AD-A021 241

INVESTIGATION OF NEW AIRDROP ENERGY DISSIPATER MATERIAL

C. E. McClung, et al

Monsanto Research Corporation

Prepared for:

Army Natick Development Center

July 1975

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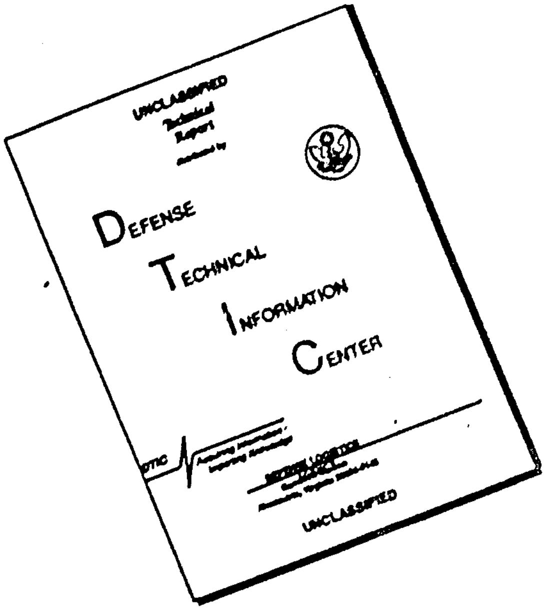

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REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER
TR 75-98 AMEL

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)
INVESTIGATION OF NEW AIRDROP ENERGY DISSIPATER MATERIAL

5. TYPE OF REPORT & PERIOD COVERED
Final Report of 21 Jan-21 Nov 74

6. PERFORMING ORG. REPORT NUMBER
MRC-DA-476

7. AUTHOR(s)
C. E. McClung, J. L. Schwendeman, I. O. Salyer, and A. L. Marcum

8. CONTRACT OR GRANT NUMBER(s)
DAAK03-74-C-0080

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Monsanto Research Corporation
Dyaton Laboratories
Dayton, OH 45407

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
1F262203AH86-02-4-033

11. CONTROLLING OFFICE NAME AND ADDRESS
US Army Natick Development Center
Aero-Mechanical Engr Lab, AMXNM-UBR
Natick, MA 01760

12. REPORT DATE
July 75

13. NUMBER OF PAGES
98

14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)

15. SECURITY CLASS. (of this report)

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)
Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

CUSHIONING	LIQUEFIED GASES	SOLVENTS	FOAM
IMPACT SHOCK	POLYSTYRENE	POLYMERS	VAPOR PRESSURE
INSULATION	PNEUMATOGENS	STORAGE	ATMOSPHERIC PRESSURE
AIRDROPOPERATIONS	BLOWING AGENTS	TANKS (CONTAINERS)	STATIC STABILITY

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The object of this program was the development of a foam plastic which can be expanded by the user for use as an airdrop energy dissipater material. The approach included the development of a foam solution which can be shipped and stored in its unexpanded form, and the prototype equipment to generate rectangular pieces of foam.

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

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The developed formulation is based on polystyrene dissolved in a liquified gas. The gas acts as both a solvent and a pneumatogen for the polymer. Solvation is accomplished in a closed tank where the solution remains until needed. Opening a discharge valve on the tank produces instant foam, which can be handled immediately. Expansion takes place as the pressure (partial vapor pressure of the solvent) drops to atmospheric pressure.

The prototype equipment includes an extrusion die with a rectangular opening, which attaches to the tank discharge valve. The die is fitted with a screen which is necessary to produce slabs of foam which are rectangular and at a manageable extrusion rate. The prototype equipment produces foam panels which are approximately 3 inches thick by 12 inches wide. The length is determined by the capacity of the tank and the length of time the valve remains open.

The prototype equipment produces foam with characteristics equivalent to more conventional polystyrene foams. The suitability of the foam as an airdrop energy dissipater material was not completely established and remains to be determined.

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1. INTRODUCTION

The objectives of this program were to develop foam solutions (or gels) and to design equipment capable of using these solutions to mold polystyrene foam into boards or slabs suitable for use in airdrop applications. The overall final size of molded polystyrene was to be either 3 inches by 3 feet by 8 feet, or 3 inches by 1 foot by 8 feet.

Our efforts produced a moldable foam formulation, a method to slab mold a 3 x 12 x 18 inch piece, and an extrusion molding process capable of forming 3 x 12 inch foam boards or planks 6 feet long, or of indefinite length, depending on the capacity of the supply tank.

Foams prepared by the extrusion molding technique were tested for energy absorption. The foam densities of these materials were in the 2-10 lb/cu ft (pcf) range. At these densities, polystyrene foam impact strengths were too high for the load capacity of the impact tester. This indicated that during a subsequent phase of this work, two major goals would be better control of foam density and improved cell structure, as a pre-requisite to obtain the desired physical properties.

A prototype foam generator was designed and built during this program. It was delivered to the Army at the conclusion of the project.

2. TECHNICAL DISCUSSION

2.1 HISTORY OF INSTANT FOAM AT MONSANTO

Instant polymeric foams were first developed by Monsanto Research Corporation approximately nine years ago. An instant foam generally consists of a polymer dissolved in liquefied gas and solvent combination. Instant foams have been made from polystyrene, vinyl acetate and other polymeric materials. Foams prepared previously lacked the ability to be shaped or molded on release to atmospheric pressures.

Of the instant foams prepared, polystyrene has the best possibility of meeting the impact absorption requirements necessary for an airdrop energy absorbing material.

INSTANT FOAM FORMULATION AND PREPARATION

An investigation to reformulate instant polystyrene was initiated under Contract No. DAAK 03-74-C-0080. Objectives were to develop a controlled molding process to produce foams useful as energy absorbers in airdrop applications. All work was based on an original "standard" formulation, as given in Table 1. The formula was modified to achieve the objectives of this program.

Table 1

STANDARD INSTANT POLYSTYRENE FOAM FORMULATION

Ingredient	By Weight[1]	PPHP[2]
Lustrex HH-101[3]	157.0	100.0
Microballoons[4]	3.0	1.9
Triton X-200[5]	10.0	6.4
Freon 11[6]	12.0	7.6
Dimethyl ether[7]	70.0	44.6

[1] Weight in grams

[2] PPHP - parts per hundred polymer

[3] Polystyrene - Monsanto Company

[4] IG 101 - glass microballoons - Emerson and Cummings

[5] Sodium salt of alkyl aryl sulfonate - Rohm and Haas

[6] Trichlorofluoromethane - DuPont

[7] Dimethyl ether - Matheson Products

Initially, all foams were prepared in 16 oz glass pressure bottles. These inexpensive pressure vessels are very useful in the study of formula variables. The bottles are transparent and the solvation process and viscosity changes can be observed. Charging an instant foam to a bottle generally follows this stepwise procedure:

1. Condense the dimethyl ether. This is done by passing the gas through a dry ice cold finger condenser and collecting the condensate in a dry ice chilled flask.

2. Transfer polystyrene beads to a clean, dry, preweighed bottle.

3. Add the glass microballoons, place a stopper (cork or rubber) in the bottle, and shake to disperse the microballoons.

4. Transfer the surfactant to the bottle. If the surfactant is a liquid, it can be weighed directly into the bottle. If it is a solid, it can be pre-mixed with the microballoons and steps 3 and 4 combined.

5. Add co-solvent Freon 11, or other compound.

6. In an explosion-proof hood, transfer the liquefied gas (dimethyl ether or other gas) to the bottle. At first, the gas will boil off, cooling the bottle and its contents. The required amount of gas is added by weight. A slight excess (1 g) is added to compensate for weight loss (by boil off) during the capping operation. Put a cap on the bottle, and allow it to warm to room temperature. (Generally, six bottles were charged at a time.)

7. Dissolve the polymer. Solvation of the polystyrene is generally effected at room temperature by placing the bottles on a wheel rotating in the vertical plane.

Three modes of agitation were employed: first, continuous slow rotation on the wheel; second, intermittent rotation on the wheel (e.g. 10 minutes stationary to permit drainage, followed by 15 second rotation to change position). A third method was to place the charged bottles in a 50°C oven and rotate the bottles (end for end) three times a day.

The first two methods required three days to a week for complete solvation. Using the third method, solvation could be completed in as little as 24 hours. Solvation time was markedly influenced by the nature of the formulation.

To assure complete solvation and uniformity, the elapsed time was arbitrarily set at one week for all foam solution formulations.

2.3 FORMULA VARIABLES STUDIED

Several formulation studies were made employing the bottle technique. The variables investigated were:

- Surfactants and combinations.
- Solvents (boiling at or above room temperature).
- Gaseous solvents (liquefied gas).
- Combinations of the above.

During these investigations 170 bottle experiments were made. These experiments involved 81 surfactants or combinations of surfactants with other additives (see Table 2 for a listing of these materials).

To systematically evaluate the surfactants and formula additives, a simple, effective set of test procedures were developed. These tests are given in Table 3 which lists the property measured and a description of the specific test method used. The table further separates these tests into properties measured while the foam solution was in the bottle (Section A). Section B describes test methods appropriate to the instant foam after release from the storage vessel.

The data for the surfactants which appeared most promising in the screening tests are presented in Table 4. Properties of both the foam solution and the foam itself are presented in the table. The data are listed below the variable (surfactant) tested. For example, the foam solution with Igepal CO-970 required 10 seconds to flow from one end of the bottle to the other. There was no free liquid phase, indicating the surfactant was compatible with polystyrene solution. The foam solution did not adhere to the wall of the bottle. This indicated that all the foam solution would drain cleanly from the supply tank wall and be available to make foam. Furthermore, cleanup of the tank for reuse would be easier if the walls drained clean.

Table 2

LIST OF SURFACTANTS AND SURFACTANT/ADDITIVE COMBINATIONS

Trade Name	Chemical Description
	Anionic Surfactants
Triton X-200	sodium salt of alkylaryl polyether sulfonate
Duponol WAQ*	sodium lauryl sulfate
Igepon AC78	coconut oil acid ester of sodium isethionate
Igepon T-33	sodium-*n*-methyl-*n*-oloyl-taurate
Igepon TC-42	sodium-*n*-methyl-polmitoyl taurate
Zelec DX*	alcohol phosphate composition
Zelec NK	alcohol phosphate composition
GAFAC MC-470	partial sodium salt of a complex organic phosphate ester
GAFAC RE-870*	free acid complex organic phosphate ester
GAFAC RA-600	free acid complex organic phosphate ester
	Nonionic Surfactants
Atlas G 3570	cationic polymeric amine
Igepal CO-970*	nonylphenoxypoly(ethyleneoxy) ethanol
Igepal CO-630	nonylphenoxypoly(ethyleneoxy) ethanol
Igepal CO-210	nonylphenoxypoly(ethyleneoxy) ethanol
Igepal CO-990	nonylphenoxypoly(ethyleneoxy) ethanol
Igepal CA-420	octylphenoxypoly(ethyleneoxy) ethanol

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*Surfactant used at several concentrations

Table 2 (continued)

Trade Name	Chemical Description
	Nonionic Surfactants
Igepal DM-630	alkylphenoxypoly(ethyleneoxy) ethanol
Igepal DM-430	alkylphenoxypoly(ethyleneoxy) ethanol
Igepal CTA-639	alkylphenoxypoly(ethyleneoxy) ethanol
Pluronic L-63	polyalkyloxypoly(ethyleneoxy) ethanol
Pluronic F-68	polyalkyloxypoly(ethyleneoxy) ethanol
Pluronic F-104	polyalkyloxypoly(ethyleneoxy) ethanol
Pluracol TP-1540	polyalkyloxypoly(ethyleneoxy) ethanol
Pluracol GP-3030	polyalkyloxypoly(ethyleneoxy) ethanol
Pluracol TP-4640	polyalkyloxypoly(ethyleneoxy) ethanol
Pluracol P-104	polyalkyloxypoly(ethyleneoxy) ethanol
Thanol SF-6500	polyalkyloxypoly(ethyleneoxy) ethanol
Merpol HCS	poly(ethyleneoxy) ethanol
Renex 20	polyoxyethylene ester of mixed fatty and resin acids
Atlas 300	mono and diglycerides of fat forming fatty acids
Atlas G-1096	polyoxyethylene sorbitol hexa-oleate
Atlas G-1441	polyoxyethylene sorbitol lanolin derivative

Trade Name	Chemical Description
Nonionic Surfactants	
Atlas 1556	polyoxyethylene blends of polyhydric alcohol fatty esters
Atlas G-1702	polyoxyethylene sorbitol beeswax derivative
Atlas G-2684	polyoxyethylene sorbitan monooleate with mixed fatty and resin acids
Alcolec powder	soy phosphatides 95%
Surfactants with Additives and/or Combinations	
Igepal CO-970 zinc stearate	nonylphenoxypoly(ethyleneoxy) ethanol
Igepal CO-970	50/50 solution nonylphenoxypoly(ethyleneoxy) ethanol and water
Igepal CO-970	75/25 solution nonylphenoxypoly(ethyleneoxy) ethanol and water
GAFAC MC-470 water	50/50 solution of partial sodium salt of a complex organic phosphate ester and water
GAFAC MC-470	75/25 solution of partial sodium salt of a complex organic phosphate ester and water
Igepal CO-970 Union Carbide L-534	57/43 mixture of surfactant to silicone surfactant
Igepal CO-970 Union Carbide Y-6202	57/43 mixture of surfactant to silicone surfactant
Igepal CO-970 antimony oxide	67/33 mixture of surfactant flame retardant
Igepal CO-970 antimony oxide	75/25 mixture of surfactant flame retardant

Table 2 (continued)

Surfactants with Additives and/or Combintions

Trade Name	Chemical Description
Zelec DX antimony oxide	67/33 mixture of surfactant to flame retardant
Zelec DX antimony oxide	75/25 mixture of surfactant to flame retardant
Duponol WAQ antimony oxide	67/33 mixture of surfactant to flame retardant
Duponol WAQ antimony oxide	75/25 mixture of surfactant to flame retardant
Hycar Iatex 2200X22	Tested at 10, 20, 30, 40 and 50 parts per 157 parts of Lustrex HH-101
Igepal CO-970	10 parts of Igepal CO-970 to 12 parts chloroform per 157 parts of Lustrex HH-101
Igepal CO-970 butyl ether	10 parts of Igepal CO-970 to 12 parts butyl ether per 157 parts of Lustrex HH-101
Igepal CO-970 toluene	10 parts Igepal CO-970 to 12 parts toluene per 157 parts of Lustrex HH-101
Igepal CO-970 tritolyl tritolyl phosphate	10 parts Igepal CO-970 to 12 parts tritolyl phosphate per 157 parts of Lustrex HH-101
Triton X-200 microballoons	10 parts of alkylaryl sulfonate to 3.0 parts nucleation beads
Igepal CO-970 alcolecec powder	83/17 mixture of nonionic to cationic surfactant
Igepal CO-970 antimony oxide	83/17 mixture of nonionic surfactant to nucleating agent
Flameout 5600-B1 antimony oxide	87/13 mixture of fire retardant to nucleating agent

Note: Numerous other combinations were tested but not listed.

Table 2 (continued)

Trade Name	Chemical Description
	Silicone Surfactants
Dow Corning DC-200	silicone oil - 500 centipoise
Dow Corning DC-200	silicone oil - 1000 centipoise
Dow Corning 190	silicone oil
Dow Corning 194	silicone oil
Dow Corning 1312	silicone oil
Dow Corning 11-630	silicone oil
Union Carbide L-520	silicone oil
Union Carbide L-534	silicone oil
Union Carbide L-540	silicone oil
Union Carbide L-5310	silicone oil
Union Carbide L-5420	silicone oil
Union Carbide Y-6138	silicone oil
Union Carbide Y-6202	silicone oil
US 103	special polyvinyl chloride cell stabilizer
	Fluorocarbon Surfactants
FC-95	perfluoronate organic compound
FC-98	perfluoronate organic compound
FC-128	perfluoronate organic compound
FC-134	perfluoronate organic compound
	Plasticizers
	50/50 mixture diallyl phthalate and antimony oxide

Table 2 (continued)

Trade Name	Chemical Description
Flame Retardants	
Niax Fire Retardant 3-CF	
Flameout 5600-B1	
Antimony oxide	
Mono (DBP) phosphoric acid	
Bis DBP phosphoric acid	
Tris (DPB) phosphate	
Weston CP-1	
Tetrabromophthalic anhydride	
Powdered Nucleating Agents	
	zinc stearate powder
	antimony oxide

Table 3

METHODS OF TESTING FOAM SOLUTION AND PROPERTIES

	Property	Test Method
	A. Physical Properties of Solution in Bottles	
1.	Foam solution viscosity	The bottle was turned upside down and time elapsed for the foam solution to flow from the bottom to the top was recorded in seconds.
2.	Surface liquid	The quantity of free liquid on top of the foam solution was recorded.
3.	Bottle conditions	Whether or not the foam solution adhered to the bottle walls was recorded.
	B. Physical Properties of Extruded Foam	
1.	Extrusion through 1/8 inch diameter	Diameter of the extruded foam was measured.
2.	Flow rate, ft/min	Length of foam strand extruded as a function of time was measured.
3.	Moldability, #1 die (Fig. 1)	How well the foam was shaped as it passed thru die #1 was noted.
4.	Cell structure	Cell size and uniformity were noted.

Table 4

INSTANT FOAM SOLUTION AND FOAM PROPERTIES

Run No.	172343A	172319B	172329C	172329D
Surfactant	Triton X-200	Igepal CO-970	Duponol WAQ	Zelec DX
Section A. Internal Bottle Test				
Foam solution viscosity, sec	30	10	>30	>30
Surface liquid	none	none	none	none
Bottle condition	solution adhered to wall	solution did not adhere to wall	solution adhered to wall	solution adhered to wall
Section B. Foam Properties				
Expanded diameter of foam exiting from 1/8 in. hole	7/16	9/16	3/4	9/16
Flow rate, ft/min	20	12	60	36
Moldability Die #1	average	fair	average	average
Cell structure	irregular	most uniform	average	average

The properties in section B of Table 4 are those of the instant foam after it was released to the atmosphere through a 1/8 inch diameter hole. For example, using Igepal CO-970, the foam diameter expanded 4.5 times to a 9/16 inch diameter foam strand when the solution exited through a 1/8 inch diameter hole.

