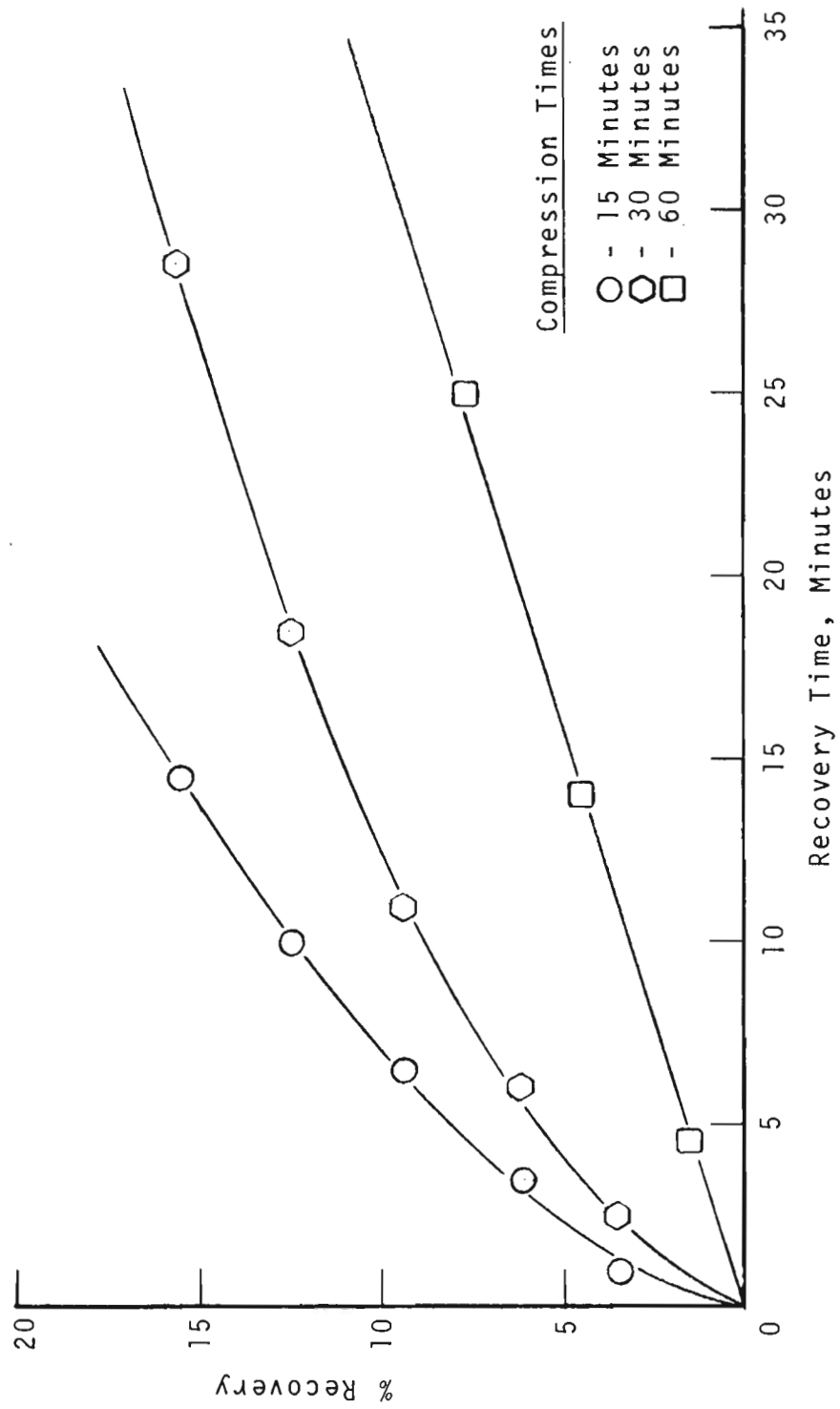


Figure 5. Foam Recovery at -20°F .

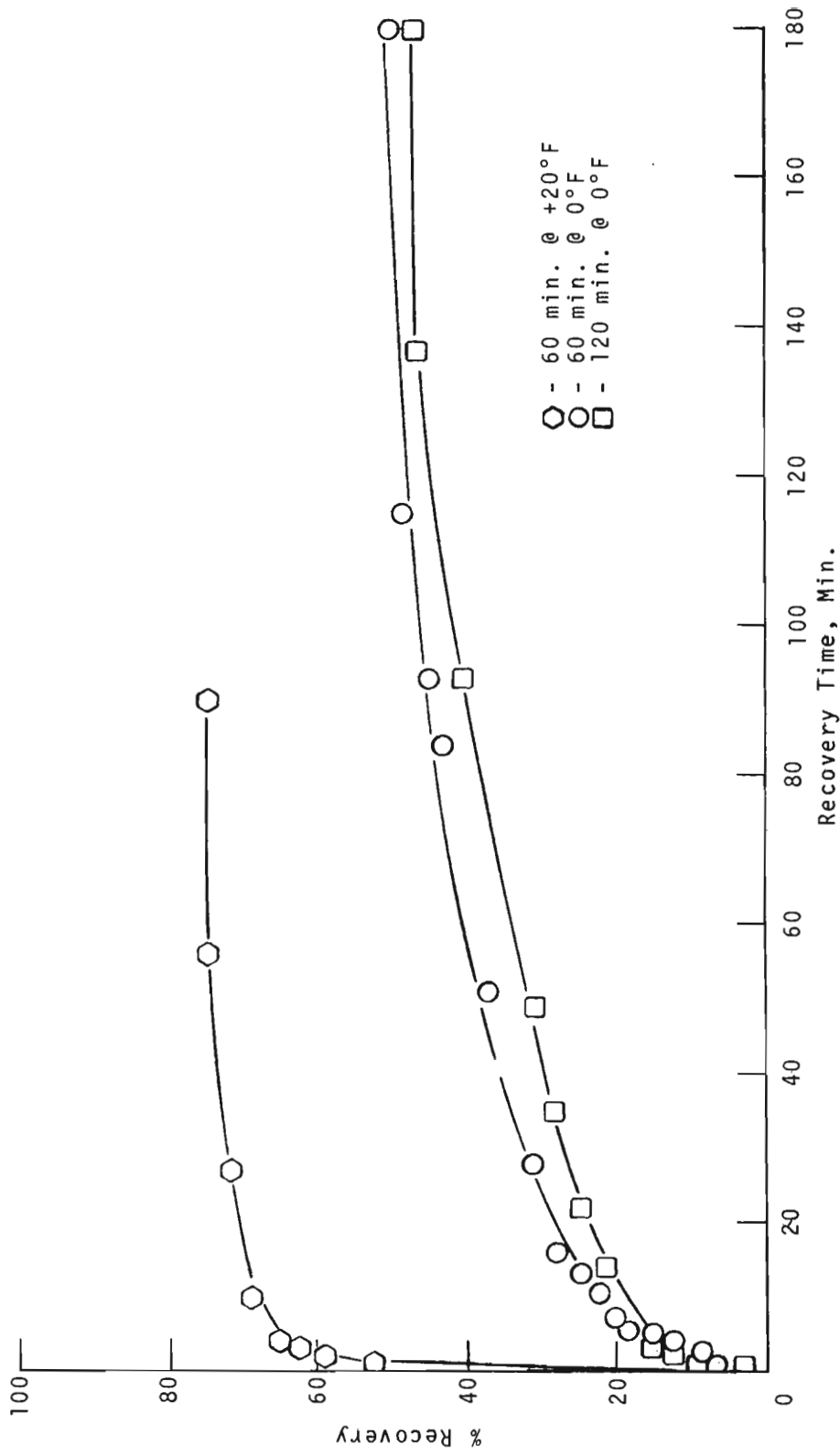


Figure 6. Foam Recovery.

