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MATERIAL RELATING TO THE STUDY OF CELLULAR PLASTICS FOR POTENTIAL MARKET APPLICATIONS IN EMERGING NATIONS

February 18, 1985

Submitted by

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CELLULAR PLASTICS

Introduction

Cellular plastics, called also foamed or expanded plastics, are becoming materials of increasing commercial reality. Foams may be classified according to structure into two general types:

1) Closed-cell foams, in which each individual cell is completely closed in by a thin membrane of polymeric material.

2) Open-celled foams, in which the individual cells are intercommunicating.

Virtually every type of thermoplastic or thermoset resin can be foamed. In general, the basic properties of the respective plastics are present in the foamed product, except, of course, those which are changed by the conversion to cellular structure. Thus, there is opportunity to make selection according to end-use requirements. It is frequently feasible to tailor a cellular plastic to meet specific end-use requirements.

Commercially, extruded panels can be produced in the form of slabs, planks, boards, sheets, molded shapes, extruded insulation, and sprayed coatings. In addition, several types of expanded plastics can be foamed in place, or "packed-in-place" in an existing cavity for potting of electrical components within a housing or for providing thermal insulation or structural strength.

A cellular plastic can be developed by several methods (not all of them applicable to all the materials which will be considered within these notes).

1) Air or gas is whipped into a suspension or solution of the plastic, which is then hardened by heat or catalytic action or both.

2) A gas is dissolved in a resin and expands when pressure is reduced.

3) A liquid component of the mix is volatilized by heat.

4) Water produced in an exothermic chemical reaction is volatilized within the mass by the heat of the reaction.

5) Carbon dioxide gas is produced within the mass by chemical reaction.

6) A gas, such as nitrogen, is liberated within the mass by thermal decomposition of a chemical blowing agent.

7) Tiny beads of thermoset resins, hollow or expandable by heat, are incorporated in a plastic mix.

Nine chemical types of cellular plastics are of commercial importance at this time. They may be classified according to chemical composition as follows: cellulose acetate, epoxide, phenol formaldehyde, polyethylene, polystyrene, silicone, urea-formaldehyde, urethane, vinyl.

History of Cellular Plastics

The development of foamed phenolic resins, the first reported expanded plastic, dates from about 1915. This first foamed plastic resulted from the reaction of phenol formaldehyde before Dr. L. H. Baekeland, seeking to develop a non porous resin, found means of preventing the development of voids. Thus, the recent development of foamed plastics has involved learning how to do, under controlled conditions, the very thing that Baekeland so painstakingly avoided doing.

The development of the first commercially important phenolic foams dates from about 1935 when the use of phenolic "microballoons" in the special syntactic type of foam dates from about 1941.

Epoxy foams were first developed in 1939 to meet the need for a suitable material of light weight for the encapsulation of electronic components. The first very light density epoxy foams, 2 p.c.f., were developed in 1955.

About the time the first syntactic foams were developed combined in epoxy resins, or glass spheres of phenolic resins embedded in epoxy resins, later similar hollow spheres of urea resins became available and resin beads, that expanded, came to be used in foams of this type. Another modification of "syntactic" foams was found in small sealed beads of polystyrene, containing dissolved gas, which were mixed into epoxy resins and expanded by the exothermic heat release during the cure of the system.

Urea formaldehyde foams were first produced in Germany prior to World War II. In the form of stable sheets were used as thermal insulation.

The first published reports of foamed vinyls appeared during World War II in Germany. The problem of the blowing agents which produced delayed commercial development of chemically expanded vinyls in the United States, but safe, practically nontoxic blowing agents became available. A process of mechanical blowing by absorption and expansion of air under pressure was developed in the United States prior to 1960. Improvement in the processing of vinyl foams has been accelerated by the development of vinyl plastisols which can be fused without the application of pressure. Consequently, a commercial process for the production of closed cell vinyl foam was developed using pressure-molding techniques.

Urethane technology was well developed in Germany by the mid 1930's. Bayer and co-workers produced urethane foams by reacting polyisocyanates with diethylenediol or higher hydroxyl containing compounds in the presence of water. American survey teams sent to Germany shortly after the War reviewed the progress made by the Germans, this led to the licensing of German owned patents to the American chemical industry. Stimulated research resulted in the development of practicable production techniques, improvements in equipment design and reliability, and formulations based on materials other than alkyd type polyester resins. A review of the American patent literature revealed that duPont in a series of patents applied for in 1939 and 1940, and granted in the early 1940's, had done much work along these lines. Their patents covered the preparation of polyisocyanates with the various glycols, alkyd resins, polyamides, polyesters, diamines, polyester amides, etc.

The extrusion of foamed polystyrene was based upon developments in Sweden in the mid-1930's. Commercial production in the United States was begun in 1944. Expandable polystyrene was first developed in Germany about 1942. Subsequently, a similar product was developed in the United States and introduced to the market in early 1954.