The flow rate of Igepal CO-970 was far less than that of other surfactants, suggesting it was not as good a slip agent or lubricant for the foam solution. However, Igepal CO-970 made the most moldable solution. Die #1 pictured in Figure 1 was used to establish moldability. The other three dies shown were also evaluated during this program. The last test run was an observation of cell structure, and Igepal CO-970 gave the most uniform cell structure.

The original surfactant at the start of the program was Triton X-200, a 30% solution of a sodium salt of alkylarylpolyether sulfonate. Based on the screening tests early in the program, this surfactant was replaced with Igepal CO-970 [nonylphenoxypoly(ethyleneoxyethanol)] in the bulk of the later work. This surfactant improved foam cell uniformity, lowered solution viscosity and acted as a reasonably good release agent for the foam solution from the pressure vessel walls. Furthermore, a recognizable improvement in moldability resulted from the use of Igepal CO-970.

With this knowledge, numerous derivatives of nonionic surfactants based on phenoxypolyethyle neoxyethanol were evaluated. Igepal CO-970 had the best balance of overall properties of all nonionics tested.

Two surfactants, Duponol WAQ (a water solution of sodium lauryl sulfate somewhat comparable to Triton X-200) and Zelec DX (an alcoholic phosphate composition) also improved foam properties over those obtained with Triton X-200. Zelec DX in later work yielded polystyrene foams with improved physical properties.

2.3.1 Estimated Cost of Instant Foam

An estimate of material costs (based on late 1974 prices) was made. The foam solution material cost is \$0.556/lb. Assuming the solutions are made in large quantity (3000 gal batches) a labor cost would be \$0.03 per pound. Based on these calculations, the foam solution would cost approximately \$0.60/lb. The cost of a cubic foot of 2 lb/cu ft foam would be about \$1.78.

Figure 1. Bottle Dies Used to Extrude Instant Foam

2.4 MOLDED INSTANT POLYSTYRENE FOAM

Several methods of molding instant polystyrene foam are possible. Three of these were tried during this program. They were:

- Instant — From a 2 inch pipe cylinder into a closed mold
- Bulk - Vertical rise within a closed mold.
- Extrusion - Through die nozzles with and without screens.

Instant molding methods were investigated first. The mold size selected was 3 x 12 x 18 inches (a potentially usable modular panel size) which was larger than any previously attempted using the instant foam process. Foam slabs this large would be of sufficient size to permit the determination of physical, mechanical and impact data. The foams molded were based on the foam formulations listed in Table 5.

Table 5

TYPICAL INSTANT FOAM MOLDING FORMULATIONS

Ingredients	A	B	C
Lustrex HH-101	100	100	100
Glass microballoons	1.9	1.9	1.9
Surfactant	12.7	6.4	6.4
Freon 11	7.6	15.28	7.6
Dimethyl ether	44.6	-	-
Methyl chloride	-	44.6	44.6

In general, these formulas vary in the quantity and type of surfactant, amount of Freon 11, and type of pneumatogen/solvent (i.e. dimethyl ether or methyl chloride).

Preparation of the foams was accomplished by placing an amount of foam solution, weighing 3.14 times the formula weight, into a 2.0 inch diameter pressure vessel (see Figure 2). These pressure vessels were constructed of 2.0 inch steel pipe capped on one end and adapted to take a 1-1/4 or 2.0 inch ball valve.

Figure 2. Two Inch Diameter Pressure Vessels Fitted With Ball Valves

2.4.1 Charging of Pipe Pressure Vessels

Several pressure vessel charging procedures were investigated. In general, the most reliable procedure was identical with that used for charging glass pressure vessels except that, because of its mass, the pipe was pre-cooled in a dry ice/acetone bath for 30 minutes prior to adding the condensed dimethyl ether or methyl chloride.

2.4.2 Solvation of Polystyrene

Complete solution of the polymer was necessary to obtain high quality foam. The most important variable in effecting complete solution was found to be the time used in mixing, and this took one week. After being charged, the pressure vessel was placed on a wheel rotating in the vertical plane and tumbled for 48 hours at room temperature. It was then transferred to a 120°F oven where its position was changed three times daily for five days to assure complete solvation. The effects of performing solvation at temperatures other than ambient (75°F) and 120°F have not been determined. Once solution has been completed, the charged tanks of solution can be stored indefinitely.

It must be pointed out that the process described is appropriate only for laboratory work. Alternate methods of solution should be worked out for large scale production. Preliminary inquiries indicate that the Ross Equipment Company makes a mixer that is designed for the preparation of high viscosity polymer solutions. The use of such a piece of equipment would greatly expedite preparation of instant foam solutions. Comparatively large amounts of the material could be prepared, then transferred to storage and shipping tanks. Once the solution is in the tanks it can be used as needed.

2.4.3 Direct Instant Foam Molding in Mold of Fixed Dimensions

The pressure vessels charged with foam solution were attached to 3 x 12 x 18 inch plywood molds (see Figure 3) with close nipples. Attempts were made to mold instant polystyrene with the valve partly opened. This slow method of molding formed a twisted mass of foam that was partly fused together. No real molding was observed. With the valve approximately half open, a partially shaped foam was formed. Well formed molded pieces were possible only when the valve was fully open and the mold filled rapidly with expanded foam (Figure 4).

Figure 3. Plywood Mold Open for Inspection (3 x 12 x 18 Inch). Note vent holes in one end of mold.

Figure 4. Molding Made with Fully Opened Ball Valve

The effects of temperature on molding were studied employing foam formulation A given in Table 5, except that the quantity of surfactant was increased to 12.7 parts per hundred parts polymer. The molding temperatures selected were 60, 80, 100 and 120°F. The results of this work are shown in Figures 5, 6, 7 and 8. Moldability improved with each incremental drop in temperature, the best molding temperature being 60°F. This was attributed to the slower and more controlled rate of foam formation at the lower temperatures. It is believed that this property applied to all formulations studied in this program. Possible solvent pneumatogens which have lower vapor pressures at ambient temperatures of 75 to 80°F probably would improve the moldability of instant polystyrene foam.

2.4.4 Sliding End Mold

A sliding end mold (Figure 9) was designed and built. It was believed this mold would offer one approach to forming foam boards with increased length. The movable end of the mold furnishes the initial resistance to form and mold the foam. As the mold fills, the foam pushes through, furnishing its own back pressure. The movable end of the mold then moves back and foam continues to be formed.

For best results, it was necessary to locate the pressure vessel in an elevated position relative to the mold, thru use of a 90° elbow (Figure 10).

Using these cylinders and a 9 gallon (2100 in.^{3}) cylinder, a study was made to establish the amount of resistance required to shape the instant foam when released from the pressure vessel. In practice, the mold was attached to a pressure vessel with a closed nipple. The mold was mounted at a 45° angle to the horizontal. Five, 15 and 20 pound lead weights were used to furnish resistance to the movement of the sliding portion of the mold. The valve was opened fully during the test. The 5 and 15 pound weights did not offer sufficient resistance to foam formation to induce molding. The resistance afforded by the 25 pound weight did not prove sufficient to cause the instant foam to mold without formation of knit lines. One one occassion the sliding end was forced out past the stop and the weight dropped back into the foam.

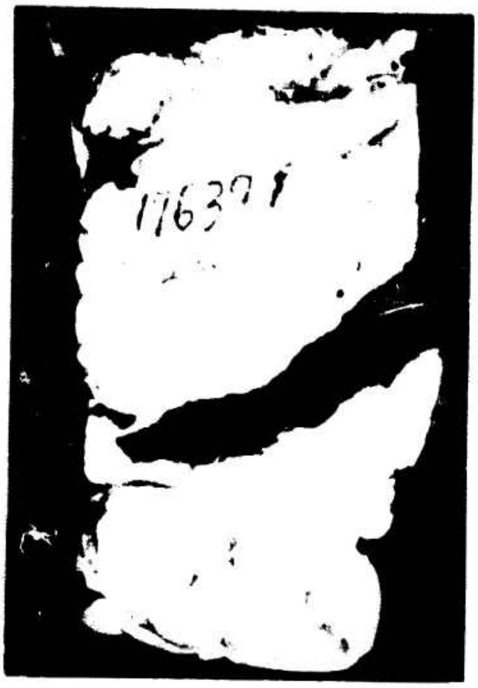

Figure 5. Molding Temperature 120°F

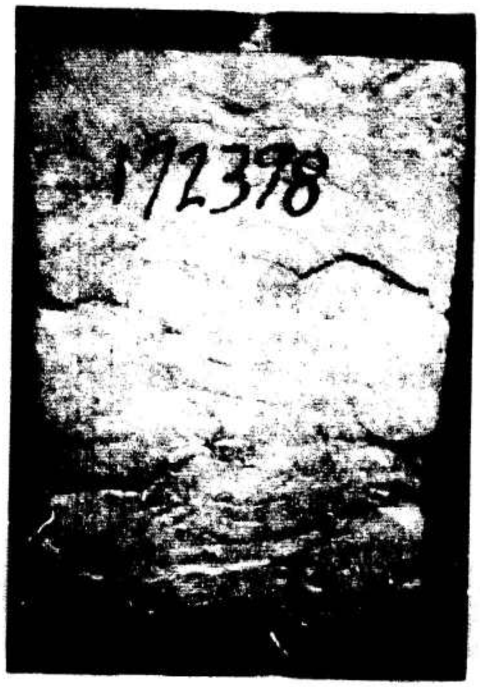

Figure 6. Molding Temperature 100°F

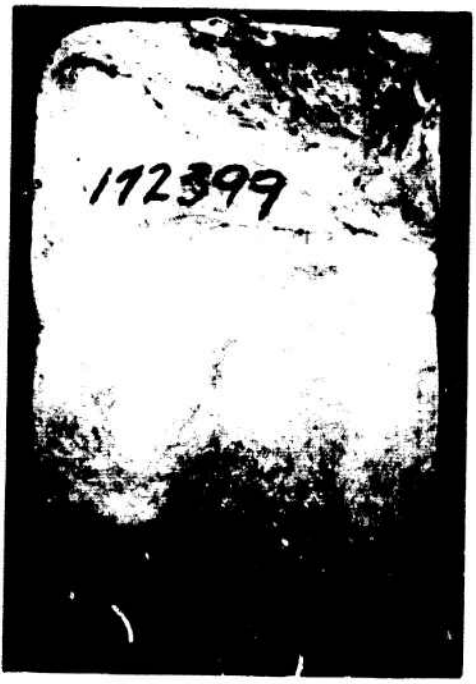

Figure 7. Molding Temperature 80°F

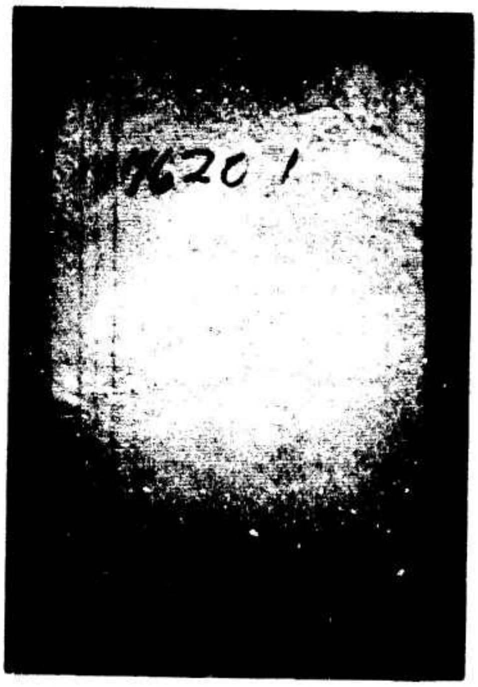

Figure 8. Molding Temperature 60°F

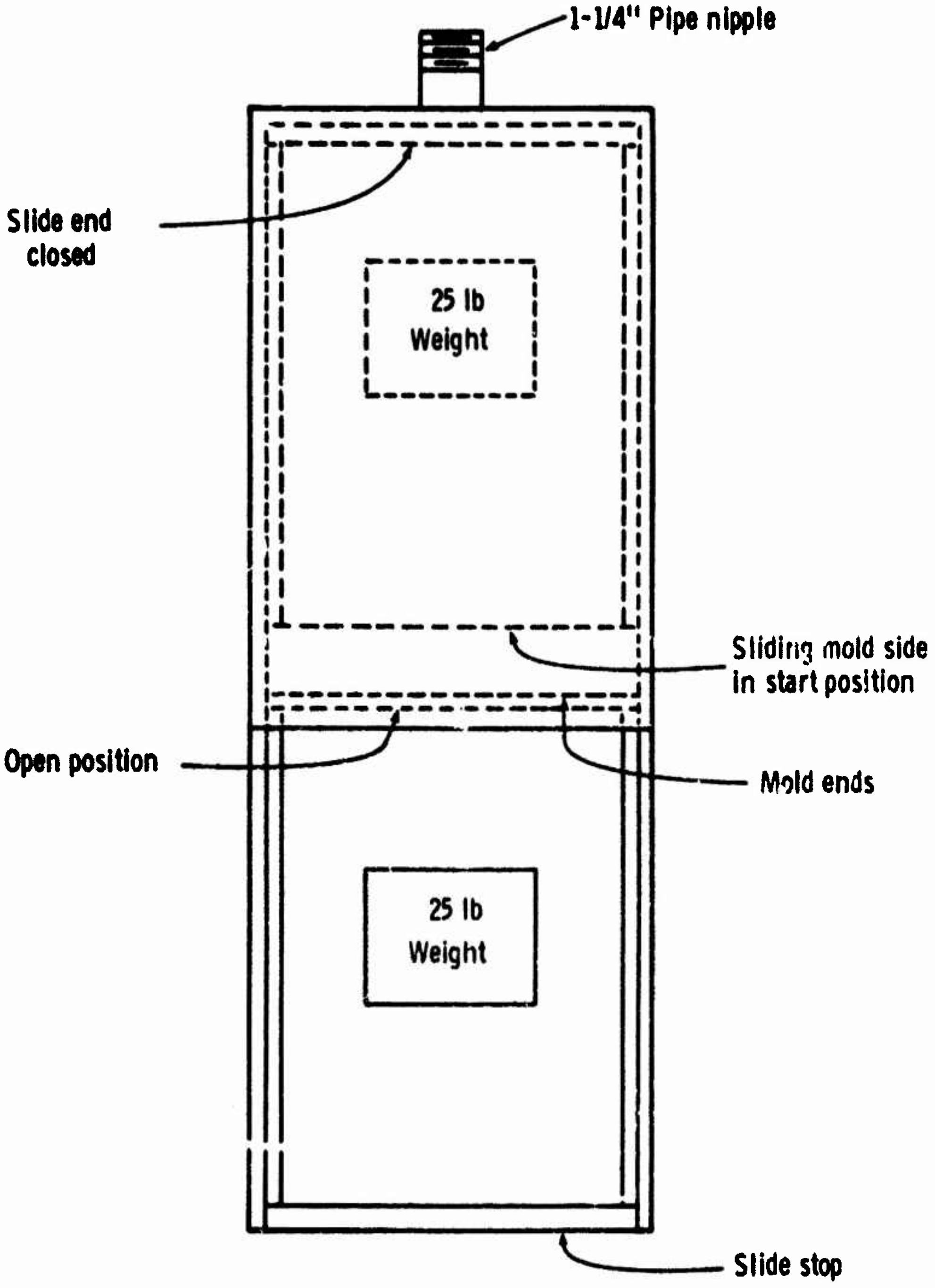

Figure 9. Mold with Sliding End Closure

Figure 10. Two Inch Pipe Vessel with 90° Elbow

The sliding mold was scaled up to a 3 x 12 x 48 inch size. This mold is shown in use in Figure 11. Figure 12 shows a foam (176217E) molded in the four foot long mold. The sample was prepared using the 25 pound weight for resistance to foam flow and a partially opened 1-1/4 inch ball valve. The top and bottom of the mold were lined with polyethylene to act as a slip agent. The foam molded well with no knit lines, forming a 36 inch long sample after shrinkage. The problem of shrinkage was believed to be caused by improper molding techniques.

A second attempt to mold a slab of foam in this mold resulted in the 25 pound weight being thrown forcefully from the mold. Work on the sliding end mold was terminated at this point. Feasibility had been shown, but a considerable amount of design work would have been needed to make this a dependable, safe method of forming foam moldings. It was believed that direct extrusion through a die was a more promising way to produce foam boards and slabs.

2.4.5 Physical Properties of Molded Instant Polystyrene Foam

Compressive strengths of molded foams were measured on an Instron testing machine at a crosshead speed of 0.2 inches per minute. Testing was in compliance with military specification MIL-P-26514B, with the exception that the foams, being rigid, were not flexed prior to test. The test specimens were 2 x 4 x 4 inches and, when required, consisted of one or more pieces of the same test material.

The foams tested were selected from the best molded piece made with the combination of surfactant and pneumatogen under investigation (See Table 6).

Four foams were molded using different amounts of Triton X-200 as surfactant, different amounts of Freon 11, and different pneumatogens. The foams tested exhibited no outstanding properties, and there was no significant difference in properties between the four combinations, indicating that the amounts of surfactant and Freon 11 and type of pneumatogen did not greatly affect the foam's physical properties. There was a drop in compressive strength with each drop in foam density, which was expected.