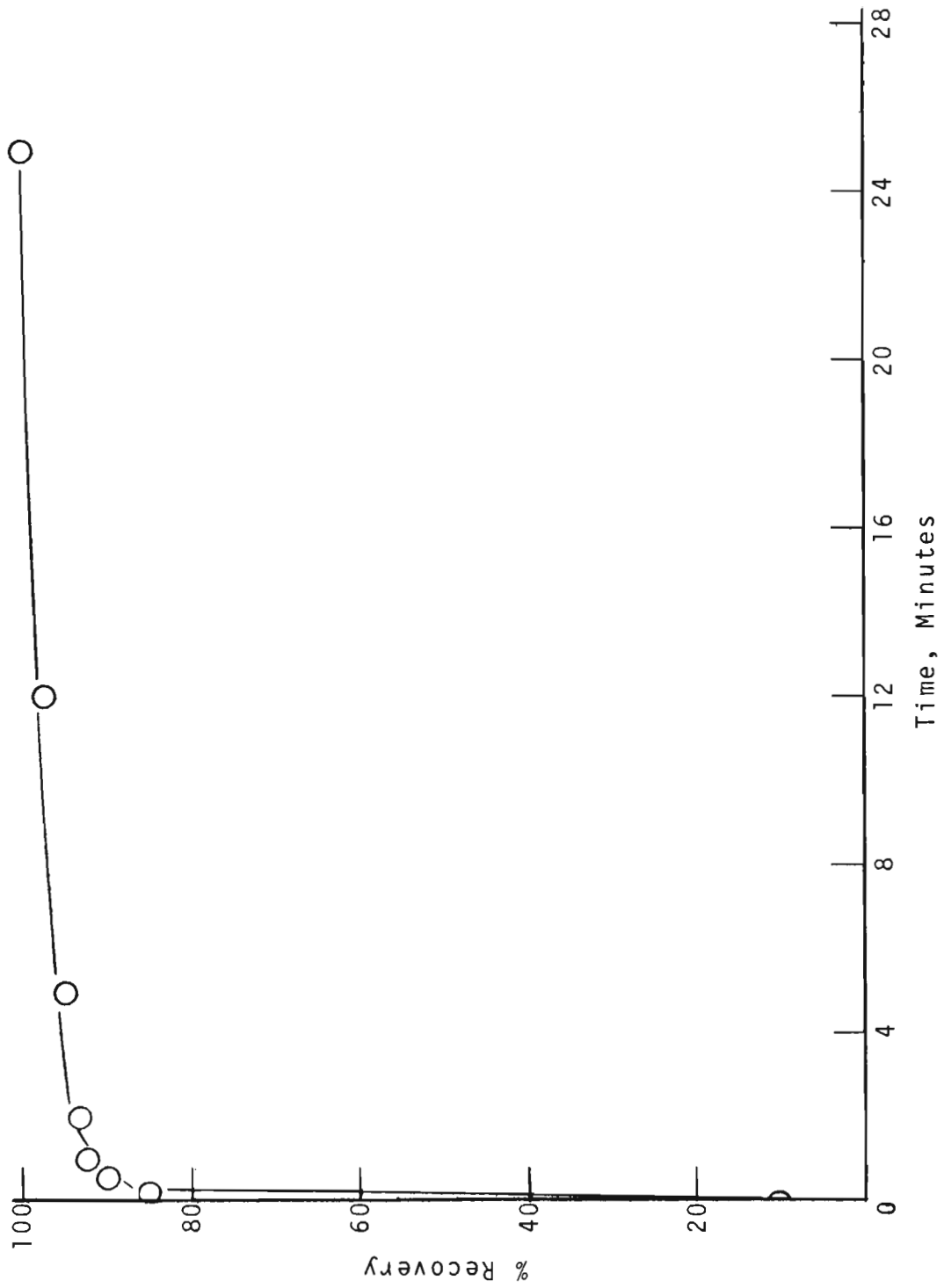


Figure 7. Foam Recovery at Room Temperature (4" Cubes).

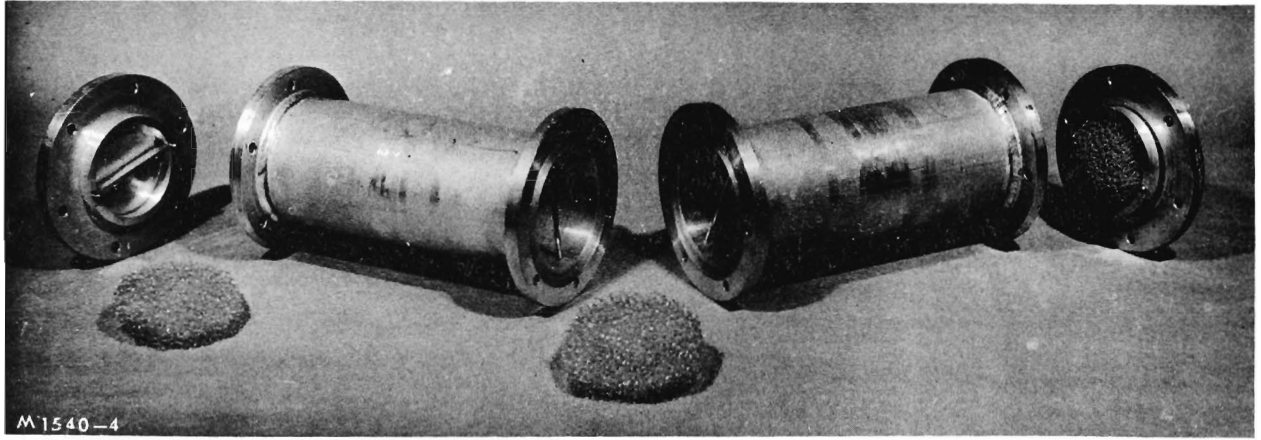


Figure 8. Slosh Tube.

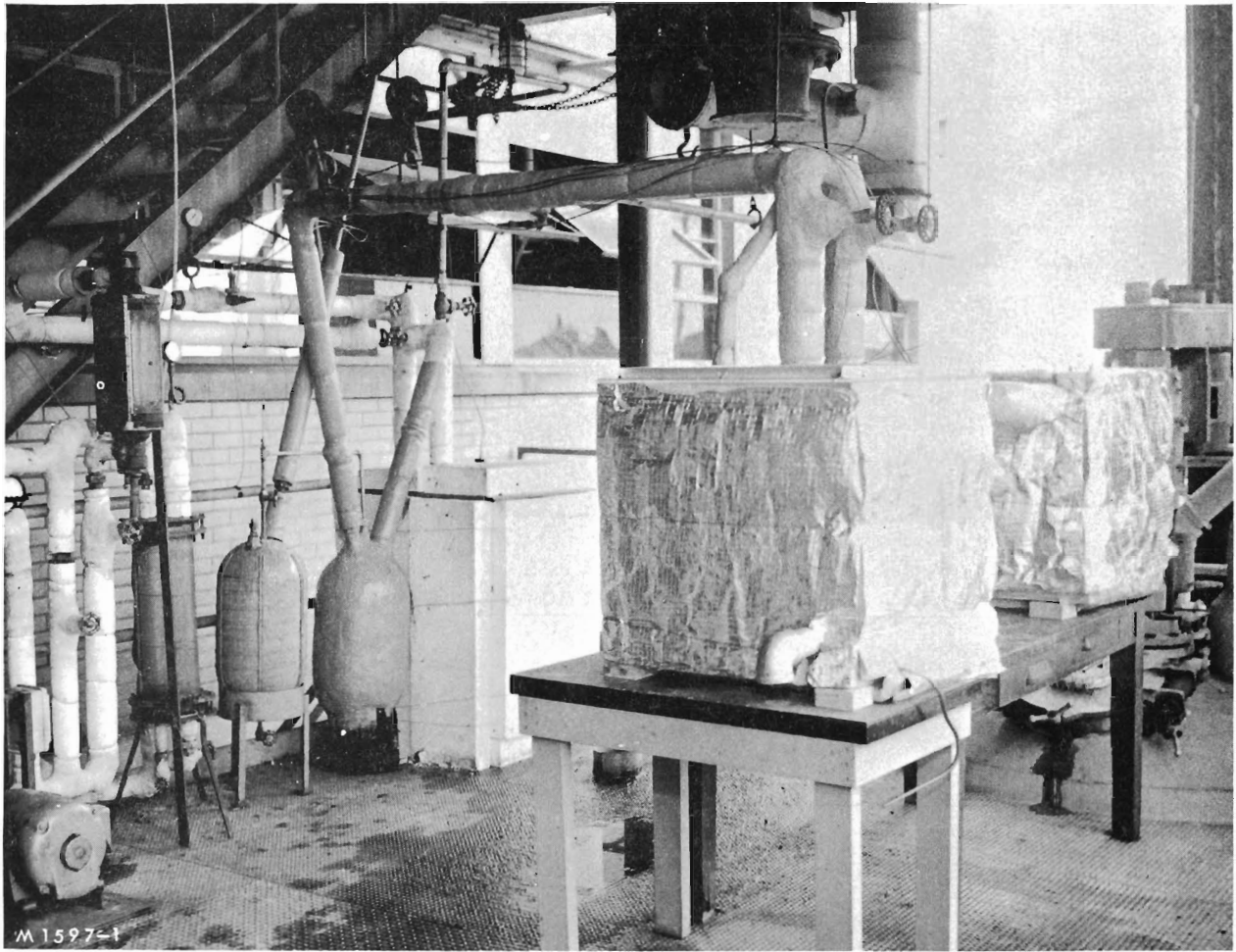


Figure 9. Vent Icing System.

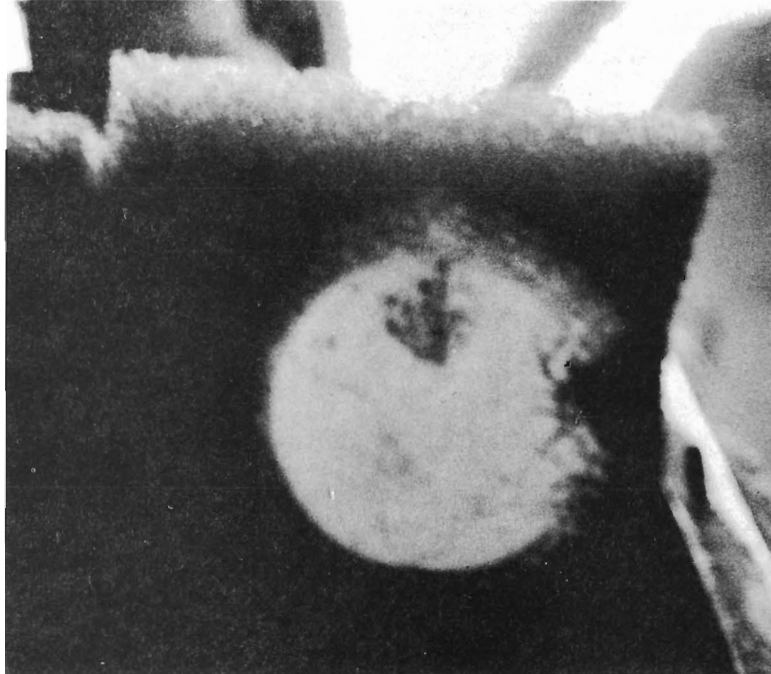


Figure 10. Ice Accumulation on Foam at Cube Inlet Following Run #11.



Figure 11. Ice Formation on Wire Screen and Foam at 10-Minute Mark During Run #13.

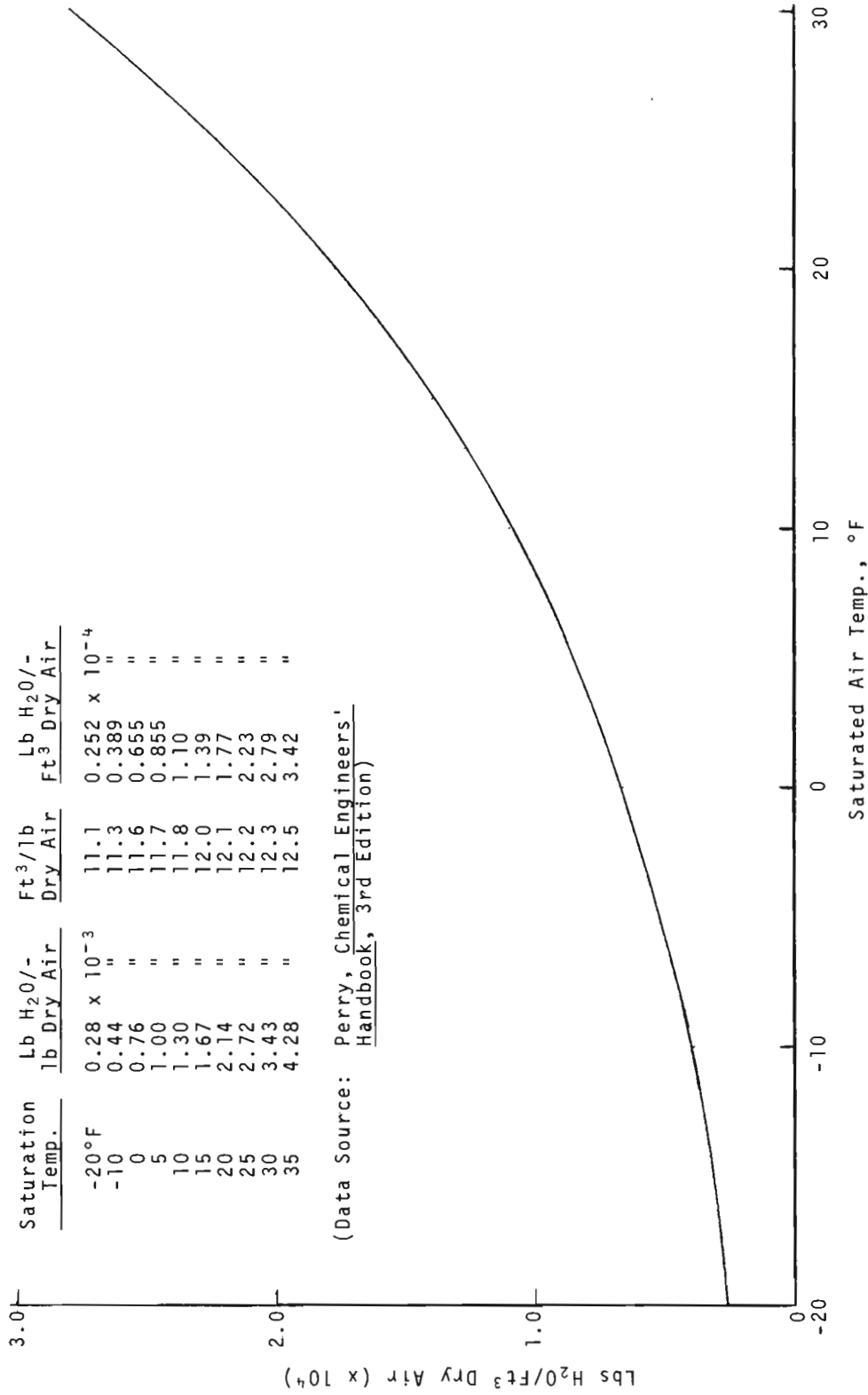


Figure 12. Psychrometric Chart for H₂O in Air.