Figure 11. Molding of Instant Foam Using 2100 Cubic Inch Tank and 48 Inch Long Sliding Mold

Figure 12. Slab of Foam Molded in Sliding Mold, 36 Inches Long

Table 6

PHYSICAL PROPERTIES OF MOLDED INSTANT POLYSTYRENE FOAM
MADE FROM A 3 x 12 x 48 INCH CLOSED WOOD MOLD

Sample No.	Surfactant	Parts[1]	Freon 11	Parts	Pneumatogen	Density, pcf	Compressive Strength, psi 25%	50%	65%	Recovery,[2] %
172371	Triton X-200	6.4	Freon 11	7.6	methyl chloride	1.56	4.7	7.1	9.6	64
172385	Triton X-200	6.4	Freon 11	15.3	dimethyl ether	1.9	5.6	8.3	12.5	67
172374	Triton X-200	12.7	Freon 11	15.3	dimethyl ether	1.8	4.3	6.2	9.2	68
172375	Triton X-200	6.4	Freon 11	15.3	dimethyl ether	1.1	3.5	5.0	6.8	65
172394	Triton X-200	6.4	Freon 11	15.3	dimethyl ether	0.95	2.1	2.9	3.9	75
172389	Duponol WAQ	12.7	Freon 11	7.6	dimethyl ether	2.1	12.6	1[illegible].5	21.5	64
172393	Zelec DX	12.7	Freon 11	7.6	dimethyl ether	2.0	8.8	14.3	21.6	69
172382	Flameout 5600-B1	12.7	Freon 11	7.6	dimethyl ether	1.5	5.3	7.4	10.6	60
172383	Flameout 5600-B1	12.7	Freon 11	15.3	dimethyl ether	1.2	4.5	6.2	8.3	68
172387	Igepal CO-970 water	7.6	Freon 11	7.6	dimethyl ether	1.5	4.5	6.1	7.8	68
172379	Igepal CO-970 octabromobiphenyl	3.2	Freon 11	7.6	dimethyl ether	2.4	6.5	8.7	13.0	69

[1] Parts per hundred polymer
[2] Recovery after 65% compression and 10 minute rest period

Foam samples 172389 and 393 were made with Duponol WAQ and Zelec DX. Both are anionic surfactants of the same type as Triton X-200. The Duponol WAQ sample, 172389, caused an increase in compressive strength over all other variables investigated. This was at 25 and 50% compression.

Flameout 5600-B1, a fire retardant, was effectively used to mold instant polystyrene foam. The compressive strength of sample 172382 showed a slight improvement over the control samples, 172371 and 387.

Two test specimens made with high levels of Igepal CO-970 contained octobromobiphenyl or water at very high additive levels. The compressive strengths of the samples tested were average.

An interesting property of these foams was their high percent recovery after 65% compression. In general, the recovery improved as the density became lower.

2.5 BULK MOLDED INSTANT FOAM (DIRECTION OF RISE PARALLEL TO LENGTH OF MOLD)

Two bulk foams were prepared by transferring foam solution under pressure to a 5.0 inch diameter by 5.0 inch high pressure vessel. Figure 13 shows this apparatus. The pressure vessel was allowed to stand for several hours after charging. This insured that all the solution had collected at the bottom of the vessel. At the end of this time, the valve in the top of the tank was opened and the solution foamed and filled the pressure vessel (mold).

In the first experiment, 1.7 lbs of foam solution was charged to the vessel. This was an excess of material. The transfer took 24 hours. On the release of the pressure, foam filled the vessel, plugging the vents. When the vessel top was removed foam expansion continued, producing a mushroom shaped piece of Foam (Figure 14). The foam cell structure was large and irregular.

The second foam was made using only 0.25 lbs of foam solution. When the gas was released the foam rose and filled the pot. This sample is shown in Figure 15. The molding filled the vessel well, but it had an axial hole approximately 1-1/4 inches in diameter running its length. The hole was believed to be caused by insufficient foam solution in the mold and trapped gas in the pipe coupling between the valve in the feed line and the bottom of the vessel. This work demonstrated the feasibility of producing foams from a pressurized mold. These foams had cells elongated in the direction of foam rise.

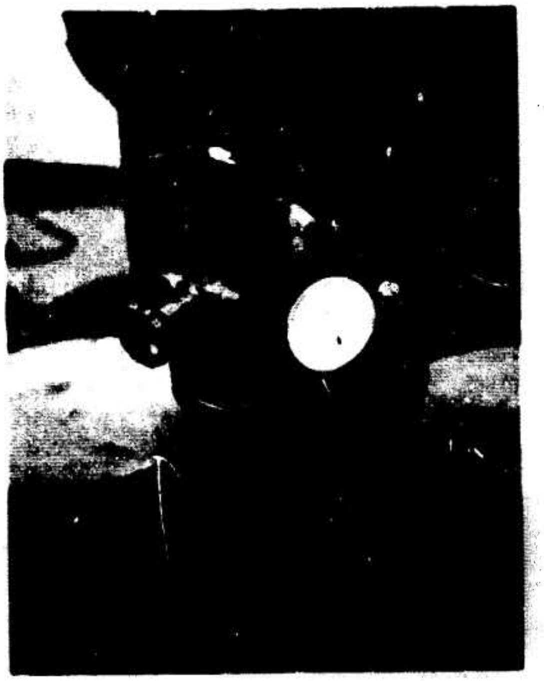

Figure 13. Pressure Vessel Being Charged with Foam Solution

Figure 14. Foam 176272 - Excess Foam Solution

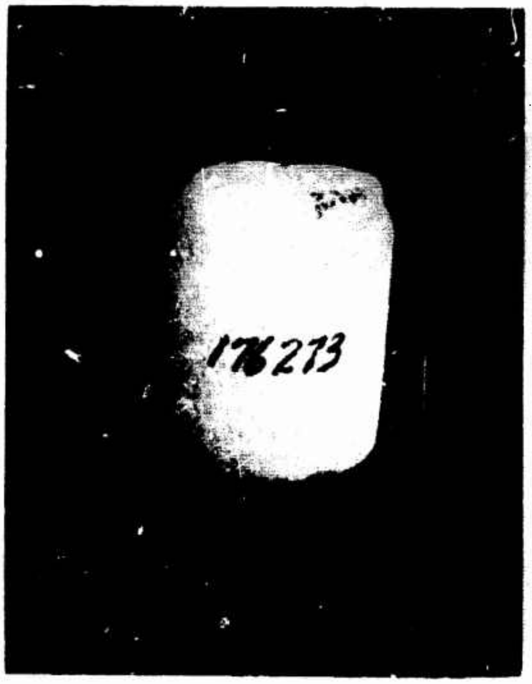

Figure 15. Bulk Molded Instant Foam

2.6 EXTRUSION MOLDED POLYSTYRENE FOAM

Extrusion of polystyrene [illegible] through a die to produce boards or [illegible] of [illegible] [illegible] an attractive method of producing [illegible] cushioning material. It offers the advantage of forming foam with the desired cross-sectional area and in desired length. To accomplish this objective it is necessary to control the [illegible] of the solution through the die so that the dwell time in the shaping portion of the die is sufficient to mold the foam.

2.6.1 Preliminary Extrusion Die Molding of Foam

As a starting point for foam extrusion molding, two T dies were made [illegible] 2 inch diameter pipe. The initial die opening was 1/8 x 6 inches. This die was attached to a [illegible] cylinder charged with 4 1/2 gallons of foam solution. Initial test runs using this die produced ribbons of foam with small cross sectional area and ragged or torn edges. They showed the feasibility of producing foam but also indicated the need for more work on die design.

As a result of these preliminary tests the original dies were modified, one externally, the other internally. The external changes were provided by two 1/4 inch thick plates with 1/[illegible] x [illegible] inch slots and a 1/4 inch plate machined with a 6 inch slot which tapered from 1/4 inch to 1/2 inch wide through the plate's thickness (See Figure 16). With a foam formulation containing Igepal CO-970 surfactant, a continuous foam extrusion was made using the plate with the 1/8 inch wide slot. This extrusion ranged from 1/8 in. to 1/4 in. thick by 5 in. to [illegible] in. wide. The sample had a corrugated appearance. The problem of corrugations running parallel to the direction of foam propagation was probably caused by gas escape through the lips of the die. This problem was not found in foams of greater thickness.

The internally modified T die is shown in Figure 17. One [illegible] is removed to show the internal details. The internal changes were incorporated to shape the foam [illegible] prior to [illegible] of extrusion. By using this die a continuous ribbon sample [illegible] x 6 1/4 to 6 1/2 inches wide) was formed. This foam was also corrugated

[illegible] die design was tested during the preliminary work. The 1 1/4 inch valve at the bottom of the tank had a 1 inch circular opening in its ball (0.785 in.^{2}). In this die a transition piece was provided which changed the circular opening to a rectangular opening of slightly less area ([illegible] x 1 1/2 inch [illegible] .75 in.^{2}). Figure 18 shows this die.

Figure 16. T Die Externally Modified to Give a Slot 1/8 x 1 x 6 Inches Long

Figure 17. T Die Internally Modified to Shape Foam Ingredient

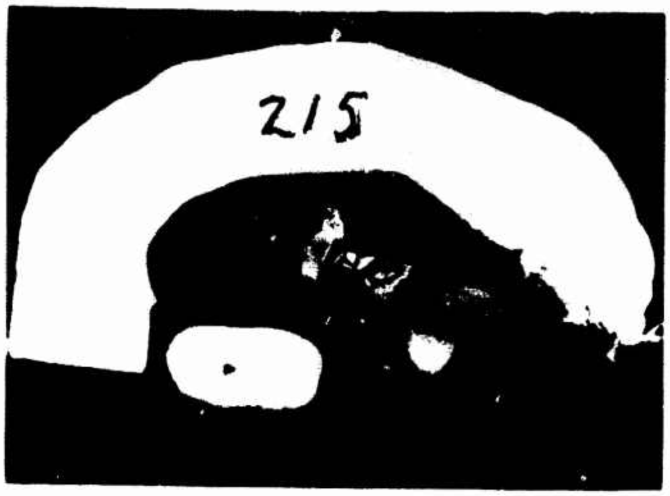

Figure 18. Equal Area Conversion Die, 4 Inches Long. Foams produced by this die are also shown.

The rectangular portion was 4.0 inches long. This die produced roughly elliptical-shaped foam boards (1-7/8 x 3-7/8 inches). The foam density was 6.4 lb/cu ft. The preliminary work showed the feasibility of continuously forming foam through a die, and the need for a more basic study of flow properties through orifices and tubes. It also indicated the need to do this work on small scale dies so that many runs could be made from one tank of solution.

2.6.2 Flow Study Through Die Orifices

To direct work on the design of extrusion type dies, a program to study the flow of instant foam solution through orifices of various sizes and geometries was initiated. This study included work on flow control, die geometries, and tank pressure. The design criteria for equipment used in this work was that the test die should be:

- Easily mounted on the foam tank.
- Easily cleaned after each run.
- Readily adaptable to orifice of selected sizes and geometries.
- Should allow a large number of runs to be made from a single tank of foam solution. This is to permit testing of a large number of orifices.

This versatile die is shown schematically in Figure 19, and photographically in Figures 20 and 21. Orifices of various sizes were made, as shown in Figure 22. Their diameters and lengths are given in inches in the following table.

Table 7

ORIFICE SIZES

Orifice Diameter, in.	Orifice Length, in.							
	1/4	1/2	3/4	1	2	2-11/16	2-3/4	6
1/8	✓	✓	✓	✓				
1/4	✓	✓	✓	✓	✓	✓	✓	
3/8	✓			✓				
5/8	✓			✓				✓
Tapered 1/4 to 3/4				✓				

All orifices are square edged; this represents the simplest, but not necessarily the best, edge condition.

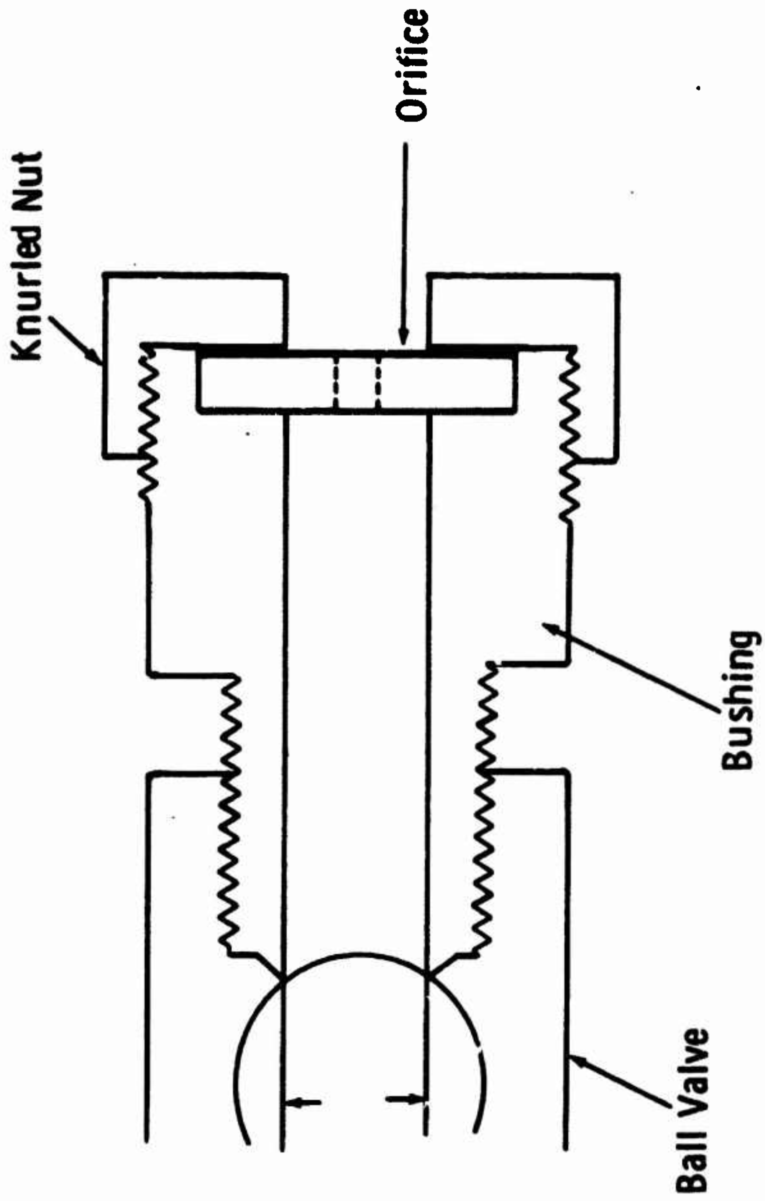

Figure 19. Test Die Concept

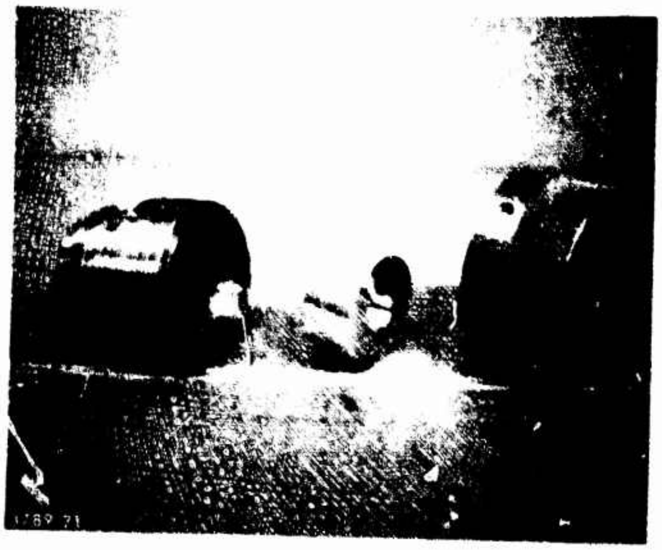

Figure 20. Test Die (disassembled)

Figure 21. Test Die (assembled to tank valve)

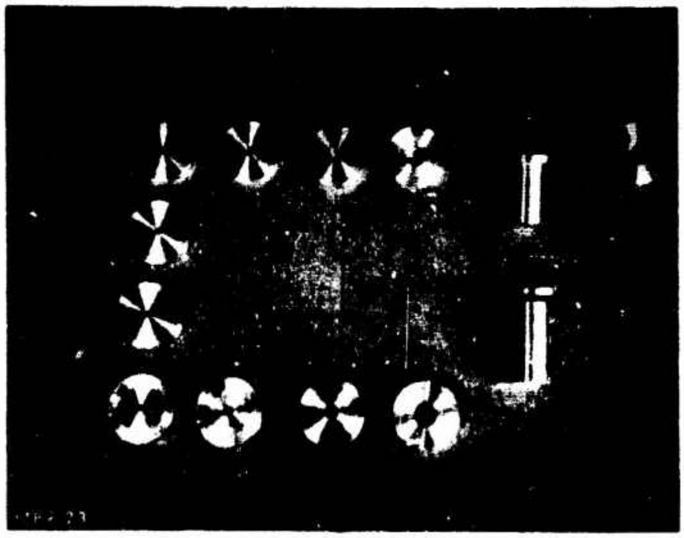

Figure 22. Test Die Orifices

2.6.3 Standard Procedure for Testing Extrusion Dies

The following procedure was used in evaluating the extrusion dies:

- The die to be tested was installed on the solution tank with its valve (Figure 21).
- The two-inch ball valve was fully open during the extrusion test unless otherwise noted.
- As the instant foam extruded, the foam was marked at 5 or 10 second intervals. Flow rates were all calculated from 10 second samples.
- From these foam samples the foam density and physical properties were determined.

Initial tests were run on two solutions which differed from each other in the surfactant used. One surfactant was Triton X-200, the other Igepal CO-970. Both solutions contained 6.4 parts surfactant per hundred parts of polymer (pphp). Because of the improved performance of Igepal CO-970, the use of Triton X-200 was discontinued in later work.