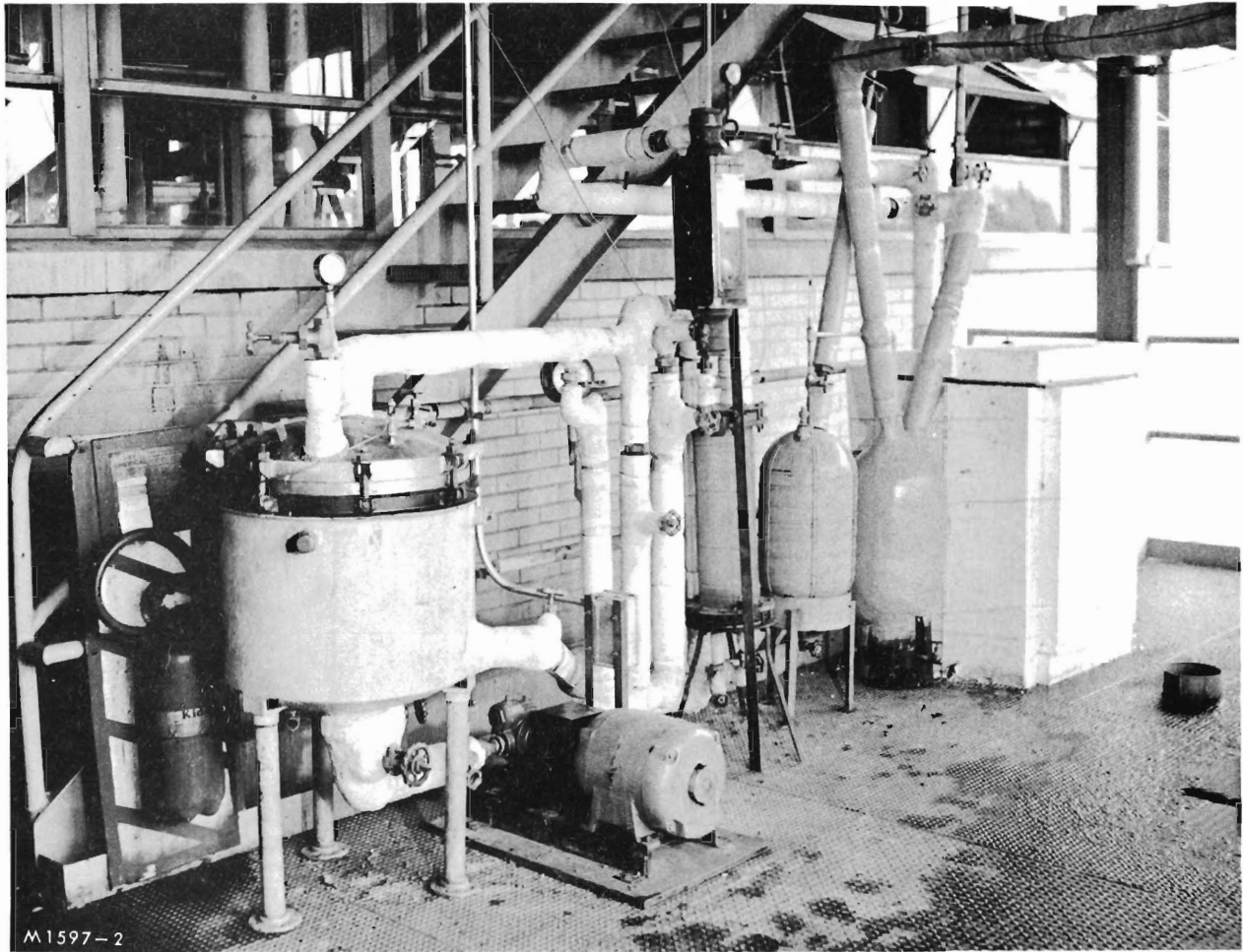
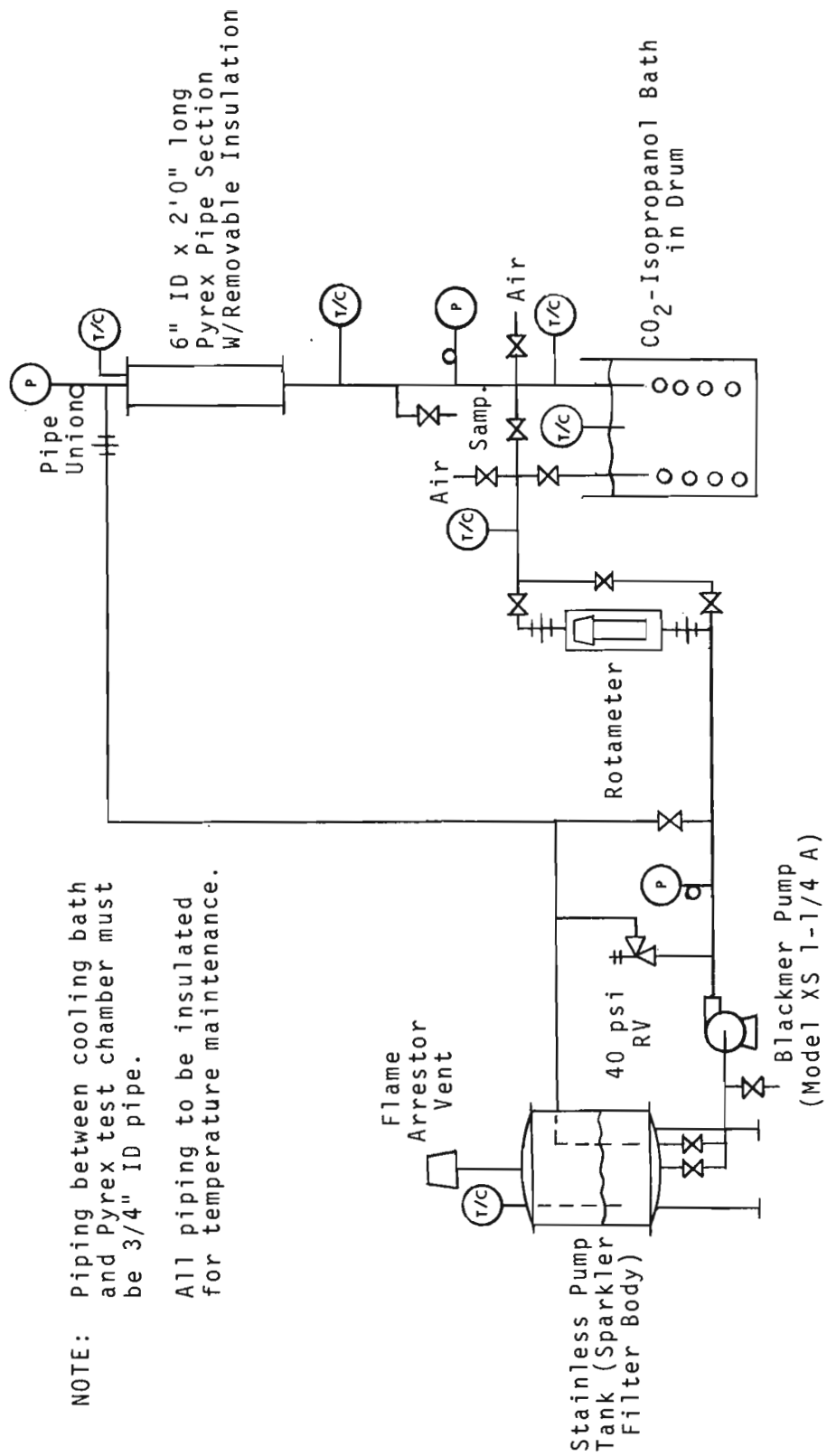


Figure 13. Dynamic Flow System.



NOTE: Piping between cooling bath and Pyrex test chamber must be 3/4" ID pipe.
 All piping to be insulated for temperature maintenance.

Figure 14. Schematic of Dynamic Flow System.

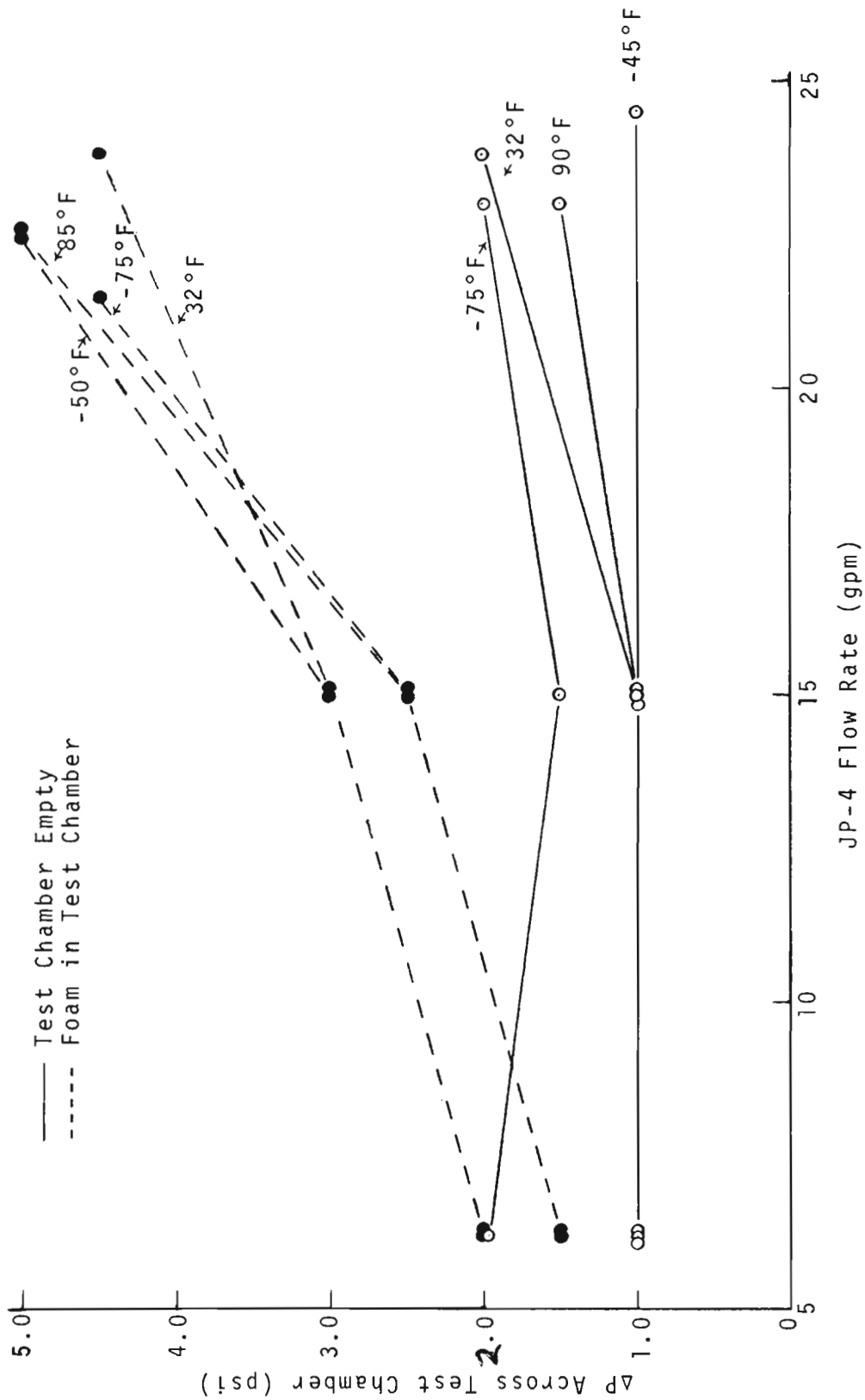


Figure 15. JP-4 Pressure Drop-Flow Relationship.