2.6.4 Effect of Orifice Diameter and Length on Foam Quality

The results of all tests run on circular sub-scale orifice dies are summarized in Table 8. General conclusions that can be drawn from this work are:

- Length to diameter ratio controls flow - e.g. with 1/8 in. diameter orifices, flow varied from 39 to 0 ft/min as the length increased from 1/4 in. to 1 in. The length to diameter ratio at which flow stopped was 8:1. With a 1/4 in. diameter orifice, flow stopped at 2-3/4 in. length (length:diameter ratio in this case was 11:1). It is possible that flow might have stopped at even a shorter length, but the limited data did not prove this.
- Increased die length results in foams of decreased diameter and higher densities. For example, as the 1/8 in. diameter orifice was increased in length from 1/4 in. to 1 in., foam diameter decreased from 7/16 in. to 3/16 in.

Table 3

DATA FROM EXTRUSION EXPERIMENTS USING CIRCULAR ORIFICES

	Cylinder Data								Sample Data					
					Weight (lb)									
Sample No.	Orifice Diam., in.	Orifice Length, in.	Tank Pressure, psi	Total Time, sec	Start	End	Δ Wt	Rate of Delivery lb/sec	Time, sec	Length, ft	Diam. in.	Density, lb/cu ft	ft/min	Ratio of Foam Diameter/ Orifice Diameter
IGEPAL CO-630														
176221L	1/8	1/4	50	20	91.1	90.9	0.2	0.010	10	7.5	7/16	2.54	45	3.5
176221C	1/8	1/2	54	80	88.6	88.5	0.1	0.0013	10	1.25	3/8	1.34	7.5	3.0
176221F	1/8	3/4	54	60	88.5	88.4	0.1	0.0017	10	1.0	5/16	2.6	6.0	2.5
176221M	1/8	1.0(1)	50	20	91.1	91.0	0.1	0.005	10	2.2	3/16	1.59	13.6	1.5
176221H	1/4	1/4	50	20	93.4	92.7	0.7	0.035	10	12	1	2.36	72	4.0
176221I	1/4	1.0	50	20	93.	92.8	0.2	0.010	10	8	13/16	1.68	48	3.3
176221G	1/4	2.0	52	20	91.0	90.75	0.25	0.0125	10	6.5	5/8	2.1	39	2.5
176221N	1/4	2-11/16(1)	51	20	91.1	91.	0.1	0.005	10	7.0	5/8	1.5	42	2.5
176221T	1/4	2-3/4(1)	56							3.2	1/2			2.0
176221J	3/8	1/4	50	10	92.6	91.7	0.9	0.090	5	7.5	2	.54	90	5.3
176221K	3/8	1	50	10	91.9	91.4	0.5	0.050	5	9.5	1-7/16	1.66	102	3.8
TRITON X-200														
176218F	1/8	1/4	60	20	78.5	78	0.5	0.025	10	18	7/8	1.13	[illegible]	-
176219G	1/8	1	60	20	78.1	77.7	0.4	0.020	8	9	7/16	2.6		3.5
176218D	1/4	1/4	60	20	82.5	79.25	3.25	0.1625	10	56	2-1/4	0.85	336	9
176218E	1/4	1	60	10	79.5	78.6	0.9	0.09	5	19	1-3/8	1.45	228	5.5
176218H	3/8	1	60	6	77.8	73.9	3.9	0.65	3	48	2-5/8	0.73	960	-
176218I	3/8	1/4	60	2	73.6	70.3	3.3	1.65	2	30	4-1/2	-	900	12.0
176218G	5/8	1/4	50	8	94.5	82	12.5	1.56	8	55	4 to 8	-	413	[illegible]
176237C	5/8	6	53	5	104.0	103.4	0.6	0.12	5	28	1-7/8	3.[illegible]	216	3.[illegible]
5/8" Diameter Orifice with Screen - TRITON X-200 LUBRICANT														
176221A*	5/8	1/4(2)	54	[illegible]	87.9	87.6	0.3	0.015		1.83	1-1/2	3.80	66	2.4
176221B	5/8	1/4(3)	54	20						2.25	1-3/8	[illegible].7	14.0	2.2
176237D	5/8	6(4,5)	53	3	103.4	103.0	0.4	5				5.[illegible]		
Tapered Orifices (conical) IGEPAL CO-970 Lubricant - Diameter given first is in toward valve and Tank														
176221P	1/4x3/4	[illegible]	52	20	90.75	90.1	0.65	0.033	10	6.0	1-3/8	1.[illegible]	36	5.5
176221Q	3/4x1/4		52	20	90.2	89.4	0.8	0.04	10	12.0	1-1/2	1.6	72	6.0

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[1] Would not extrude without a slight pull

[2] Screen size - 24 mesh x 0.010 wire diameter

[3] Screen size - 26 mesh x 0.007 wire diameter

[4] Screen size - 16 mesh x 0.20 wire diameter

[5] Intermittently

These findings strongly suggest that better moldability and density control can be achieved by varying the ratio of the length of the die to the cross sectional area.

Two runs (176210C and 176217C) were made using 1/4 inch and 3 inch long orifices 5/8 inch in diameter. No baffles were used in these tests. The 1/4 inch long orifice formed 44 feet of foam 2 inches to [illegible] inches in diameter in [illegible] seconds i.e. a flow rate of 130 feet per minute. [illegible] 40 feet of the 44 [illegible] completely hollow. This indicated an inadequate supply of foam solution to the die. Lengthening the 5/8 inch diameter orifice to [illegible] inches reduced the flow rate to [illegible] feet per minute. At the same time the foam diameter increased to 1 7/8 inch. Both these rates were far too fast to control shape. To gain control of flow rate (moldability) the 5/8 inch diameter orifice would require lengthening to [illegible] or more inches. The increased length would probably effect a reduction in foam diameter to an estimated 1.5 inches or less.

Attempts to control flow rate were made using two different screens. Each screen was placed before the 5/8 inch diameter 1/4 inch long orifice. The effect of the screens was to give control of flow rate, and improve cell structure. Using a 20 mesh x 0.013 inch diameter wire (with 51.8% open area) the flow rate was reduced to 11.0 feet per minute and the foam diameter to 1 1/4 inches. With a 20 mesh x 0.0075 inch wire diameter (69% open area) the flow rate increased to 13.5 feet per minute and the diameter to 1 3/4 inches. A third experiment using the 5/8 inch diameter orifice, 1.0 inches long was tried using a [illegible] mesh [illegible] inch wire diameter screen ([illegible] open area). The resulting foam extruded [illegible] rate [illegible] then [illegible] for 10 to [illegible] seconds. This [illegible] reduction of foam expansion and a necking down of the foam.

Another type of circular die was tested. It was [illegible] tapering from 3/4 inch to 1/4 inch in a 1 [illegible] length. The die was tested with the 1/4 inch orifice toward the foam solution and the taper expanding [illegible] (sample 17[illegible]). Comparing the tapered die to the straight 1/4 inch orifice, 1.0 inch long (sample 1762211) the tapered die increased the delivery rate, increased foam expansion from 13/16 in. to 1 3/[illegible] in. diameter, and lowered the density to 1.4 pcf. Reversing this die by installing the 3/4 inch diameter opening toward the foam solution improved all the properties mentioned above. An unexpected advantage resulting from reversing the die was an improvement in overall appearance. This suggested one mold design criterion; namely, using an inverted taper in the die.

2.65 Rectangular Orifices

Three miniature rectangular orifices were fabricated and tested. They are shown schematically in Figure 23, which gives the dimensions and areas of openings. They are identified as:

Type 1 die - having a straight through rectangular opening.

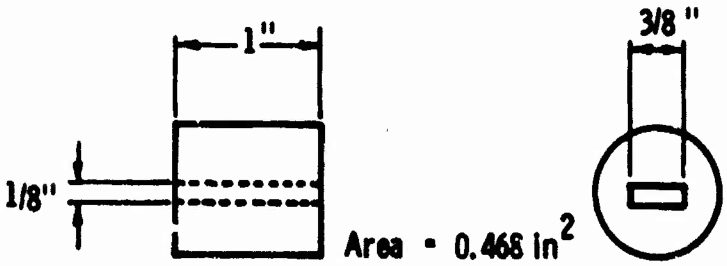
Type 2 die - having a tapered opening which is rectangular in cross section.

Type 3 die - a 2-stage die having a straight rectangular opening part way through the die, which then flares out to a larger area opening.

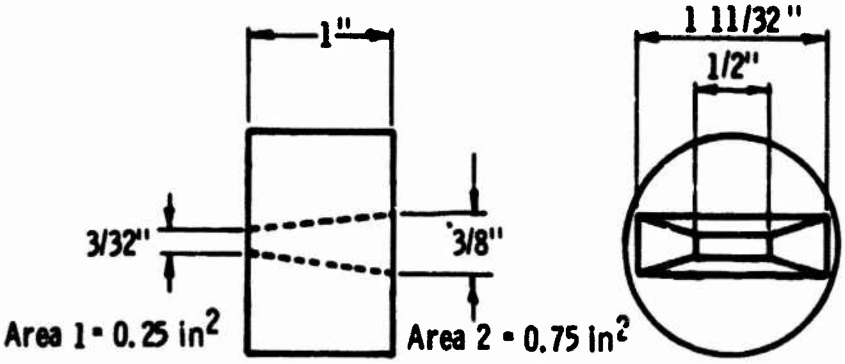
The results of tests made with these dies are given in Table 9.

The Type 1 die extruded a section of foam 3/16 in. x 5/8 in. at a flow rate of 8.0 feet per minute. These data support those obtained with a 1/8 inch circular orifice. The foam produced had a density of 4.2 pcf, much higher than for foam previously formed with this formulation (Igepal CO-970). Higher density foams generally are formed when the die is relatively long and narrow.

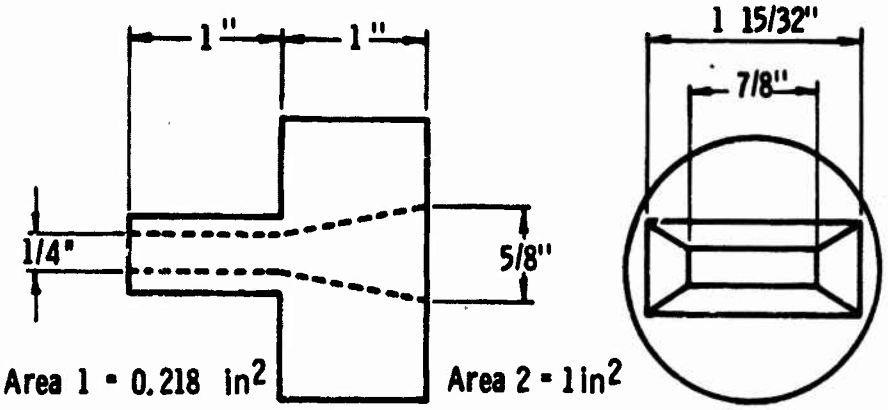
The Type 2 die has a less restrictive rectangular opening. The foam product from this die (sample 176221A-3, Table 9) was 3/4 x 1-3/4 inches in cross section. It was produced at 20 feet per minute. A sample was also made with the die reversed, having the polymer solution enter the 3/4 in. opening. This run formed a foam 1.0 x 1-3/4 inches in cross section at 18 feet per minute (sample 176221B-3). The latter foam had a more rectangular cross section, indicating that better shaping was obtained when the foam solution passed from a large area to a smaller one in the die.



Type 1 (Straight through rectangular die)



Type 2 (Flared rectangular opening)



Type 3 (Two stage die - straight rectangular opening followed by flared rectangular opening)

Figure 23. Rectangular Dies

Table 9

EXTRUSION EXPERIMENTS USING RECTANGULAR ORIFICES WITHOUT SCREEN WIRE

Sample No.	Orifice Type	Tank Pressure, psig	Flow Rate, ft/min	Density, pcf	Foam Description
176221R	Type 1	51	8.0	4.2	almost rectangular 3/16 x 5/8 x 16 inches
176221A-3	Type 2 - small area in toward valve	51	20.0	1.5	elliptical 3/4 x 1-3/4 x 40 inches
176221B-3	Type 2 - large area in toward valve	51	18.0	1.3	elliptical 1.0 x 1-3/4 x 101 inches
176237I	Type 3 - samll area in toward valve	57	16.5	1.4	rounded off rectangle 1-1/4 x 2-1/2 x 33 inches
176237J	Type 3 - large area in toward valve	57	40.0	1.9	almost rectangular 1-3/16 x 2-7/8 x 8 inches

The last two foams listed in Table 9 were made with Type 3 die. Using the die with the small area directed toward the valve (176237I) did not shape the foam as well as in the reverse position (sample 176237J). This was the best molded sample prepared up to that time.

2.6.6 Rectangular Orifice, Screen Backed

A 1/2 inch thick disc of polyethylene was cut to fit the die holder (Figure 19). The disc had a 9/16 inch x 1.0 inch rectangular opening in its center. A 16 mesh wire screen was positioned before the disc and a well formed rectangular foam board (1-1/4 in. x 2-1/2 in.) was molded at 12 ft. per minute flow rate. This is foam 176237F in Table 10.

To show the effectiveness of the wire screen in reducing flow and improving moldability, a run (176237H) was made using a 9/16 x 1.0 x 1/2 inch die without screen. The valve was fully opened for only a second. The resulting foam was a cylindrical log, 5 to 5-3/4 inches in diameter. There was no evidence of molding or shaping.

Foam No. 176237Q was made using a 24 mesh 0.015 inch diameter wire screen which had 41.1% open area. The foam produced at a rate of 20 ft/min, was 1-1/4 in. thick by 2-1/8 in. wide and had a rather uniform cell structure.

2.6.7 Effect of Various Size Screens

The early results using screens were sufficiently encouraging to warrant a more systematic study of the effect of screen size and location in the die. A number of commercial screens were purchased and tested with the 9/16 x 1.0 x 1/2 inch polyethylene die. The screens were positioned before the die. Table 11 lists these screens. The variations in the number of openings and wire diameter represent an 11% overall change in the percent open area for the screens tested. The foams showed only a slight change in cell structure but, in general, cell structure improved with the higher mesh screens.

For comparison, sample 176237H was made using no screen. The cylindrical foam extruded at a rate of 216 feet per minute. The effect of the screens was to force the instant foam solution after partial expansion to take a shape by restricted flow. The compacting or restricting effect increased the density by a factor of 2.0 to almost 2.5 times that of foam made without a screen. Furthermore, the screen wire cut the partially expanded foam. This may have caused some foam collapse and also left knit lines in the foam. These

Table 10

EXTRUSION THRU SCREEN WIRE AND A RECTANGULAR ORIFICE

Sample No.	Rectangular Orifice Width-Length-Depth, in.	Tank Pressure, psig	Flow Rate, ft/min	Density, pcf	Foam Description
176237F	9/16 x 1.0 x 1/2 screen[1]	58	12	3.6	rectangular 1-1/4 x 2-1/4 x 35 inch
176237H	9/16 x 1.0 x 1/2 no screen	56	very fast	<2.0	circular - 5-3/8 x 120 inches
176237J	9/16 x 1.0 x 1/2 screen[2]	60	20		rectangular

[1] Screen 16 mesh by 0.02 wire diameter with 46.2% open area located before the orifice.
[2] Screen 24 mesh by 0.015 wire diameter with 41.1% open area located before the orifice.

Table 11

EXTRUSION THRU VARIOUS SCREENS AND A RECTANGULAR ORIFICE[2] TO DETERMINE THE EFFECT OF SCREEN SIZE

Sample No.	Screen[1] Mesh	Screen[1] Wire Dia.	Screen Open Area, %	Tank Pressure psig	Sample Description Width-Depth-Length, in.	Density, pcf	Flow Rate, ft-foam/min	Compression Load, psi Direct. of Test	Compression Load, psi 25%	Compression Load, psi 50%	Compression Load, psi 65%	Recovery After 1 min, %	Ratio Strength/Density 25%	Ratio Strength/Density 65%
176237R	no screen		-	62	Cylindrical 4-5/8x18 ft Dia.	1.6	216	parallel	13.5	15.1	18.6	49	8.4	11.6
								perpendicular	7.3	10.2	14.0	50		
176237P	12	0.032	34.2	60	Rectangular 1-3/8x2-1/4 x 53	2.48	27	parallel	41	42	59	43	16.4	23.6
								perpendicular	26	36	52	48		
176237O	14	0.032	29.8	62	Rectangular 1-3/8x2-3/8 x 52	2.56	26	parallel	46	49	65	44	17.7	25.0
								perpendicular	27	41	60	45		
176237N	16	0.028	30.5	62	Rectangular 1-3/16x2-1/8 x 34	3.7	17.0	parallel	44.0	47.0	67	47	12.0	18.0
								perpendicular	27.0	40.0	61	47		
176237Q	24	0.015	41.1	60	Rectangular 1-1/4x2-1/8 x 40	2.7	12	parallel	61	59	71	45	22.6	26.3
								perpendicular	28	45	69	49		
176254A	24	0.015	41.1	68	Rectangular 1-3/8x2-1/4 x 43	3.1	16	parallel	97	107	147	50	31.0	47.3
								perpendicular	49	79	113	50		

[1] C. E. Tyler screens, Stainless Steel Type 304, located before the orifice.
[2] 9/16 x 1.0 x 1/2 inch orifice in a polyethylene die.

lines could be seen when the foam was cut. The foam produced by extrusion through a screen had a definite fibrillar character in the direction of foam propagation (Figure 24). The fact that some foam collapse occurred was shown by higher foam densities. As the number of wires increased from 12 to 24, the foam density increased from 2.48 to 3.1 pcf.

The compression load properties were determined in accordance with military specification MIL-P-26514. The compressive strength of polystyrene prepared by screen extrusion is higher than for standard polystyrene of comparable density. This fact is borne out by the 25% and 65% compressive strength measured parallel to the direction of extrusion (shown in Table 11). Parallel in the case of both static and impact testing means that load or impact velocity is applied in the direction of foam extrusion. Perpendicular testing means that the stress is applied in a direction perpendicular to the direction of foam extrusion. Figure 25 illustrates this.