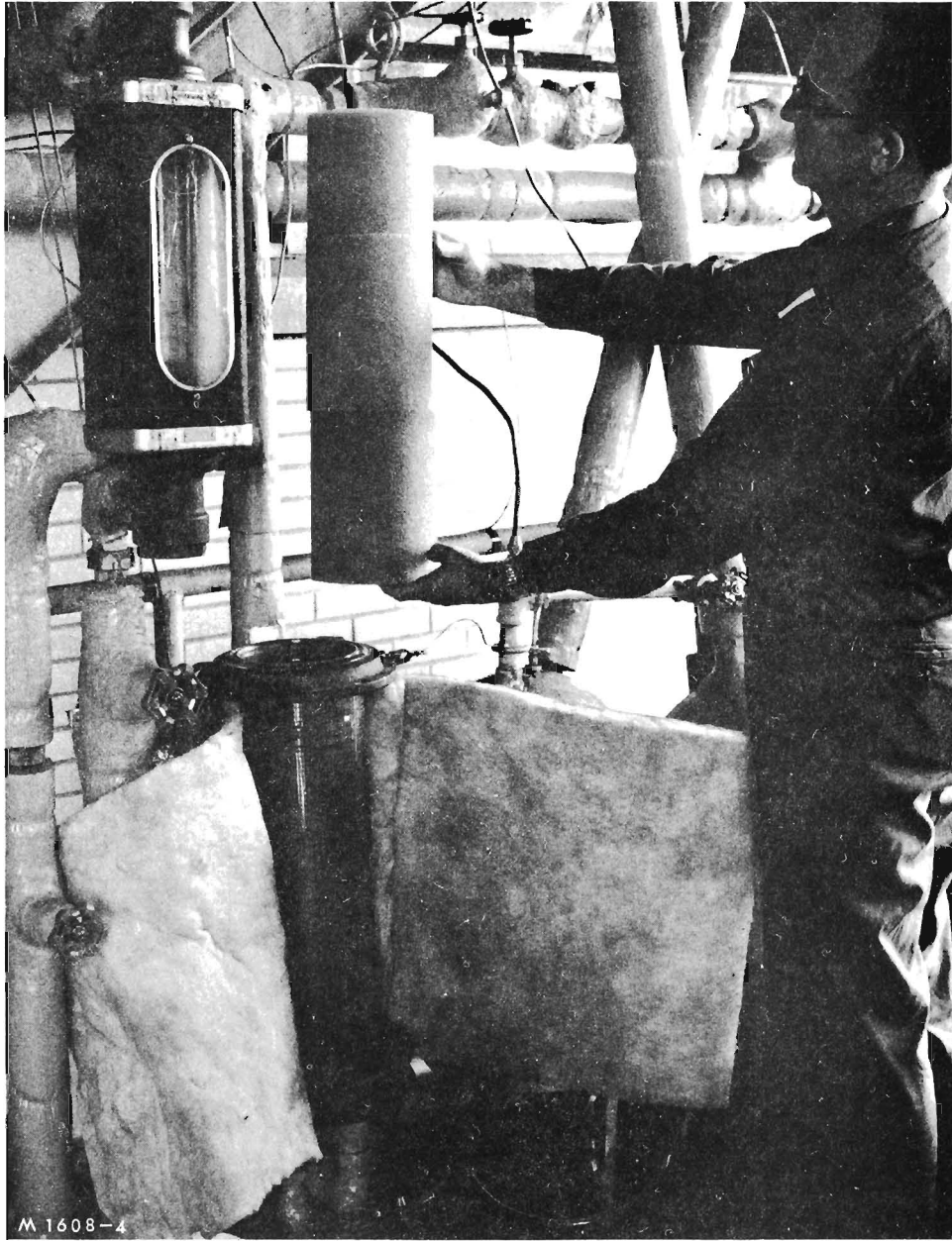


Figure 16. Placing Foam into Test Chamber.

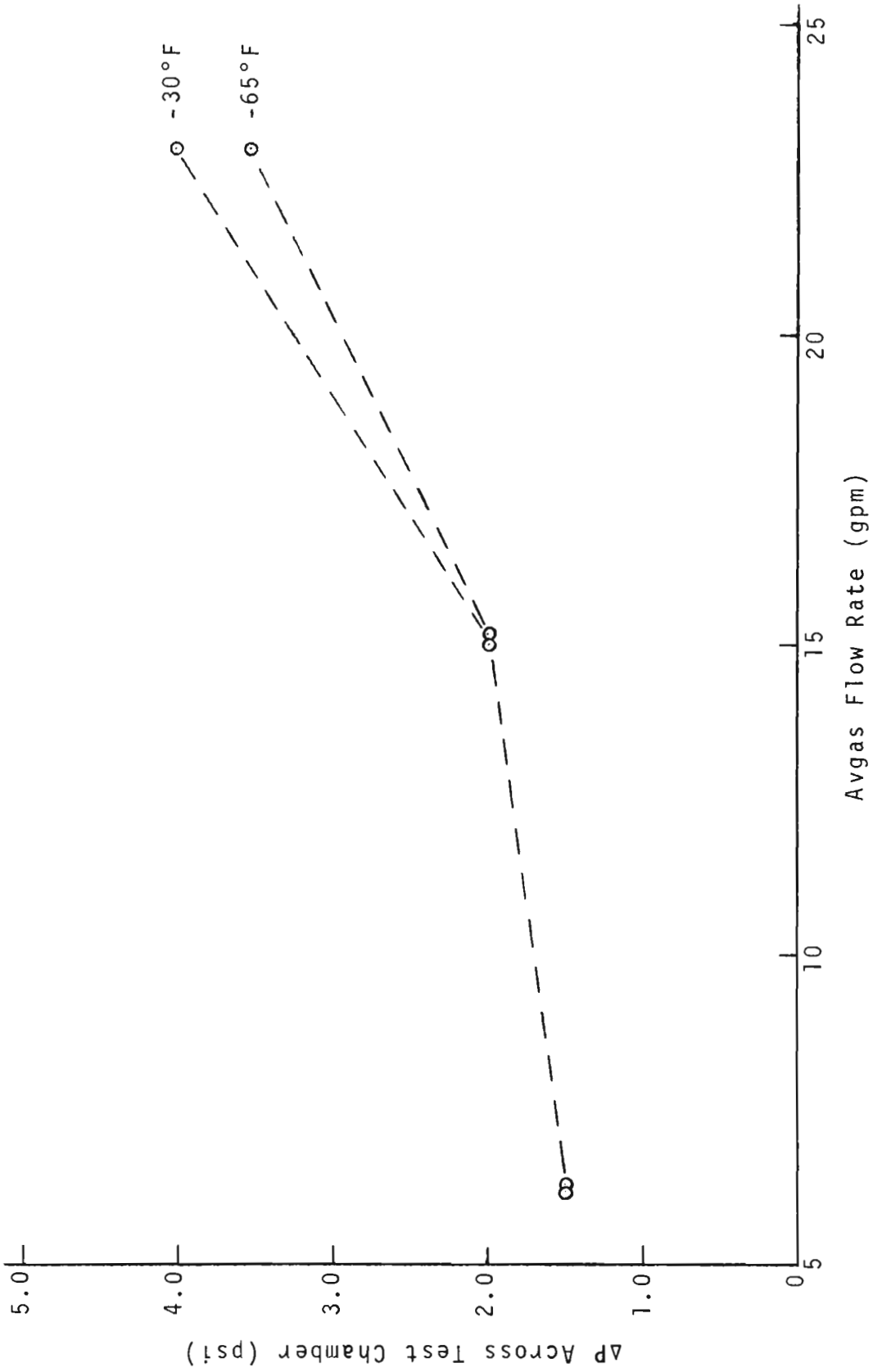


Figure 17. Avgas Pressure Drop-Flow Relationship.

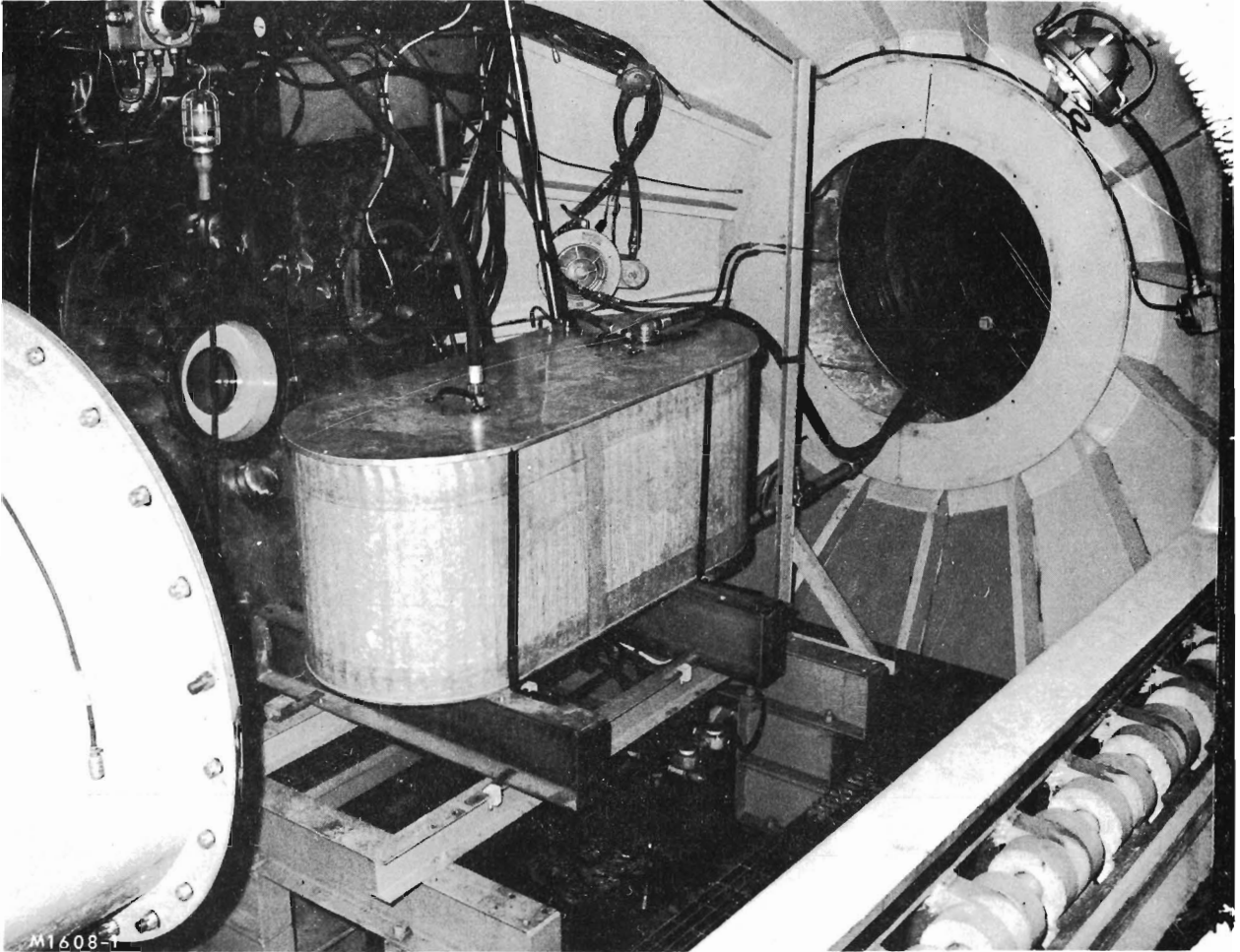


Figure 18. Pump-Out Tank Installed in Altitude Chamber at WPAFB.

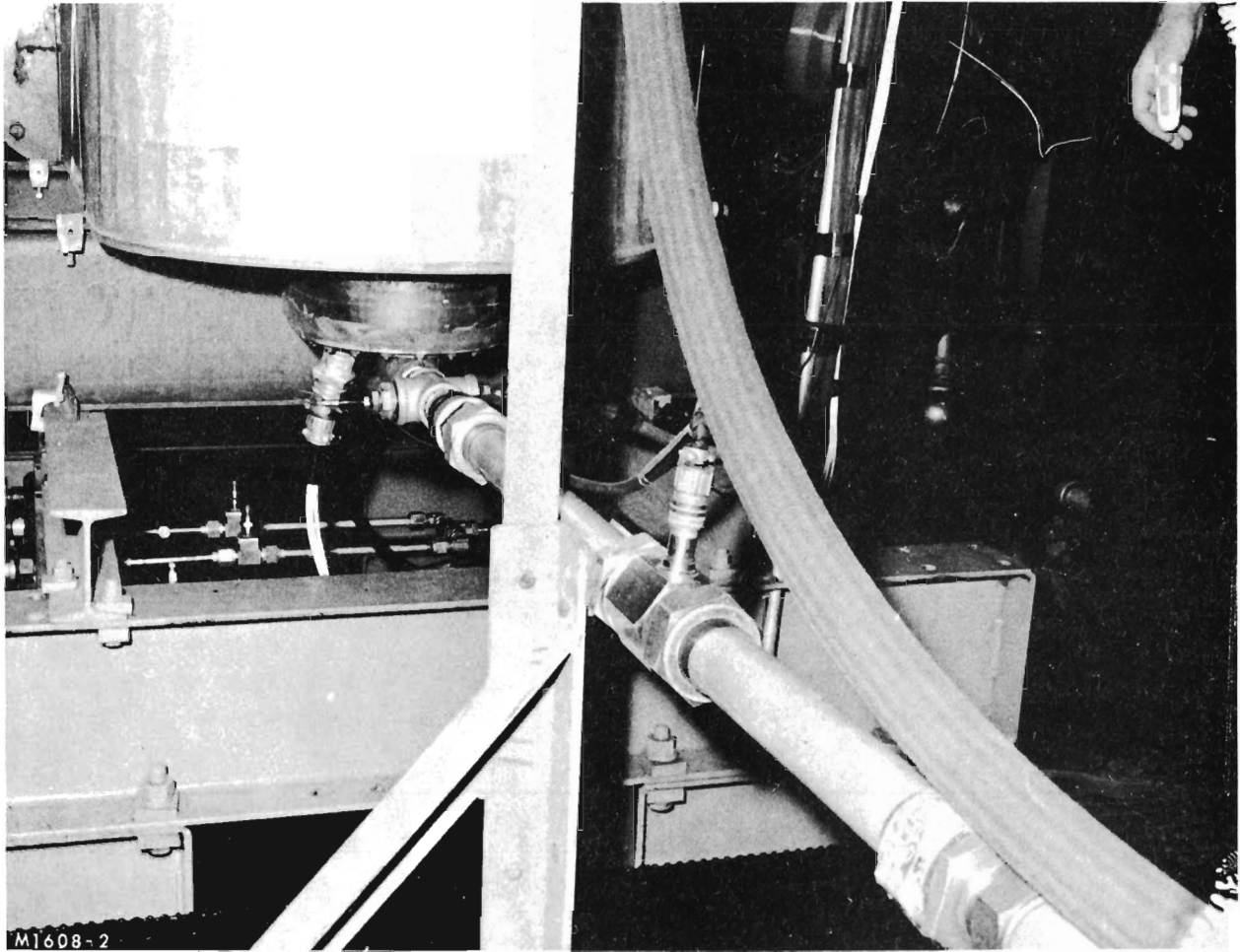


Figure 19. Pump and Pottermeter on Pump-Out Tank.