2.6.8 Effect of Screen Location

An investigation was made to establish the best screen location in relation to the die. The screen or screens were positioned before and after the die, as shown in Table 12 and Figure 26. All other test conditions were maintained as constants including the foam solution containing Igepal CO-970 and the 9/16 x 1.0 x 1/2 inch die.

Sample 176237U, which was made with the screen located after the die, showed only slight shaping of the foam, which was more elliptical than rectangular. Sample 17623V was extruded with the screen before the die orifice. This represents the position of the screen in earlier tests. Foams prepared with the screen in this position extruded well and produced relatively high density foams. This screen position apparently causes the greatest amount of foam collapse, or compaction of the foam. This densification was possibly caused by the screen cutting the raw expanding foam into strands and the subsequent coalescence of these strands back into a slab or board. These foams, when cut perpendicular to the direction of extrusion, had the appearance of an expanded grid.

Figure 24. Character of Foam Produced by Generating Foam Through a Screen

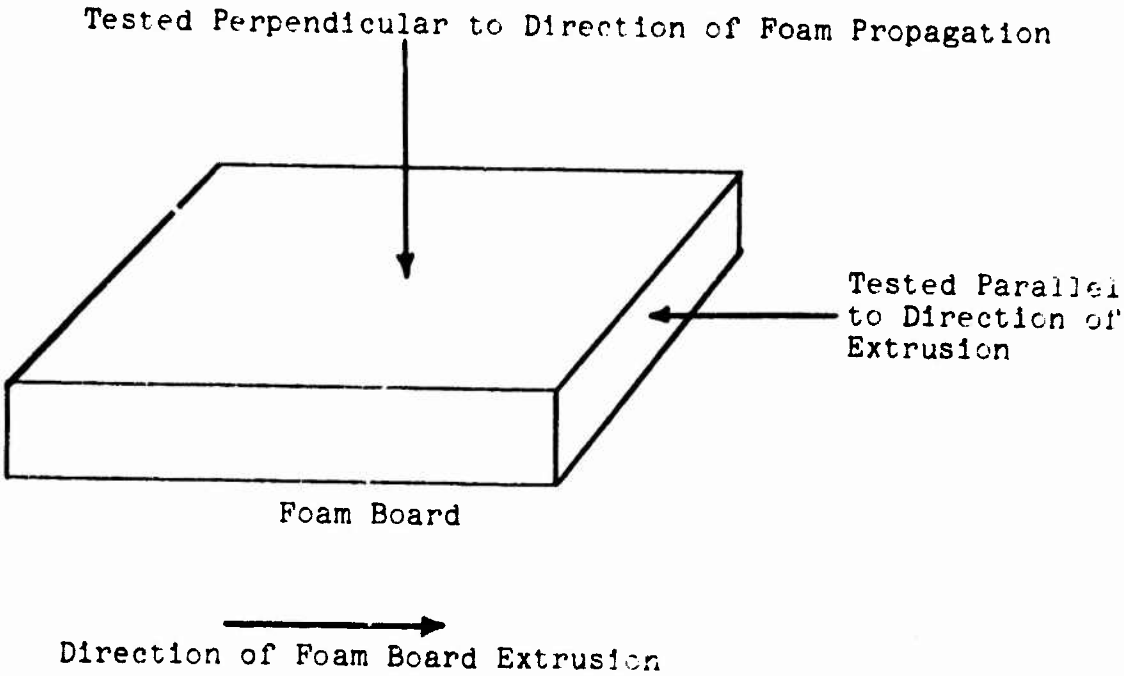


Figure 25. Convention for Direction of Testing

Table 12

EXTRUSION THRU A SCREEN AND RECTANGULAR ORIFICE[2] TO DETERMINE THE EFFECT OF SCREEN LOCATION

Sample No.	Screen[1]		Screen Location	Tank Pressure, psig	Sample Description Width-Depth-Length, in.	Density, pcf	Flow Rate ft-foam/min	Compression Load, psi				Recovery after 1 Min. %	Ratio Strength/Density	
	Mesh	Wire Dia.						Direct. of Test	25%	50%	65%		25%	65%
176237U	16	0.20	after die	70	almost round dia. 2.0 x 2-5/8	3.0	22	parallel	7.5	15	26	62	2.5	8.7
								perpendicular	38	33	41	45		
176237V	16	0.20	before die	70	Rectangular 1-1/4x2-1/4 x 47-3/4	3.6	24	parallel	39	38	45	43	1.1	12.5
								perpendicular	23.1	35	51	48		
176237W	16	0.20	before test assembly	70	Rectangular 1-3/8x2-1/8 x 61	2.5	30	parallel	38	33	46	44	15.2	18.4
								perpendicular	8	15	26	62		
176237X	16	0.020	before test assembly	70	Rectangular 1-1/2x2-1/8 x 11	1.8	5.4	parallel	27	24	26	46	15.0	14.4
								perpendicular	7.5	13	26	56		
	24	0.015	before orifice											
176237Y	16	0.02	before test assembly before orifice	68	Rectangular 1-1/8x2.0 x 10.5	2.1	4.9	parallel	9.0	17	26	46	4.3	12.4
								perpendicular	28	29	35	46		
176221D1	24	0.015	before orifice	66	1-3/8x2-5/16 x 33	2.9	16.5	parallel	27	42	61	49	9.3	21.0
								perpendicular	54	56	73	43		
176221E1	16	0.02	before valve	70	Rectangular shape until screen blew through	-							-	-

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[1] A check or repeat run of 176237W

9/16 x 1.0 x 1/2 inch orifice in a polyethylene die.

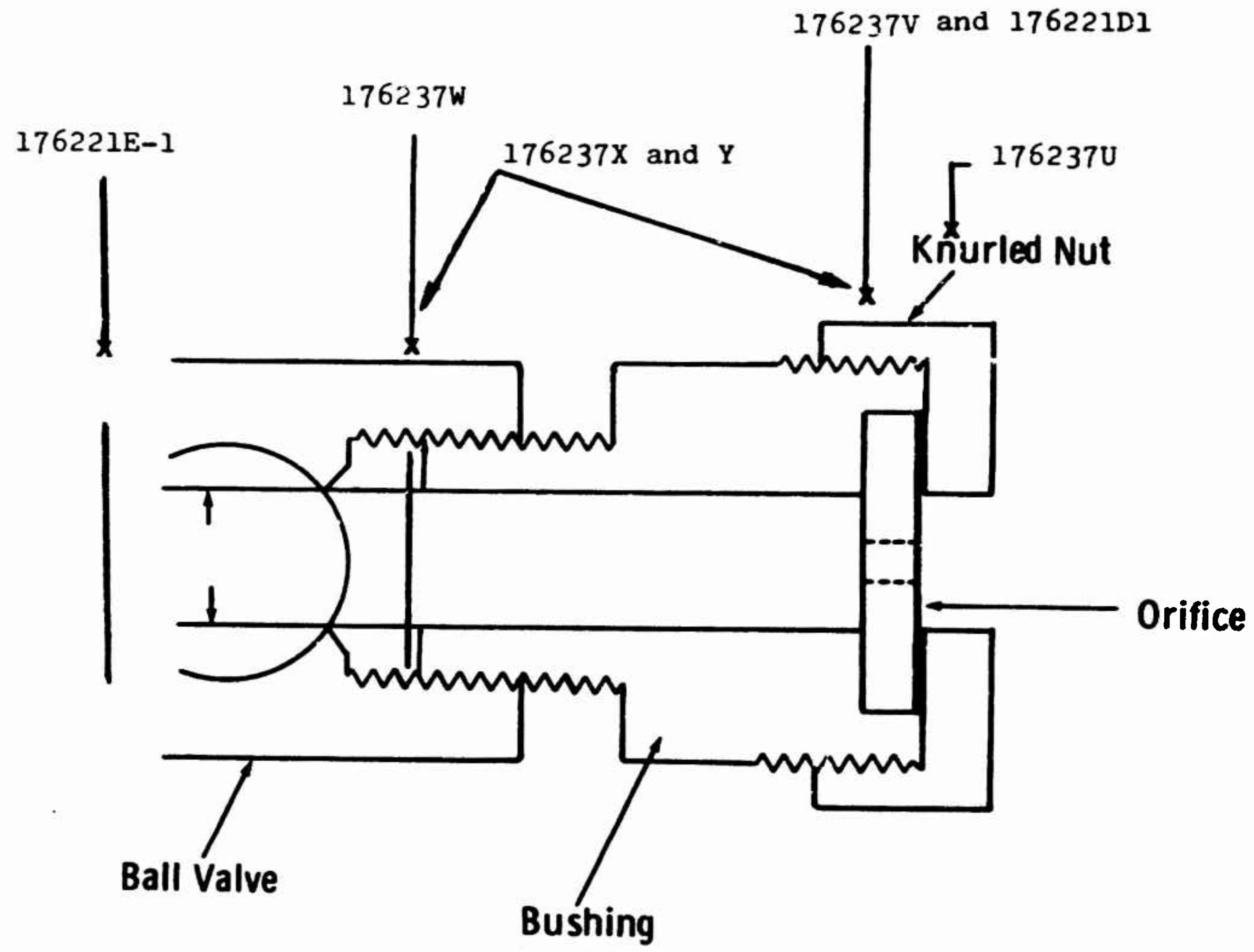

Figure 26. Test Die with Position of Screens Indicated

Sample 176237W, made with the screen located just prior to the holder for the test die, was a lower density foam with greater expansion. This foam's flow rate was the highest of the samples prepared in this series. With the screen in this position, the die molded the foam effectively.

Samples 176237X and 176237Y evaluated the effect of dual screens in the foam solution stream. The first screen was located prior to the holder for the die, and the second was positioned before the 9/16 x 1.0 x 1/2 inch die orifice. The foam produced in 176237X was a well shaped rectangular piece with irregular cell structure. Because of the cell structure this run was repeated in No. 176237Y, and a somewhat improved cell structure was obtained. The densities of both samples remained lower than for foam samples prepared with a single screen in front of the polyethylene die. The big difference was the drop in flow rate. When the sample was cut perpendicular to the direction of extrusion, no impression of the screen grid was observed.

The 16 mesh screen used in the 176237 series was replaced with 24 mesh screen, placed before the 9/16 x 1.0 x 1/2 inch die, and sample 176221D-1 was made. It was comparable to sample 176237 V prepared with the 16 mesh screen. Again, the foam density was higher and the flow rate increased to 16.5 feet per minute.

Sample 176221E-1 represents an attempt to evaluate the effect of a screen located before the 2.0 inch ball valve. The initial flow of foam indicated that such a position was feasible. However, shortly after the valve was opened, the screen was forced through the valve and into the die. The first one foot of foam through the die was molded into a rectangular section. After the screen was forced out of position, a cylindrical log of foam was extruded.

The physical properties for these foams are consistent with those of earlier samples of foam prepared by extrusion through a screen. The 25% and 65% strength to density ratios are higher than one would find with a more conventional polystyrene foam. Exceptions are samples 176237U and 176237Y tested parallel to the direction of extrusion. Their strength to density ratios are quite low, falling below 10. Screen extrusion in this application is too new to actually postulate the probable cause of these strength effects.

2.6.9 Effect of Cylinder Pressure on Foam Extrusion

The pressure of a gas varies with temperature. A study was made to determine the effects of such pressure changes on extrusion rates, density, and other foam properties. The pressure of the liquefied gas was supplmented with nitrogen to give tank pressures of 60, 70, 80, 90 and 100 psig. The foam solution contained Igepal CO-970. Extrusion was carried out through the 9/16 x 1.0 x 1/2 inch rectangular die. A 24 mesh by 0.015 inch diameter wire screen with 41.1% open area was used. It was mounted upstream from the die. The data for this study are presented in Table 13. Foam 176221D is anomalous--it was run at a different time (four days earlier) than were the other foams in the series. It had an abnormally high delivery rate which cannot be explained.

The latter four foams are comparable, having been prepared in sequence. They show an increase in flow rate with an increase in pressure. Density remains fairly constant as pressure changes, but as pressure increases, the cross sectional areas of the foam increase. The compression loads (psi) remain essentially the same except for foam 176221H-1. This sample, tested parallel to the direction of extrusion, has load bearing properties almost double those of the other foams. The results indicate a possible experimental or mathematical error in measuring the strength of this foam.

2.6.10 Molding Instant Foam Through a T Die Fitted with a Screen

The results of the work on miniature dies and screen baffles were applied to the T dies described in Section 3.6.1. An existing die of this type was modified by having a 3/4 inch wide x 6 inch long slot cut in its front face. A 24 mesh 0.015 inch wire screen was cemented to the inside of the die covering the die slot. Figure 27 shows this die schematically, while Figure 28 is a photograph of the dissasembled die.

The die length was controlled with the slant-faced plugs shown in Figure 28. The open space between the outside diameter of the plugs and the inside wall of the die was sealed with Thiokol vacuum bag sealing compound.

Table 13

EFFECT OF PRESSURE IN FOAM PREPARATION

Sample No.	Screen Location	Tank Pressure, psig	Density, pcf	Flow Rate, ft/min	Sample Description	Compression Load, psi: Test Direction	25%	50%	65%	Recovery After 10 Min., %	Ratio Strength/Density 25%	Ratio Strength/Density 65%
176221D-1	before orifice[1]	60	3.0	17.[illegible]	Rectangle 1-[illegible]x[illegible]	Parallel Perpendicular	54 27	56 47	73 62	43 49	18.0	24.3
176221F-1	before orifice	70	3.1[illegible]	9.0	Rectangle 1.[illegible] x [illegible]	Parallel Perpendicular	[illegible] 24	59 44	79 67	44 44	20.1	25.2
176221G-1	before orifice	80	3.22	9.4	Rectangle 13/16 x 2.[illegible]	Parallel Perpendicular	65 32	64 53	90 82	42 44	20.1	28.0
176221H-1	before orifice	90	3.10	10.[illegible]	Rectangle 1-1/4x2-1/4	Parallel Perpendicular	122 32	112 51	165 78	43 47	39.3	53.2
176221I-1	before orifice	100	3.19	12.8	Rectangle 1-1/4x2-1/4	Parallel Perpendicular	63 34	56 62	83 95	46 46	20.0	26.0

[1] 9/16 x 1.0 x 1/2 inch orifice in a polyethylene die with a 24 mesh 0.15 inch wire screen before the orifice

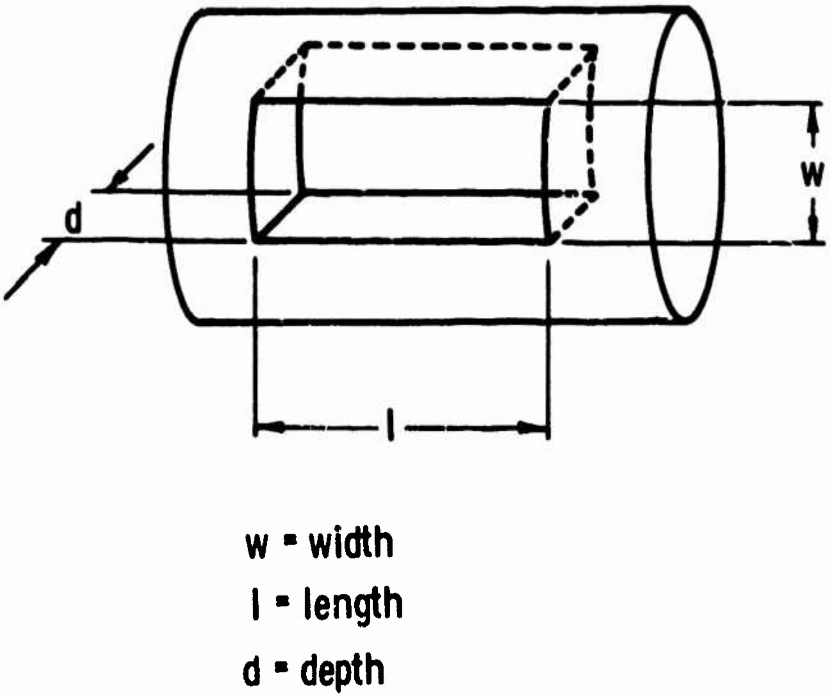

Figure 27. Schematic Drawing of T Die Slot

Figure 28. T Die With 3/4 x 6.0 Inch Slot Screen
24 Mesh 0.015 Inch Wire Diameter

As work progressed, the width of the slot was increased to 1-1/2 inches and finally to 1-5/8 inches. The final length of the die slot was 9 inches. The depth of the die path was 1/10 inch in all cases except one, in which it was increased to 1-1/10 inches by placing a slotted 1 inch thick piece of polyethylene over the die opening.

All test runs made with this die are reported in Table 14.

Runs 176237K, M and S were made with progressively longer slot lengths (3/4, 1-3/4, and 3 inch). As the slot length increased, the density of the foam product increased. A possible explanation for this increase is that as the slot length increases, the open volume within the die increases and there is more room for solvent losses in the die. As solvent loss increases, solution viscosity and polymer concentration increase. Increased viscosity would reduce flow through the screen, thus providing more time for the solvent to escape from the die. The resistance to flow through the screen could result in some compaction of the already partially expanded solution in the die, thus resulting in higher densities. The possible increase in polymer concentration in the solution, while it is in the die, would also contribute to the density increase.

Test foam 176237T was similar to 176237S in all respects except for the depth of the die opening. In the first, the depth was 1.1 inches; in the second it was 0.1 inches. Lengthening the path through the die slot results in a more rapid extrusion rate (18 versus 6.5 ft/min) and a much lower density (2.8 versus 5.8 pcf). The data indicate that by varying the depth of the die opening, control over the flow rate and density can be obtained.

The width of the slot in the die was increased to 1-1/2 inches. The slot was covered with 24 mesh screen having 0.015 inch wire. Plugs were again used to control the slot length.