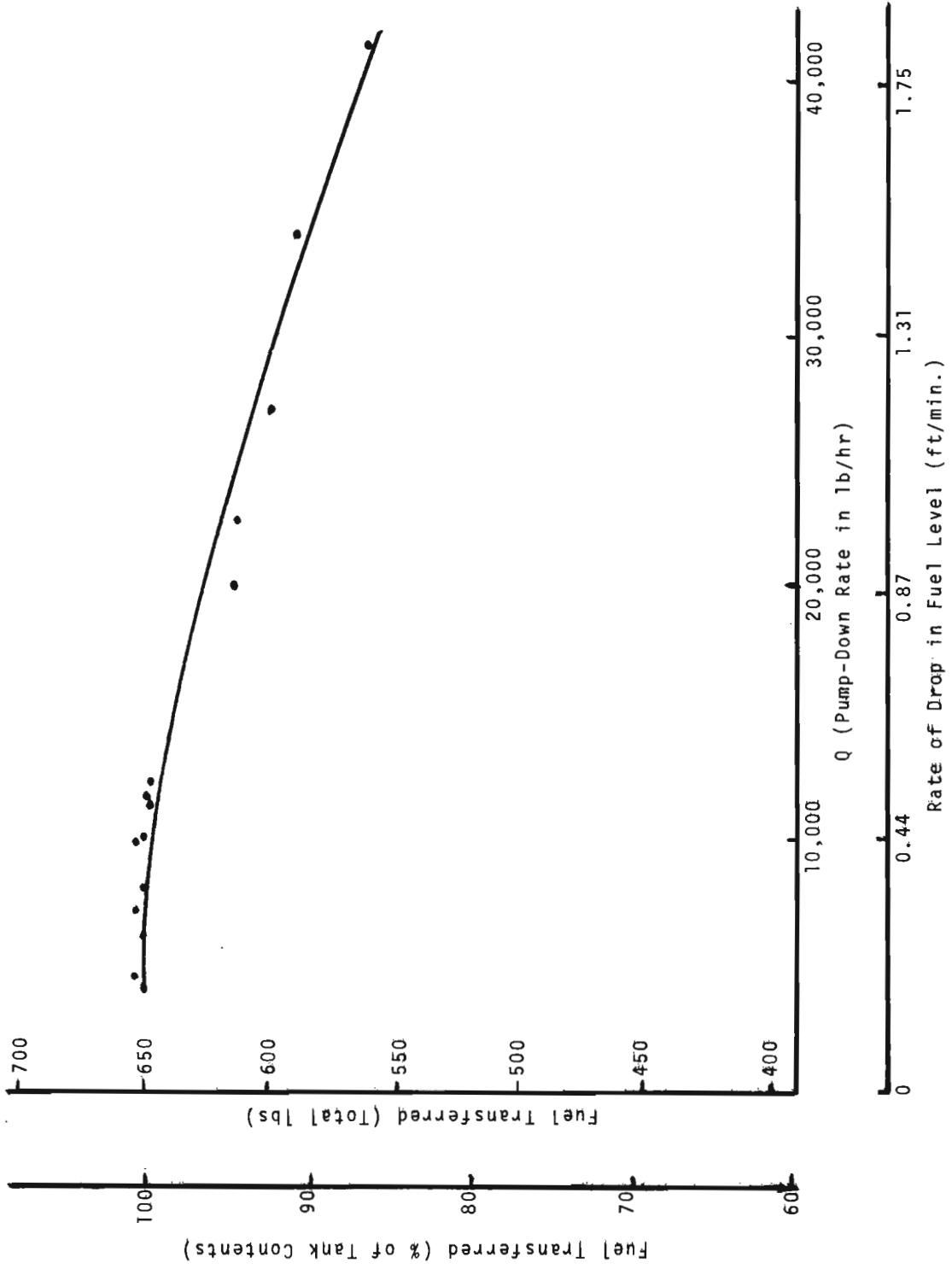


Figure 20. Pump-Down Rate.

3. EVALUATION OF BAFFLE MATERIAL - UNIVERSITY OF DAYTON RESEARCH INSTITUTE

A short-term evaluation has been completed on the experimental fuel tank baffle material which you furnished to us.

CONCLUSIONS

1. The only potential problem area discovered was the water separometer index. Tests on three fuels gave the same trend - a lowering of the WSIM after storage in contact with the baffle material.

2. Thermal stability testing indicated no problem.

3. Silting index results were good.

4. Chromatographic analysis showed no changes in fuel composition after storage with the baffle material present.

5. No change in water bottoms (water-AIA mixture) was found (in terms of refractive index) after storage with the baffle material present.

6. When JP-4 is poured into a vessel filled with baffle material, it was found that:

a. 3% of the volume of the vessel is occupied by the baffle material.

b. 2.5% of the fuel is retained in the baffle material after decanting the fuel from the vessel.

DISCUSSION

Water Separometer Index (Modified)

A 55-gallon drum was filled with baffle material, and then JP-4. The drum was stored at 130°F, and checked for WSIM as follows:

<u>Fuel</u>	<u>Date</u>	<u>WSIM</u>
Initial JP-4	11/22/65	97
JP-4 in baffle drum	11/23/65	54
JP-4 in baffle drum	12/14/65	51

Because of this large drop in WSIM, it was decided to run more tests; this time in the laboratory with the fuels stored in glass. This was done, both with JP-4 containing AIA, and JP-4 with no AIA.

<u>Fuel</u>	<u>Storage Time</u>	<u>WSIM</u>
Control JP-4 (no AIA)	--	94
JP-4 with baffle material (no AIA)	48 hrs.	63
Control JP-4 (with AIA)	--	88
JP-4 with baffle material (with AIA)	48 hrs.	71
JP-4 with baffle material " "	48 hrs.	82
Control JP-4 " "	48 hrs.	92

In all cases there was some lowering of WSIM after contact with the baffle material.

Thermal Stability

The same 55-gallon drum of JP-4 used for WSIM was also used in the thermal stability work. All coker runs were made with the Standard ASTM/CRC version of the apparatus.

<u>Fuel</u>	<u>Date</u>	<u>Temp., °F</u>	<u>AP</u>	<u>Tube Rating</u>
JP-4 (Control)	11/23/65	300/400	0	00000011111111 (00000000011110)
JP-4 with Baffle	11/29/65	300/400	0	00001111111111 (00000000111111)
" " "	12/14/65	300/400	0.40	0001111223321 (0000011112221)
" " "	12/29/65	300/400	0.06	11111111111111 (00000000000000)

Chromatographic Analysis

Analyses were made using a Burrell K-7 Kromotog with Apiezon L column packing. The baffle material was checked in two systems: (1) 30% toluene - 70% isooctane mixture, and (2) the same JP-4 used in the other studies.

Analyses of the toluene-isooctane mixture and the JP-4 before and after 48 hours contact with the baffle material showed no changes.

Water Bottoms Study

Two wide-mouth quart jars were filled with baffle material and a mixture of distilled water-AIA (99.6% methylcellosolve; 0.4% glycerol). The samples were monitored in laboratory storage by refractive index. Results are as follows:

	<u>Refractive Index</u>			
	<u>Initial</u>	<u>After 3 Days</u>	<u>After 7 Days</u>	<u>After 21 Days</u>
25% AIA-75% Distilled Water	1.3536	1.3538	1.3544	1.3538
40% AIA-60% Distilled Water	1.3665	1.3667	1.3663	1.3665

These results indicate no changes in the composition of the mixture during this relatively short storage period.

Volume Study

The storage capacity loss resulting from filling a container with baffle material was determined. A 2-liter graduated cylinder was found to hold 3% less JP-4 when filled with baffle material. Another 2.5% was retained in the baffle material when the JP-4 was decanted from the cylinder.

Silting Index

JP-4 was stored with the baffle material in a glass container in the laboratory for 48 hours. No effect was noticed on silting index, determined with the standard Millipore apparatus.

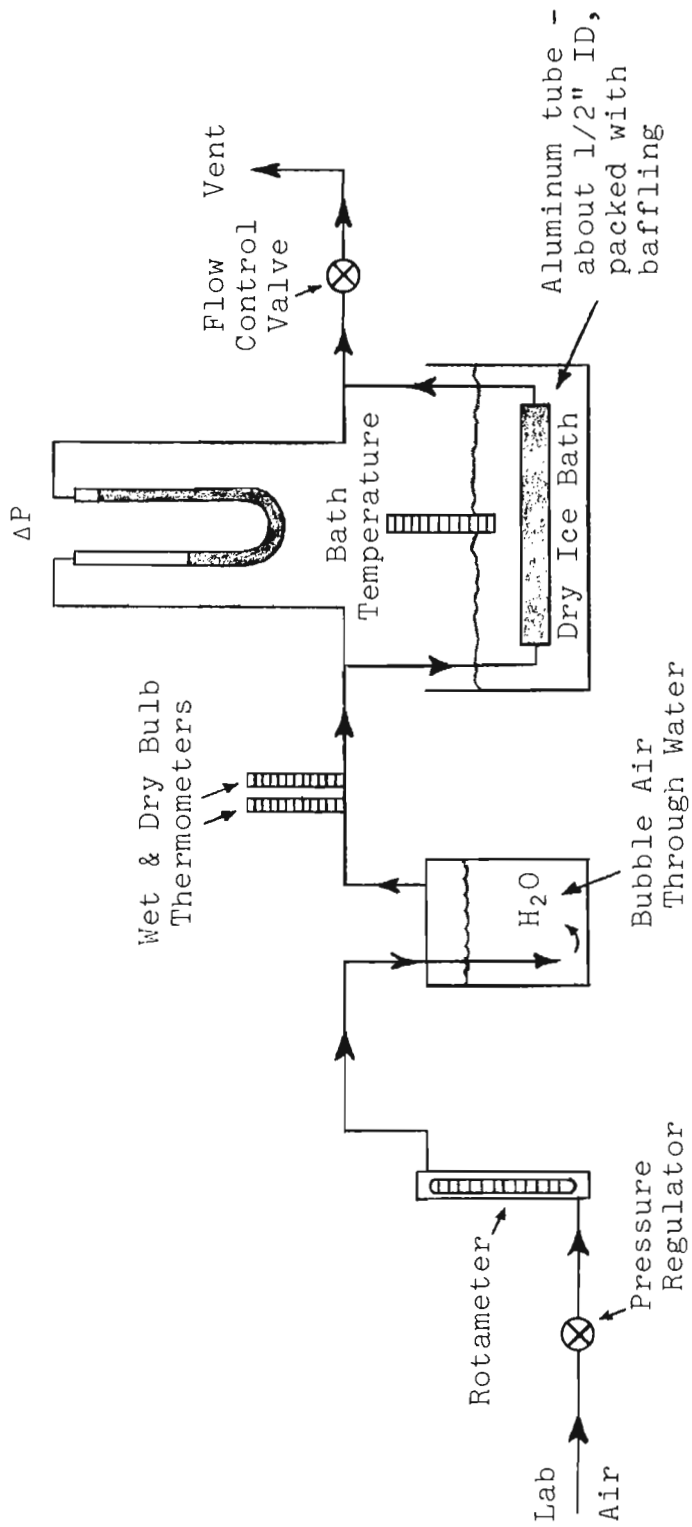
	<u>JP-4</u>	<u>JP-4 With Baffle Material (After 48 hrs.)</u>
Silting Index (#1 head)	1.44	0.41
Silting Index (#2 head)	0	0

Icing Test

A rig was fabricated for the purpose of finding whether the presence of baffle material in a 1/2" aluminum tube contributed to its plugging (by icing) when a stream of water-saturated air was passed through the tube at low temperatures. The tube was about 12" long, the saturation level of the air was checked with a wet and dry bulb thermometer, and the plugging of the tube was measured with a water manometer. The tube was chilled by immersion with a dry ice-jet fuel bath while the moist air was passing through (see sketch below). Results are as follows:

<u>Tube Packing</u>	<u>Bath Temp., °F</u>	<u>Air Flow, l./min.</u>	<u>ΔP, in.H₂O</u>	<u>Time, mins.</u>
Baffle	-65	3.0	10 ⁺	54
Baffle	-65	3.0	11.4	47
Baffle	-65	8.0	7.0	11
Baffle	-65	8.0	8.3	16
No Baffle	-65	3.0	9.0	72
No Baffle	-65	8.0	10.1	17
No Baffle	-65	8.0	10.3	15

These results indicate that the pressure drop across the tube was of about the same magnitude whether baffle material was present, or not.



4. MICROBIOLOGICAL COMPATIBILITY TESTS ON POLYESTER URETHANE FOAM - UNIVERSITY OF DAYTON RESEARCH INSTITUTE

A polyester urethane 10 pore per inch, type "Z" foam and a biocide treated foam are being evaluated for use as baffles in fuel tanks of military aircraft. Two short-term experiments were conducted to determine the effect of these polymers on the growth of fuel-utilizing microorganisms. In the first experiment, polyester urethane was added to the test system in the presence and absence of anti-icing additive, and in the second experiment, the foam containing a tetraethylthiuram disulfide was incorporated in the test system. Subsequently, growth of the test organisms in the aqueous phase of each test system was followed.

MATERIALS AND METHODS

A mineral salts medium, either a pH of 7.2 for bacteria or 5.6 for fungi, was used as the aqueous phase of the test system. Samples of each polymer were cut to fit the culture vessels. Culture vessels, with polymer and 35 ml of the medium, were sterilized in an autoclave at 15 psi for 15 min. Then 135 ml of filter-sterilized JP-4 fuel were added to each vessel aseptically. When desired, a 25% anti-icing additive (99.6% methyl Cellosolve, 0.4% glycerol) and water solution was added to the medium and fuel treated to give 0.1% anti-icing concentration.

Each test system was inoculated with 0.1 ml of bacterial cells (Pseudomonas aeruginosa) or with a 1-ml suspension of fungal spores and mycelium from a Hormodendrum (Cladosporium) culture. Both organisms are capable of utilizing JP-4 jet fuel as a sole source of carbon.

Incubation was carried out at 37°C (bacterium) and 26°C (fungus) under static conditions. Growth measurements of the bacterium were determined.

RESULTS

Comparative data on total populations of bacteria in the presence and absence of polyester urethane are shown in Table I. Polyester urethane did not enhance the growth of bacteria in the aqueous phase of the test system. Qualitative growth of the fungus was determined after 30 days of incubation at 26°C under static conditions by visual observation for the development of a distinct mycelial mat.

An identical test system was used in the second experiment except the anti-icing additive was incorporated in the fuel (0.1%) and medium (25%). Comparative growth measurements of Pseudomonas aeruginosa in this system are shown in Table II. Viable bacterial cells were not recovered after 6 hrs. of contact with the anti-icing additive in this experiment, but good growth of the test organism was observed in the control (an identical test system without additive). Fungal growth did not develop in either test system when the anti-icing additive was present at a concentration of 25% in the aqueous phase.

10-Pore per inch reticulated type "Z" foam containing tetraethylthiuram disulfide as an inhibitor was incorporated in similar test system. This compound did not inhibit the growth of P. aeruginosa in any systems. After 30 days of exposure to Hormodendrum (Cladosporium) spp. at 26°C, fungal mycelium grew on the surface of the polymer and plugged the porous structure.

SUMMARY AND CONCLUSIONS

Under the conditions of these experiments, polyester urethane did not enhance or inhibit the growth of P. aeruginosa, but provided a matrix for the attachment of fungal mycelium. Likewise, 10-pore per inch reticulated type "Z" foam containing tetraethylthiuram disulfide failed to inhibit growth of the test bacterium.

When the anti-icing additive was added to the systems at a concentration of 25% in the aqueous phase, both bacterial and fungal growth was inhibited.

If polyester urethane is used as a baffle material in the fuel tanks of military aircraft where the concentration of anti-icing additive is below 25%, and fungal growth occurs, fuel flow through the system might be seriously impaired.

Table I

Comparative Growth of Pseudomonas sp. in the
Presence and Absence of Polyesterurethane

Incubation Time (Hours)	Mineral Salts Medium Polyesterurethane JP-4 Fuel		Mineral Salts Medium (No Polymer) JP-4 Fuel	
	A	B	A	B
	0	4.4×10^5	6.9×10^5	6.0×10^5
24	1.4×10^8	1.4×10^8	1.8×10^8	9.6×10^7
48	2.1×10^8	1.6×10^8	2.6×10^8	2.9×10^8
72	4.4×10^8	6.3×10^8	3.0×10^8	3.2×10^8
120	3.4×10^8	2.5×10^8	1.6×10^8	1.8×10^8
168	2.8×10^8	1.8×10^8	1.5×10^8	1.0×10^8
216	2.5×10^8	2.8×10^8	1.3×10^8	2.0×10^8
312	3.1×10^8	2.8×10^8	3.6×10^8	2.5×10^8
360	2.6×10^8	3.2×10^8	1.6×10^8	3.3×10^8
408	2.4×10^8	4.1×10^8	2.2×10^8	6.1×10^8

Table II

Comparative growth of *Pseudomonas aeruginosa* in a mineral salts medium in the presence and absence of polyesterurethane and anti-icing additive - methyl cellosolve (98.6%), glycerol (0.4%)

Incubation Time (Hours)	Contents of Culture Vessel											
	Polymer JP-4 Jet Fuel Additive (No Polymer)		JP-4 Jet Fuel Additive (No Polymer)		Polymer Additive (No JP-4 Jet Fuel)		Additive (No Polymer or JP-4 Jet Fuel)		JP-4 Jet Fuel (No Polymer or Additive)			
	A	B	A	B	A	B	A	B	A	B	A	B
0	4.3 x 10 ⁵	2.6 x 10 ⁵	4.9 x 10 ⁴	1.2 x 10 ⁵	1.6 x 10 ⁵	9.0 x 10 ⁴	8.4 x 10 ⁴	5.6 x 10 ⁴	4.8 x 10 ⁵	5.8 x 10 ⁵		
6	NG	NG	NG	NG	NG	NG	NG	NG	7.3 x 10 ⁶	9.9 x 10 ⁶		
24	NG	NG	NG	NG	NG	NG	NG	NG	8.2 x 10 ⁷	7.6 x 10 ⁷		
48	NG	NG	NG	NG	NG	NG	NG	NG	2.2 x 10 ⁸	2.2 x 10 ⁸		
72	NG	NG	NG	NG	NG	NG	NG	NG	4.0 x 10 ⁸	3.0 x 10 ⁸		
96	NG	NG	NG	NG	NG	NG	NG	NG	2.8 x 10 ⁸	1.3 x 10 ⁸		
168	NG	NG	NG	NG	NG	NG	NG	NG	9.8 x 10 ⁸	8.2 x 10 ⁸		
216	NG	NG	NG	NG	NG	NG	NG	NG	3.8 x 10 ⁸	3.1 x 10 ⁸		
264	NG	NG	NG	NG	NG	NG	NG	NG	2.4 x 10 ⁸	2.4 x 10 ⁸		
336	NG	NG	NG	NG	NG	NG	NG	NG	2.7 x 10 ⁸	2.8 x 10 ⁸		
384	NG	NG	NG	NG	NG	NG	NG	NG	2.2 x 10 ⁸	1.8 x 10 ⁸		
432	NG	NG	NG	NG	NG	NG	NG	NG	2.0 x 10 ⁸	3.3 x 10 ⁸		

NG = No growth of test organisms.