Two experiments were run using the 1-1/2 inch slot width and 3 inch length. They are not directly comparable as two different solutions were used, one having 65 parts of solvent/pneumatogen per hundred parts of polymer, and the other 70 parts. Moreover, the solution with the lesser amount of solvent was used at higher pressure, 90 psi rather than 80 psi. However, the results suggest that higher pressure is more important than polyme concentration (over the limited range) in promoting fast flow of

Table 14

EXTRUSIONS THRU 2 INCH PIPE T DIE WITH SCREEN[3] AND RECTANGULAR ORIFICES

Sample No.	Rectangular Orifice Width-Length-Depth, in.	Tank Pressure, psig	Extrusion Rate, ft/min	Density, pcf	Foam Description
176237K[1]	3/4 x 7/8 x 1/10	57	6.0	3.9	rectangular
176237M[1]	3/4 x 1-3/4 x 1/10	57	5.2	4.9	rectangular 1-3/16 x 4.0 x 62 in.
176237S[1]	3/4 x 3.0 x 1/10	80	6.5	5.8	rectangular 1-1/4 x 5-1/2 x 93 in.
176237T[1]	3/4 x 3.0 x 1-1/10	72	18.0	2.8	flat with rounded sides 1-1/4 x 5.0 x 123 inches
176221J1[1]	1-1/2 x 3.0 x 1/10	80	5.0	4.3	rectangular 3 x 5-1/2 x 67 in.
176289A[2]	1-1/2 x 3.0 x 1/10	90	37.1	7.9	3-3/4 x 6-3/8 x 123 in.
176227G[2]	1-1/2 x 6.0 x 1/10	80	5.6	6.2	4 x 11 x 105 in.
176238A[2]	1-1/2 x 5-7/8 x 1/10	90	6.1	5.6	rectangular 2-7/8 x 9 x 162 in.
176289B[2]	1-1/2 x 6.0 x 1/10	80	6.0	5.0	3 x 8.5 x 58 in.
176295	1-1/2 x 6.0 x 1/10	80	7.5	8.6	4 x 10-3/4 x 60 in.
181303[2]	1-5/8 x 6.0 x 1/10	80	14.5	5.5	2.75 x 13.25 x 58 in.
181311[2]	1-5/8 x 9.0 x 1/10	80	6.8		2.5 x 12 x 82 in.

[1] Foam solution had 70 parts methyl chloride per 100 parts polymer.
[2] Foam solution had 65 parts methyl chloride per 100 parts polymer.
[3] 24 mesh 0.015 inch wire.

the solution through the die. Moreover, the results, taken along with those reported in Table 13 and 176237T of Table 14, strongly suggest that rapid extrusion rates lead to lower density foams.

The remainder of the tests, except 181311, were run with 5-7/8 or 6 inch long slots. The densities of these runs were in the 5 to 6.2 pcf range, except for 176295, which had a density of 8.6 pcf. This was a non-standard formula containing Zelec DX. Extrusion rates were from 5.6 to 7.5 ft/minute, except for 181303 which extruded at 14.5 ft/minute. This was the first run made in the final type die (described in Section 4.3) which had a 1-5/8 inch wide slot and could accommodate a 9 inch long opening. In 181303 the opening was partially blocked to give only a 6 inch opening. This may account for the faster extrusion rate.

Run 181311 was run with the 1-5/8 inch wide opening and the full slot width of 9 inches.

2.6.11 Summary of Extrusion Studies

As a result of the extrusion studies it was shown that "instant" polystyrene could be delivered at a slow, controlled rate and with a rectangular cross section. Characteristics of the procedure involved, and the foam produced indicated the following:

- A slow flow rate gave long enough dwell times in a shaping die to form the foam into useful shapes.
- The flow rate and foam density could be controlled by varying the ratio of the length of the foam passage through the die to the cross-sectional area of the die opening. For circular dies it was found that flow would stop when the length to diameter ratio was between 8 and 11 to 1.
- Screens or baffles, in conjunction with the rectangular orifice, were necessary to produce the desired rectangular cross section foam.
- Foam extruded at a controlled rate could be handled and processed downstream from the foam generator. Sufficient residual solvent was left in the foam immediately after generation to permit straightening and secondary shaping of the foam.

- Boards of foam could be produced that were 2.5-3.0 inches thick by 12-13 inches wide and of indefinite length. Length was determined by how long the valve was kept open and by the capacity of the supply tank.

- The foam was rigid enough shortly after formation to be cut.

- The foam had no residual tack. This permitted stacking of the foam moldings and boards.

As a result of the formulation work and the extrusion studies, we were able to design and build a prototype foam generator. This work is discussed in a subsequent section of the report.

2.7 IMPACT TESTING OF FOAMS

Impact tests were run on all large samples prepared by extrusion through the 2 inch pipe T die. Two samples prepared in a wooden mold (Section 3.4.3) were also tested. Samples were generally 8 inches square and 3 inches thick. The only exceptions to this were a limited number of tests run on 6 x 6 x 3 inch and 5 x 5 x 3 inch samples. These exceptions are noted in the table summarizing the impact data.

The impact tests were run on a Hardigg Impact Tester. In this apparatus, the sample to be tested is impacted by a flat flaced tup which is 8 in. x 8 in. in area. The amount of weight impacting the sample is determined by the actual weight of the tup and the weights which can be added to it up to a total of 150 pounds. The greatest drop height with this apparatus is 48 inches. Weights are added to the top of the tup and occupy some of the space that could be used for drop height--thus at 150 pound tup weight the maximum drop height is reduced to 40 inches.

A transducer mounted on the tup measures the deceleration time history of the impact which is recorded with the aid of a tracing oscilloscope. The oscilloscope records G's of deceleration and milliseconds of the first impact only. Figure 29 is a photograph of the record of one of the impact tests (Test No. 11). Deceleration in G's is measured on the vertical scale (1 cm = 20 G's) and time on the horizontal scale (1 cm = 10 milliseconds).

Vertical scale measures deceleration	1 cm = 20 G
Horizontal scale measures time	1 cm - 10 m-sec

Figure 29. Photo of Oscilloscope Trace Run No. 11

Some 22 impact tests were run on molded or extruded polystyrene foam. The test specimens used were 3 x 8 x 8 inches in size, except as noted in Table 15.

Table 15 lists the raw data obtained from the impact tests. It will be noted that a number of different weights were used and, more importantly, several different drop heights. The last three columns of the table are derived data. The potential energy is the product of the weight of the tup and the height it was dropped from. To eliminate the variable height factor, the potential energy in foot pounds (which would be equal to the kinetic energy at the time of impact) was arbitrarily divided by a uniform drop height (3 ft) to get a normalized weight and a normalized static load given in pounds/in.^{2}.

The first four tests in Table 15 were made on relatively low density molded foams. Two tests were made with minimal loadings (16.9 lb or 0.265 psi). The recorded G's of deceleration were 51 and 50 for foams 172371 and 172375, respectively. Increasing the static stress to 0.6 psi increased the G's of deceleration to 58 and 74, indicating the foam had bottomed out when impacted. Therefore, the peak G's of deceleration would be attained at lower static loads than possible with this tester.

The next sample in Table 15 is 176289A - a sample extruded from a 1.5 x 3.0 x 0.1 inch T die. The test sample was tested parallel to the direction of extrusion with a static load equivalent to 0.6 psi. Additional tests were conducted on the same sample using progressively higher loads until no further testing was possible. A second sample from 176289A, with the impact load applied perpendicular to direction of extrusion, was tested at 0.265 psi static load. The maximum deceleration increased to 100 G's and the duration of impact dropped to 8 milliseconds. This indicated that the imposed static stress was too low.

The same sample was retested (Run No. 7) using additional weights to produce a static stress of 0.6 psi. The deceleration dropped to 76 G's, the same value as was obtained in Run 5 which was tested parallel to the direction of extrusion. Runs No. 5 and 7 show a duration of impact in milliseconds of 11 and 13, respectively. This indicates that some foam flexing or cracking did occur. At a static load of 1.0 psi applied perpendicular to sample 176289A, a deceleration of 76 G's was recorded with a duration of 20 millseconds, indicating further foam crushing. After this drop (Run No. 8) the foam thickness had decreased to 21% of its original value.

Table 1[illegible]

IMPACT TESTING OF LARGE SAMPLES BY [illegible] INCH PIPE T DIE

Run No.	Sample No.[1]	Sample Size, in.	Density, lb/ft³	Direction of Test	Drop Height, in.	Weight, lb	Static Load, psi	Deceleration, g	Deceleration Time, msec	Reduction in Thick., %	Calculated Potential Energy, ft/lb	Calculated Normalized Static Weight for 3' Drop	Calculated Normalized Static Load psi
1	172371	3x8x8	2.2	perpendicular	48	16.9	0.264	51	51	-	67.6	22.5	0.352
2	172371	3x8x8	2.2	perpendicular	48	38.4	0.6	58	26	17	153.6	51.2	0.8
3	172375	3x8x8	2.1	perpendicular	48	16.9	0.264	50	22	2.1	67.6	22.5	.352
4	172375	3x8x8	2.1	perpendicular	48	38.4	0.6	74	26	5.4	153.6	51.2	0.8
5	176289A	3x8x8	2.97	parallel	48	38.4	0.6	76	11	-	153.6	51.2	0.8
6	176289A	3x8x8	2.75	perpendicular	48	16.9	0.265	100	9	2.1	67.6	22.5	.352
7	176289A	3x8x8	2.75	perpendicular	48	38.4	0.6	76	13	-	153.6	51.2	0.8
8	176289A	3x8x8	2.81	perpendicular	45.5	64	1.0	76	20	2.1	243	81	1.27
9	176289B	3x8x8	5.45	perpendicular	45.5	64	1.0	92	11	2.1	243	81	1.27
10	176289B	3x8x8	5.45	perpendicular	45.0	96	1.5	52	12	2.1	360	120	1.87
11	176289B	3x8x8	5.45	perpendicular	42.0	128	2.0	61	19	23	448	149	2.33
12	176289B	3x8x8	6.05	perpendicular	42	128	2.0	54	15	8.3	448	149	2.33
13	176222G	3x8x8	6.15	perpendicular	42	128	2.0	49	13	17	448	149	2.33
14	176222G	3x8x8	7.18	perpendicular	40	150	2.34	46	22	12	500	167	2.61
15	176238A	3x8x8	7.53	perpendicular	42	128	2.0	61	15	4	448	149	2.33
16	176238A	3x8x8	7.57	perpendicular	40	150	2.34	56	19	6.3	500	167	2.61
17	176295	3x8x8	8.56	perpendicular	42	128	2.0	78	16	4.1	448	149	2.33
18	176295	3x8x8	9.59	perpendicular	40	150	2.34	57	17	2.1	500	167	2.61
19	176238A	3x6x6	7.8	perpendicular	40	126	3.5	52	19	2.1	420	140	3.90
20	176238A	3x5x5	8.0	perpendicular	45	72.5	2.9	60	17	18	272	91	3.65
21	181303	3x8x8	5.1	perpendicular	40	150	2.34	46	14	22	500	167	2.61
22	181303	3x5x5	5.5	perpendicular	40	87.5	3.5	42	25	29	392	131	5.25

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[1] Samples 172371 and 172375 were prepared in a wooden mold (Table 6)

These runs (5,6,7 and 8) indicate that foam sample 176289a was being stressed sufficiently to obtain the minimum deceleration (76 G's) attainable with this foam. Increased static load would not decrease the deceleration but would result in an increase in the duration of impact and additional depth of foam crushing.

Of further interest were runs No. 5 and No. 7, made on the same foam. As mentioned, one of these samples was tested parallel to the direction of extrusion, and the other perpendicular. Each sample had a deceleration rate of 76 G's with only 2.0 milliseconds difference in duration of impact. Thus, the cushioning ability of this foam would be essentially the same regardless of the direction of use.

The remaining portion of the data compiled in Table 15 were obtained by essentially the same method. For example, runs 9, 10 and 11 were made on a 5.45 pound per cubic foot sample (Sample 176289B) at 1.0, 1.5 and 2.0 psi static loads. With each incremental increase of static load there was a proportional decrease in deceleration. Coupled with an increase in duration of impact, as well as an increase in percent of the foam height loss, this indicated a minimum deceleration close to 50 G's.

Runs 13 through 18 were made at relatively high loadings and drop heights of 40-42 inches. This is the maximum possible height on the test instrument for the weight used. In the table, samples are arranged in the order of increasing density.

Figure 30 presents a plot of deceleration versus normalized static load (psi). An examination of these curves indicates that the molded samples (172371 and 172375) are being stressed at loads higher than that which would give minimum deceleraiton. This is inferred from the slope of the curve. The remainder of the curves, which are for extruded samples, indicate that because of the high density of the foam the samples are being stressed at loads too small to give the minimum deceleration attainable with that sample.

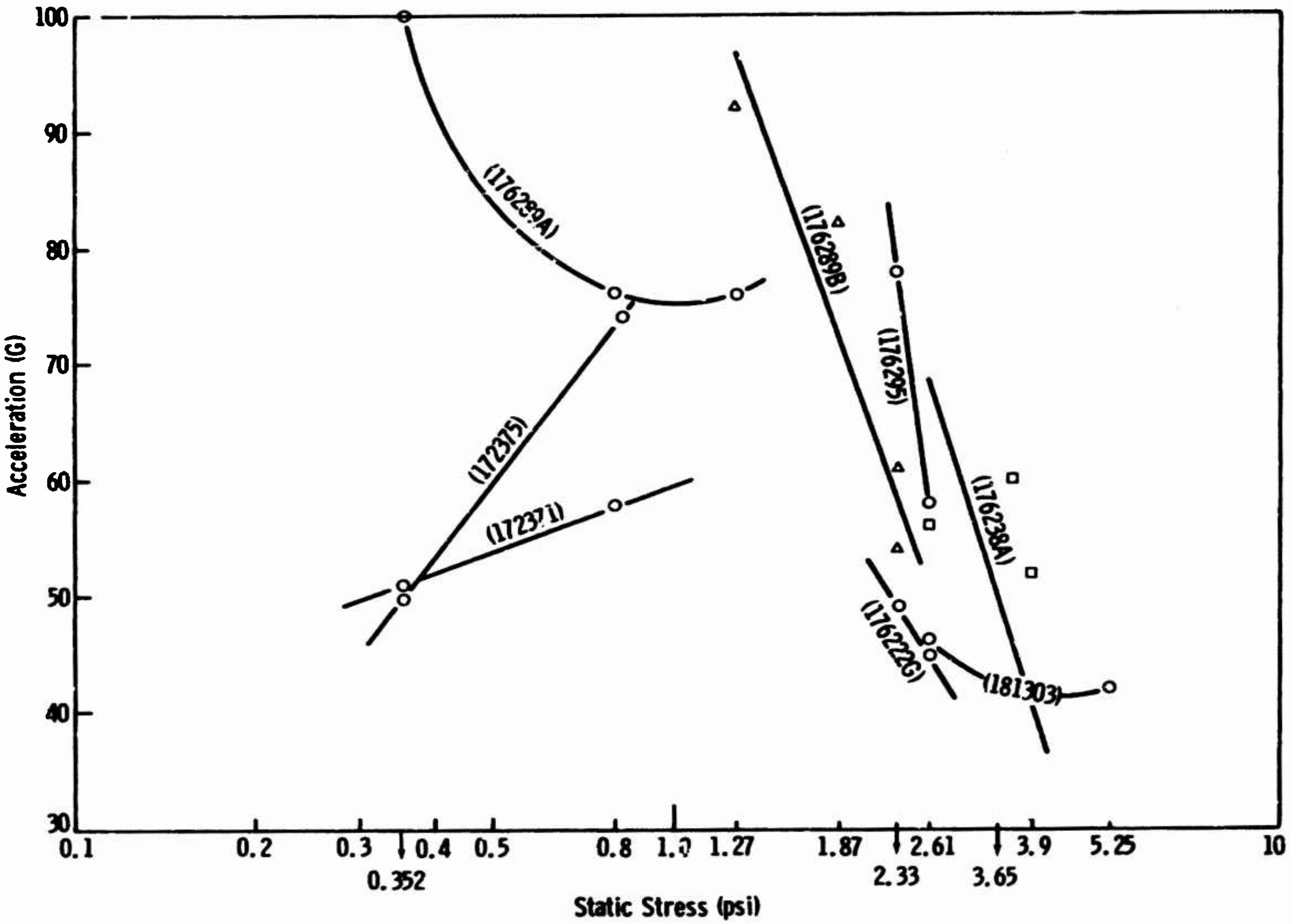

Figure 30. Plot of Normalized Deceleration Versus Static Loads (psi).

There are two possible exceptions to this. One is foam No. 176289A which, on the basis of four tests at three different static loads, appears to give a minimum deceleration at a static load of 1 psi and 75-76 G's deceleration. The other exception is foam No. 181303. It is possible that this curve has a minimum at about 42 G's and 5.9 psi load. However, this assumption is based on two widely scattered points.

All impact testing was done at the end of the contract period on foams made during the program. It would have been more meaningful to have routinely tested foam samples for impact response during the progress of the program. Based on this experience, an impact tester has been designed by Monsanto Research Corporation and it will be built for use on subsequent programs on energy management.

3. PROTOTYPE EQUIPMENT DESIGN AND FABRICATION

With the completion of the foam molding and extrusion studies of this program, the design of a prototype foam generator was undertaken. The prototype equipment breaks down into four subunits, as follows:

- Stand on which to mount the other subunits and their auxiliary equipment.
- Tanks to hold the foam solution during storage and to supply solution to the die at time of use.
- A forming die to be used in extruding a foam board.
- Auxiliary equipment, including a nitrogen cylinder along with a pressure regular, pipe fittings, tubing and valves.

Overall views of the equipment are shown in Figures 31 and 32.

3.1 TANK STAND

The tank stand design is shown in Figure 32. It was fabricated from 2 inch pipe and the necessary 2 inch tees, elbows and nipples. The stand was assembled by threading the parts together and tack welding the connections to give permanence to the assembly.

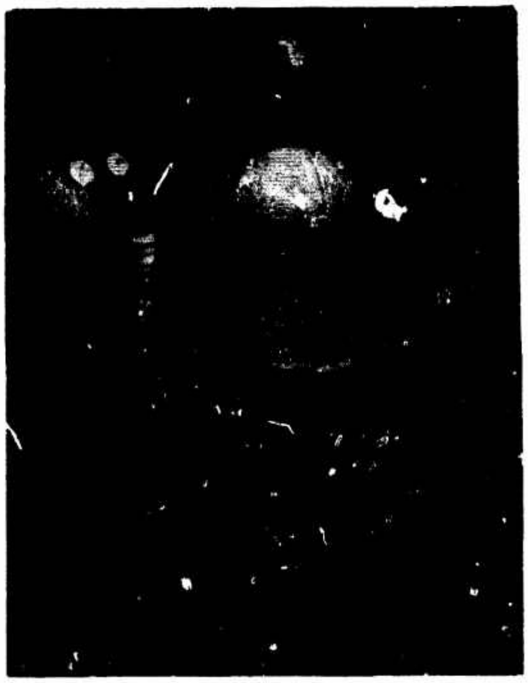

Figure 31. Prototype Foam Generator

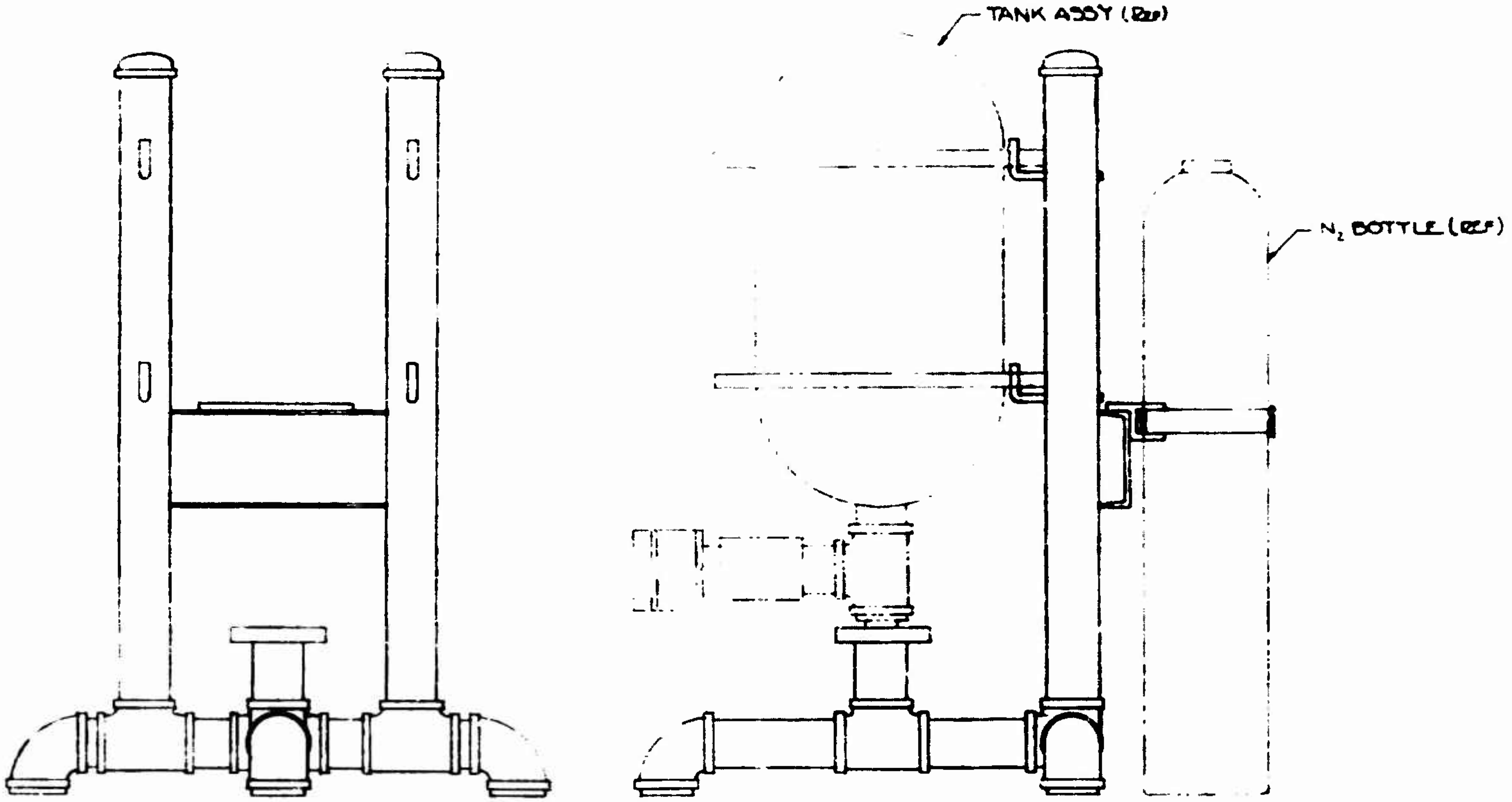

Figure 32. Tank Stand Foam Extrusion Unit

The two upright members of the stand were given lateral rigidity by welding a 4 inch channel to them. This channel also provided a member for securing a cylinder holder to the stand. The holder was needed for the nitrogen cylinder used to supply a supplimental pressure to the foam solution tank. Four L-shaped hooks were installed on the upright members for use in mounting the solution tanks on the stand.

A platform type member was provided as a part of the base to furnish support to the base of the tank when it is mounted on the tank stand. It is adjustable in height to accommodate small variations in the dimensions of different tanks.

3.2 FOAM SOLUTION TANKS

Each foam solution tank is a 2100 cubic inch (9.1 gallon) stainless steel aircraft type breathing oxygen tank. Figure 33 shows details of the tank. The pressure rating is 400 psi, which is well above that used in operating the foam system 80 to 100 psig at 75°F. One end of the tank (upper end when in use) was fitted with a 1/4 inch quick disconnect fitting. This connection afforded a means of providing supplemental nitrogen pressure to the tank. Figure 31 shows the nitrogen line in place. A gauge in the nitrogen line monitored solution tank pressure.

The lower end of the tank has a 2 inch closed nipple welded in place. This nipple provides a means of assembling a pipe tee to the tank. The lower end of the tee is closed with a pipe plug and furnishes a means of supporting the tank when it is mounted in the stand. The side entry is provided with a close nipple leading to a 2 inch ball valve.

Each tank was mounted in square wooden frames which permit the tanks to be stacked during storage. The frames have holes positioned to fit the hooks on the stand as a means of supporting the tanks during use.

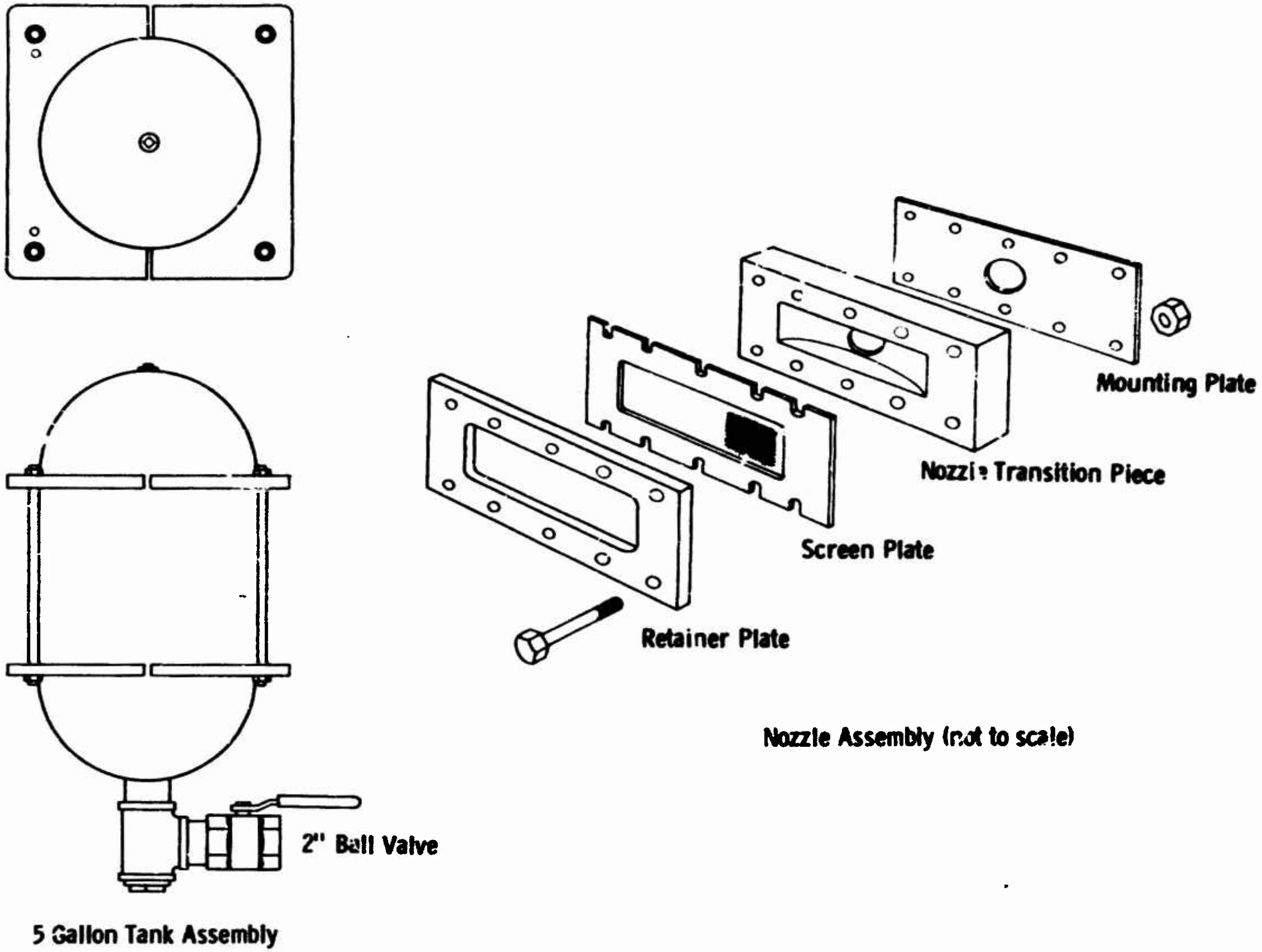

Figure 33. Tank Assembly and Nozzle Assembly Foam Extrusion Unit

3.3 EXTRUSION DIE

The components of the extrusion die are shown in Figure 32. The mounting plate piece serves to assemble the die to the 2 inch tank valve and to the other die components.

The nozzle itself serves as a transition piece (Figure 33) between the 2 inch valve opening (1-7/16 inch diameter) and the rectangular opening necessary to extrude rectangular boards. This piece was sized so as to permit extrusion of a 3 x 12 inch foam board. Figures 34 and 35 show this transition piece.

In constructing this nozzle transition piece, a wooden model was made first. In the design and fabrication of the model, the general interior configuration of the early test dies was maintained as nearly as possible. The model was tested for ability in producing foams. After the proper configuration was achieved, a silicone impression of the wooden model was made. The silicone casting was then used as a form to cast a metallized epoxy part which became the final type die. The interior was treated with mold release to facilitate the flow of foam solution.

A screen plate was made to be mounted in front of the nozzle transition piece. It was made of 0.1 inch thick aluminum and provided with a slot 1-5/8 inches wide x 9 inches long. This slot produced a 3 x 12 inch thick foam board. The screen plate was fitted on the upstream side with a 24 mesh screen of 0.015 inch diameter wires and a 41.0% open area. The screen was assembled to the rear surface of the plate using epoxy adhesive.

A one inch thick aluminum retainer plate was provided to help hold the screen in place. This plate can be replaced by bars bolted to the top and bottom of the die to provide stiffening for the 0.1 inch screen plate.

3.4 TESTING OF FINAL TYPE DIE

After completion, the final type die was tested by mounting it on a fully charged tank of foam solution. Two tests were run with the ball valve fully open.

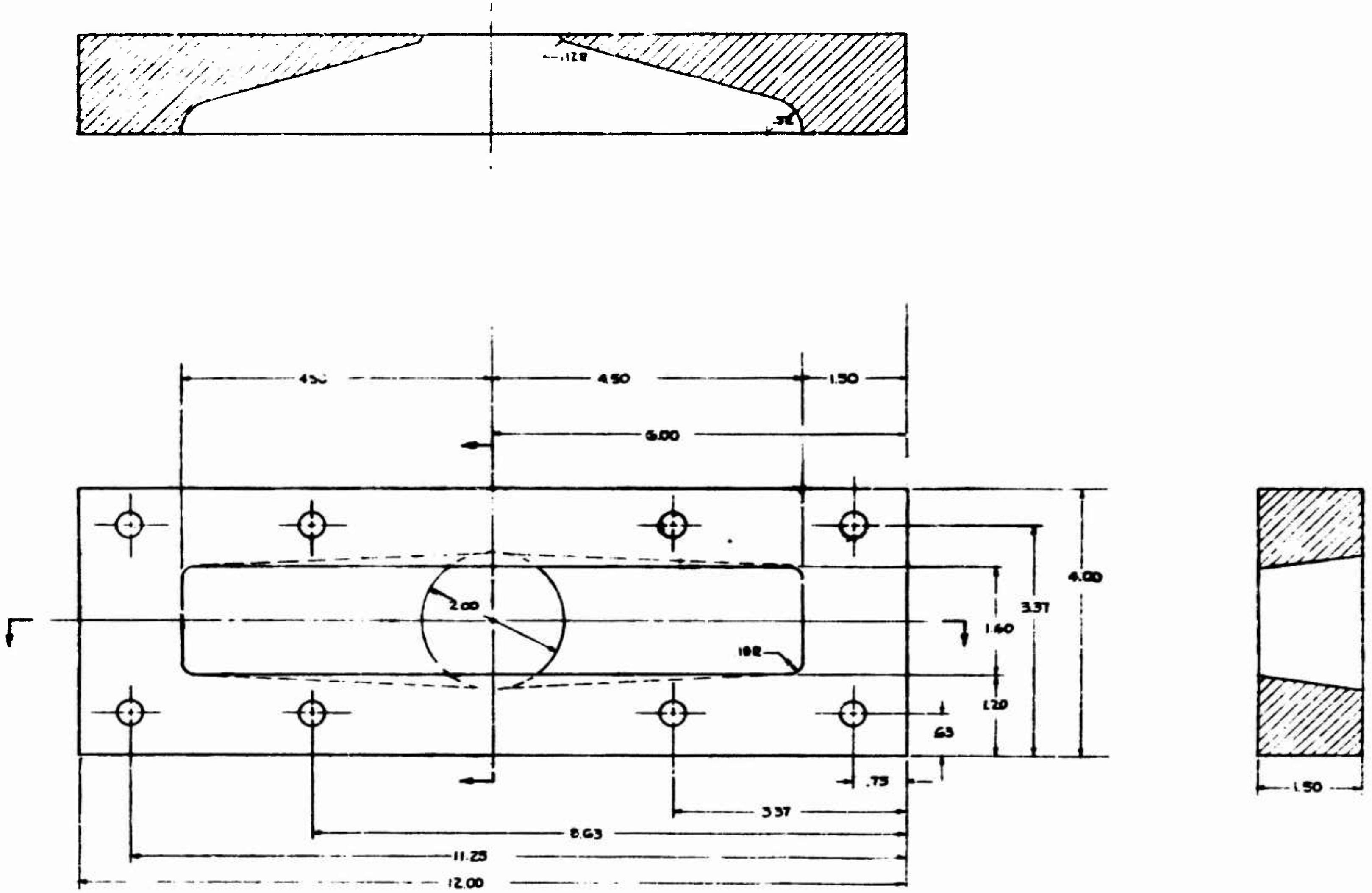

Figure 34. Nozzle Transition Piece

Figure 35. Epoxy Die Transition Piece

Boards 2-3/4 x 13 inches and 2-1/2 x 12 inches in cross section were produced. Figure 36 shows the foam produced by the die. After the tests, it was found that the die itself was easily cleaned of residual foam. However, the screen was difficult to clean, requiring soaking in solvent (toluene and/or acetone) and visual checking to be sure that all the mesh was free of foam after cleaning.

This die must be run continuously after the valve is opened. It does not have a capability of intermittent operation. Once the flow of foam is stopped, the die must be disassembled and cleaned of residual foam. Extra screens were provided with the prototype equipment so that several consecutive runs could be made.

The cleaning requirement is a weakness in the present design. The possibility of providing a sliding type valve, to be mounted in the front of the die to retain liquid foam solution in the die, was considered. It was decided that such a gate valve was a feasible approach to intermittent operation. However, the design and fabrication of such a complicated valve was not within the scope of this contract.

3.5 PROTOTYPE DELIVERY

After testing, the prototype unit was shipped to Natick Laboratories. Four tanks were provided, each to contain 5 gallons of foam solution. The tanks were shipped with all dry ingredients (polystyrene, glass microballoons and surfactant) charged to the tank. The solvent/pneumatogens were added at Natick by Monsanto Research Corporation personnel.

This procedure was necessary in order to avoid the lengthy process of obtaining Department of Transportation approval to ship these tanks under pressure.

Each tank was charged with the following ingredients:

Lustrex HH-101	28.56 pounds
Microballoons	0.54 pounds
Igepal CO-970	1.83 pounds
Tetrachloroethylene	1.09 pounds
Methylene chloride	13.83 pounds

Figure 36. Foam Sample 181303 Being Extruded Through Prototype Die

Once all ingredients were charged to the tanks, the tanks were rotated on a scheduled basis to insure that the ingredients were dissolved and adequately mixed. The above formulation did not contain any flame retardant additives. As such, the foam is flammable. Work undertaken after the completion of the program using pentabromophenylallyl ether produced foams which are self-extinguishing.

Instructions for charging the tanks and for dissolving the polymer in the [illegible] mixture and for operating the foam generator were furnished with the equipment. These instructions are included in this report as Appendix A, B and D.

[illegible]. PROGRAM SUMMARY

This program to develop a foam plastic for airdrop cushioning systems resulted in the following accomplishments:

- A moldable polystyrene foam solution was developed. This system was based on high heat polystyrene (Lustrex HH-101), glass microballoons, a non-ionic surfactant (Igepal CO-970), and methyl chloride and tetrachloroethylene as solvents. Since it is a liquefied gas, the methyl chloride also acts as a pneumatogen for the polystyrene foam. This foam solution is capable of forming a polystyrene foam which can be handled immediately after generation.

- A foam molding process was developed in which the foam solution flowed into a 3 x 12 x 18 inch wooden mold and filled it to give foam moldings with densities of approximately 2 lb/cu ft.

- The feasibility of transferring foam solution under pressure from a storage tank to a mold, and subsequently forming a foam by releasing the pressure, was demonstrated.

- A foam extrusion process was also developed and [illegible] the final system. Methods were developed to [illegible] the rapid flow of the pressurized foam solution and its subsequent rapid expansion on pressure release. This permitted extrusion of [illegible] cross-sectional area. These methods were based on maintaining the necessary length to cross-sectional area ratios in a die opening, and on providing baffles to impede flow [illegible] were used as the [illegible] program.

- The principal emphasis during the program reported on was developing a foaming solution which was capable of being molded or extruded to give foam boards or modules, and a prototype piece of equipment to extrude such foam boards. Because of the emphasis placed on the above work it was not possible, within the funds available, to determine whether the foams developed on this contract had a rectangular stress strain curve and a dynamic compressive strength level in the range of 5400 to 7200 psf to at least 70% strain.

- The foams produced during this work were white. From other work it is known that these foams can be pigmented. Black, indigo, blue, red, and green instant type foams have been produced during other programs.

- The recycle capability of this foam was not demonstrated during this program. However, there is no reason to believe these foams could not be redissolved and used over again.

- The environmental limitations on the foam systems performance was not determined. From other work, we know that the present lower temperature for making foam is -10°C. The useful temperature range for the foam itself has not been defined. The foam produced by this system is polystyrene, as such water would have no effect on it.

- The isotropic properties of the foam have not been determined.

- The shelf life of the foam solution has been demonstrated to be in excess of one year. There is no reason to suspect the shelf life is not in excess of two years.

- The full range of temperatures and environments in which the foam can be produced has not been defined as yet.

- The foam can be handled immediately after generation, it remains pliable enough to be shaped after about 30 seconds after generation. It is not sufficiently fluid as formed to permit filling of intricate, irregular shaped cavities.

5. RECOMMENDATIONS

It is recommended that the investigation of forming airdrop cushioning material from polystyrene foam be continued. This foam should be formed by an extrusion process to give the capability of making foam boards or planks of specified cross sectional area and of whatever length is needed. These boards could be cut at the time of generation, or later, to give modular sized pieces for cushioning.

In any subsequent program, it is specifically recommended that work be done to obtain better control of the density of the foam. It should be possible to achieve this control by a minor amount of work on the formulation and a major amount of work on the die itself. It is believed that much better control of density can be obtained by the proper ratio of die length to cross-sectional area. Another area of investigation connected with foam density should be a study of screen size and the possible replacement of screens by the use of guide plates in the die both to slow down the flow of solution and to distribute it across the die face.

As a possible aid to density control, the use of shaping and sizing rolls just downstream from the die should be investigated. To be effective, they would have to be positioned close enough to the die to act on the foam while it is still somewhat plastic.

A design problem that [illegible] should be a part of any future work would be to provide a gate valve of some type that would close the die outlet on the downstream side. The provision of such a valve would permit intermittent operation of the equipment.

A provision for multiple solution entries into the die should be investigated. The use of such multiple entries should provide for better distribution of foam solution to all parts of the die opening.

[illegible] foam generation was an [illegible] problem in this program. This was caused when the [illegible] of the tank pushed out [illegible] faster than it could drain down away from the [illegible] started the [illegible] The possibility [illegible] supply of foam solution [illegible]

If there is a need for anisotropic foams with the cells elongated in the direction of the foam propagation, the design of an extrusion system capable of doing this should be part of any future program. Such a system should extrude relatively large cross sections of foam that can be sliced to give modular thicknesses.

More thorough impact testing of the product is necessary in any subsequent program.

A study of a more adequate method for preparing foam solutions should be a part of any future program. The method should be usable in plant size tanks and mixers. It should be scaled to producing large batches of solution (50-100 gallons).

A part of any subsequent program should be the design of tanks that meet the Army's requirements and are in compliance with the Department of Transportation (DOT) regulations. Tank design should start early in the program so that DOT approvals on tanks can be obtained in time to ship the equipment at the end of the program.

Any subsequent program should be aimed at producing, for the Army, a prototype foam generator that can be used to generate foam under field conditions. It should meet any specific requirements that the Army might request.

APPENDIX A

PROCEDURE FOR CHARGING INSTANT FOAM INGREDIENTS TO A PRESSURE TANK

Prior to use, each tank is thoroughly cleaned. If the tank is new, a water rinse to remove debris, followed by an acetone rinse, should be adequate. If the tank previously contained instant foam solution, the polymer residues should be removed by washing with toluene. After all the polymer residues have been removed, rinse with acetone and finally, sweep the tank with dry nitrogen.

The following procedure is used to charge a pressure tank with the ingredients to make instant foam; the quantities given are those necessary to charge a 2100 cu in. (9.1 gallon) tank. Appropriate adjustment in quantities should be made for other sized tanks.

1. Charge 28.6 lbs (12.97 kg) of polystyrene (Lustrex HH-101) and 0.54 lb (244.9 g) glass microballoons to the tank. Stopper the tank and roll the tank on a drum roller to distribute the microballoons throughout the polymer. Add 1.83 lb (830.1 g) surfactant (Igepal CO-970). Roll once more to mix the dry ingredients.

2. Assemble a 2.0 inch street elbow and a 2.0 inch ball valve to the tank.

3. Pressure check the tank and fittings using 100 psig N_2. Check for leaks using soap solution. Tighten the pipe connection if leaks are found.

4. Slowly vent off the nitrogen. Precaution: Do not vent too rapidly as microballoons and/or surfactant may be carried out in the nitrogen stream.

5. Attach a vacuum line to the tank through the 2 inch ball valve. Open the valve and evacuate the tank. Apply vacuum for 1 hour.

6. Using the vacuum in the tank, siphon in 1.09 pounds (494.4 g) of tetrachloroethylene into the tank. To compensate for liquid holdup in the suction line, 20 grams excess tetrachloroethylene is initially weighed in the solvent

supply container. Just prior to emptying the solvent container, shut off the valve. Allow the excess tetrachloroethylene to drain from the suction line.

(7) Attach the solvent/pneumatogen charge line to an inverted methyl chloride tank. Either the methyl chloride supply tank or the foam solution tank may be placed on a scale. Transfer 13.83 pounds (6.27 kg) of methyl chloride to the foam solution tank. Shut off the methyl chloride and the instant foam tank valves. Caution: Slowly release the line pressure in a well ventilated area before disconnecting the tanks.

(8) Roll the tank back and forth several times on the floor while it warms up. Then, follow procedure for solvating the polystyrene given in Appendix B.

APPENDIX B

INSTRUCTIONS FOR SOLVATION OF INSTANT FOAM INGREDIENTS

After charging the ingredients to the tank (Appendix A) the following procedure should be used to effect solvation of the polymer. Solvation can be carried out at 120°F, or at normal room temperatures 70-75°F. If elevated temperature is used at least 7 days are needed to effect solvation. If the lower temperature is used, 14 days will be needed to effect solvation. Regardless of the temperature, the following procedure should be followed.

1. Rotate each tank 90° about its longitudinal axis three times daily, i.e., morning, noon and evening; rotation should always be in the same direction. The tanks need not be rotated over weekends.

2. The tanks should be placed in the valve down position every other day. They should be allowed to remain in this position overnight.

3. Twenty-four hours prior to use, the tank should be placed in the valve down position to make sure all the solution drains down to the valve. It could be conveniently mounted on the test stand at this time. If the tanks are heated, they should be removed from the oven at least 24 hours before they are to be used. This is to ensure that the tank temperature has reached ambient conditions.

APPENDIX C

PROTOTYPE FOAM GENERATOR SYSTEM COMPONENTS

1. Stand for tanks.
2. Four tanks containing 5.5 gallon of foam solution each.
3. One nozzle with four screens.
4. One cylinder of nitrogen.
5. One nitrogen regulator with needle valve, hose and female quick coupler.
6. One can of Frekote 33 release agent.
7. 1 gallon of toluene.
8. 1 gallon of acetone.
9. Two polyethylene squeeze bottles.
10. One dozen tongue depressors.
11. One pan.
12. Two acid brushes.

APPENDIX D

PROTOTYPE FOAM GENERATOR SYSTEM INSTRUCTIONS

GENERAL

Extrusion of polystyrene foam is as simple as opening a 2 inch ball valve. Preparation for extrusion and extrusion nozzle cleanup requires some instructions. These are as follows:

1. At least 24 hours before use, stand the tank to be used with the valve end down. The tank could be placed in the tank stand.

2. Set up the system in a well ventilated area.

3. Attach the nitrogen regulator to the nitrogen cylinder. Attach the quick coupler on the hose to the male quick coupler on top of the tank. Check the tank pressure. If it reads below 90 psi, open the nitrogen cylinder valve and adjust the regulator until the pressure in the tank and on the regulator reads 90 pounds psig.

4. With the nozzle disassembled and cleaned, spray all internal surfaces with the release agent.

5. Assemble the nozzle as per Figure D1 i.e., mounting plate, nozzle transition piece, screen plate and retainer plate, then bolt together with the eight bolts supplied. Tighten the bolts firmly, approximately 100 to 150 inch pounds of torque if a torque wrench is available. Once assembled, if an air hose and nozzle is available, blow the screen clean of any dust particles. Should a large particle be trapped inside of the nozzle, it will cause a hole to be formed through the length of the foam.

6. If a new tank is being used, open the valve slightly to bleed off the [illegible]. Cover the opening with a bag or other container to catch the initial discharge. Continue bleeding the tank until polystyrene foam extrudes. This should take approximately 45 [illegible] seconds, depending on how fast the bleed is.

7. Clean off the 2 inch ball valve threads and remove any polystyrene foam from the valve, then securely screw the assembled extrusion nozzle onto the 2 inch ball valve and position the nozzle with the long axis horizontal.

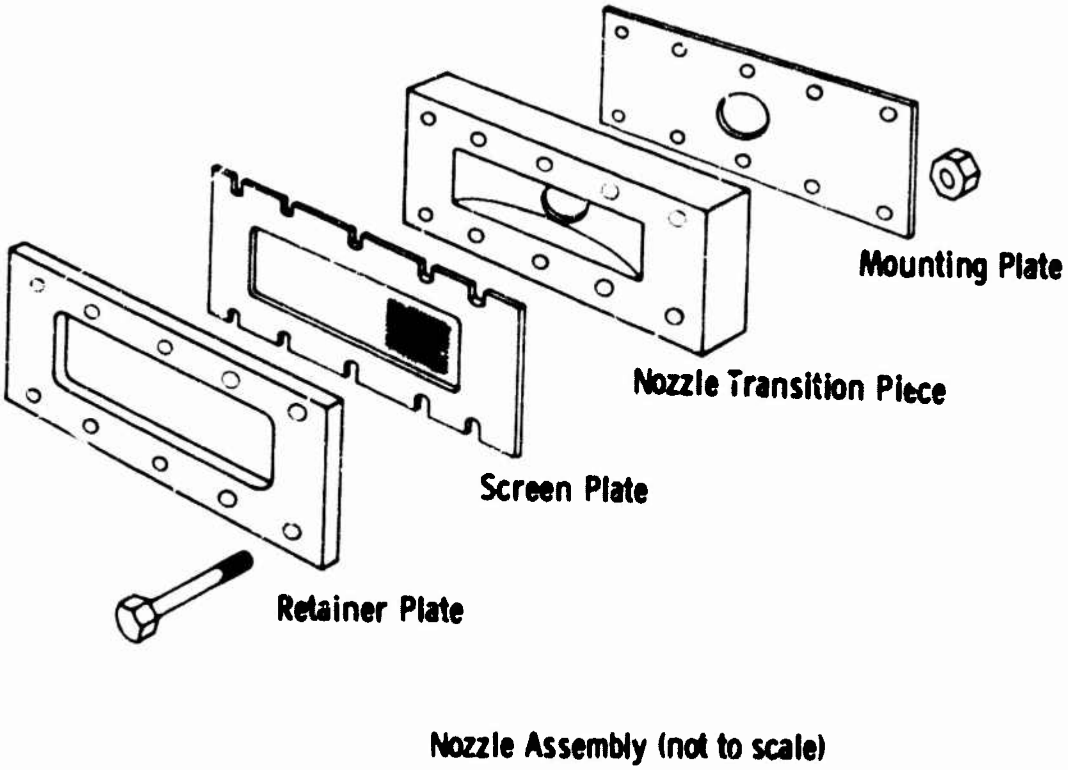

Figure D1. Extrusion Nozzle

8. Assemble the valve handle to the valve and tighten the nut. The system is ready to make an extrusion.

9. Two people should be available to make the extrusion. One person should operate the valve and watch the time of extrusion, while the other person guides the extrudate away from the die. To obtain a straight board, the extruded foam should be kept perpendicular to the die face. Attention should be paid to the corners of the die as the foam starts to extrude. There should be no hang up of foam at the corners. A slight pull of the foam at the corners will free the foam so that the extrusion is uniform across the whole board width.

10. Open the valve fully and wait for the extrudate to appear. Once it has cleared the screen, gently guide it forward away from the die.

11. Foam extrusion can continue as long as foam is being produced smoothly. When the discharge from the tank becomes gassy (discontinuous foam generation) the valve should be shut off immediately. Allow time for solution to drain off the walls of the tank before attempting to generate foam again. If much foam has been generated from the tank, the gassy discharge could indicate the tank is empty.

12. Cut the foam from the die, gently press it against the floor by hand to level it out. The foam is now ready for use. Shut off the nitrogen supply at the nitrogen cylinder when not in use.

EXTRUSION NOZZLE CLEANUP

1. Remove the nozzle from the 2 inch ball valve and clean the excess foam out of the valve cavity and threads.

2. Place the nozzle on the work bench and cut off the excess foam sticking out from the threaded end of the mounting plate.

3. Stand the die on the work bench with the screen side up, remove the bolts and cut away any excess polystyrene foam.

4. To remove the screen plate, wet the foam on the front face completely with acetone. Continue to wet the polystyrene foam with acetone until the screen can be easily lifted from the nozzle without excessive force.

5. Place the screen plate in a pan and immerse in toluene. Cover the pan to prevent the toluene from evaporating.

6. After the screen has been in the toluene for approximately one hour, rinse the polystyrene from the screen with toluene. If part of the screen is plugged with polymer, take a stiff bristle brush and punch the bristles through the screen gently until clean. While still wet with toluene, blow the screen dry with an air jet.

7. The foam remaining in the nozzle transition piece and the mounting plate should be wetted with acetone. Once the foam softens it can be easily removed. Rinse the parts with acetone and toluene until all the polystyrene has been removed. Allow the parts to dry.

8. Lightly spray all the foam contact surfaces with the release agents and reassemble the parts as described in paragraph 5 of the GENERAL section of this appendix.

APPENDIX E

TRANSFER OF INSTANT FOAM SOLUTION FROM A STORAGE TANK TO A PORTABLE TANK

Instant foam solution can be transferred from a storage tank to a small portable tank (receiver) using the following procedure.

1. Connect the portable tank to the storage tank through a pipe cross which is connected through one arm to a vacuum line and through the other arm to a methyl chloride cylinder. If a cross is not available, two pipe tees may be used.

2. Open the valve on the receive, then open the valve on the vacuum line and evacuate the receiver. Close vacuum line valve.

3. Open valve to methyl chloride cylinder and fill receiver with methyl chloride vapor at ambient temperature. Close methyl chloride valve.

4. Open valve on storage tank and allow instant foam solution to flow to the receiver. Flow may be aided by gently warming the storage tank (use a heat lamp) to increase the vapor pressure, or by applying a slight over pressure of N_2 to the storage tank. The pressure differential between the supply tank and the receiver should be 5-10 psi. Either of these expedients increases the pressure in the supply tank and causes the solution to flow into the receiver.

During the program reported on, 5.4 pounds (2460 g) of instant foam solution could be transferred from a five-gallon supply tank to a one-gallon receiver in 30 minutes.

APPENDIX F

TABLE FOR CONVERSION FROM ENGLISH UNITS TO SI UNITS

Quantity	English Unit	SI Units	To Convert English Unit to SI Unit Multiply By		
Length	inch	meter	2.540	000	E-02
	foot	meter	3.048	000	E-01
Area	square inch	square meter	6.451	600	E-04
Volume	cubic inch	cubic meter	1.638	706	E-05
	cubic foot	cubic meter	2.831	658	E-02
	fluid ounce	cubic meter	2.957	353	E-05
	gallon	cubic meter	3.785	412	E-03
Mass	pound-mass	kilogram	4.535	924	E-01
Density	pound-mass per cubic foot	kilogram per cubic meter	1.601	846	E+01
Pressure or Stress	pound-force per square inch	newton per square meter (pascal)	6.894	757	E+03
Temperature	degree Fahrenheit	degree Celsius	C = (F-32)/1.8		
Velocity	inch per minute	meter per second	4.233	333	E-04
	foot per minute	meter per second	5.080	000	E-03
Flow Rate	pound mass per second	kilogram per second	4.535	924	E-01
Viscosity	centipoise	pascal-second	1.000	000	E-03
Potential Energy	foot-pound-force	joule	1.355	818	E+00
Torque	pound-force-inch	newton-meter	1.129	848	E-01