Developmental work on rubber elastomeric silicone based foams was started in 1944. The first commercial product, which appeared in 1951, consisted essentially of powders prior to foaming. By 1951 silicone foams were prepared using premixed powders which required only heat to initiate the foaming reaction. A major breakthrough in the early silicone foams was the very high temperatures required to activate the foaming action. The minimum density obtained with these systems was 10 p.c.f. Attention has been directed to many liquid systems which can be expanded and cured at room temperature and which produce foams having a density as low as 4 p.c.f.

Cellular polyethylene, a cross-linked foam, was developed in 1944. Because of its flexibility, foams have become available in the form of slabs and blocks.

Cellular cellulose acetate was developed during World War II to serve as a reinforcement to replace balsa wood used for aircraft construction.

Cellular Cellulose Acetate

Chemistry

Unlike many of the foam plastic materials, cellular cellulose acetate involves no chemical reactions in it's production. The alteration from the flake form of cellulose acetate to the rigid foam structure is purely physical. The cellular foam structure of CCA is brought about by the sudden release in pressure on a super heated pressurized mass of molten cellulose acetate containing a volatile expanding agent. The blowing agent is a mixed liquid (an solvent (acetone and ethyl alcohol) which utilizes a comminuted mineral (100 to 325 mesh) as a nucleating agent. The solvent mixture is a good for the cellulose acetate at temperatures above 160°F. The sudden pressure release through a small orifice into a restrained foaming die causes expanding foam to assume its final board or rod shape. During the hot extrusion, the solvent plasticizes as well as foams the resin.

Properties of Cellular Cellulose Acetate

Cellular cellulose acetate is a white, rigid, cellular foam. It is not possible to foam the material in place since it is produced by the flash vaporization of a super heated solvent upon sudden pressure release.

The physical properties of cellulose acetate are presented in table.

TABLE

Properties of Cellular Cellulose Acetate

Density lb/cu ft	6.5 - 7.0
Tensile strength psi	170
Compressive strength psi - yield	125
Shear strength psi - flexed	140
Shear strength psi - compressed	125
Flexural strength psi	147
Coefficient of linear expansion per °F	2.5×10^{-5}
K factor Btu min/cu ft	0.310
Dielectric constant	1.12
Loss tangent	0.002
Moisture absorption 100% RH(lb/cu.ft)	1.05
Service temperature limitations	75°F - 350°F

Applications

Cellular cellulose acetate has found use as a core material in control surfaces of aircraft, sandwich boards, filler blocks under fuel cells, structural members in reinforced plastic boats, geodesic domes, panels used in house construction, control areas and trailer bodies.

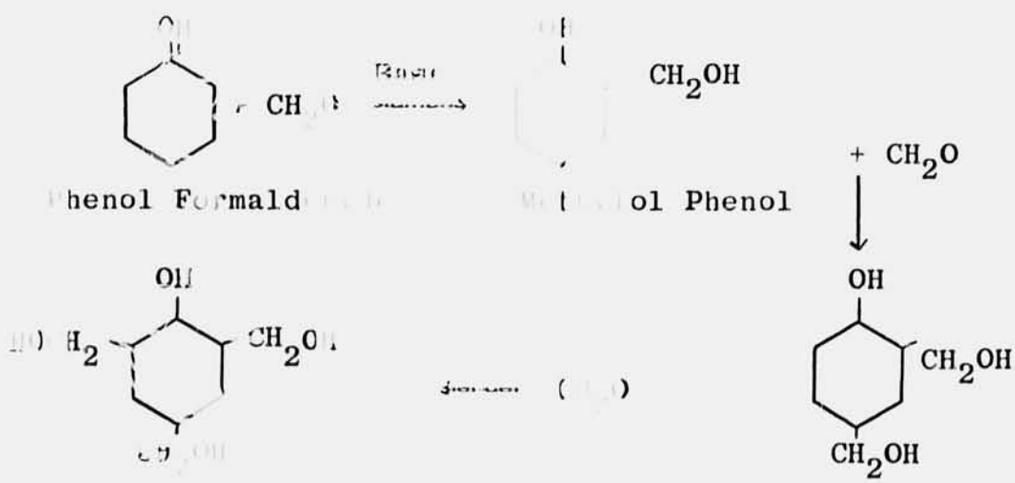
Phenolic Resins

Chemistry

Phenolic resins are a non-flexible thermoset, interconnected polymer with properties of which include low cost, good dimensional stability, low "K" factor, and heat and flammability resistance.

As represented by their name, phenolic resins are primarily polymers of phenol or phenol derivatives. In their simplest and still most prevailing form, they are condensation products of phenol and formaldehyde. Under the influence of heat and catalyst, phenol and formaldehyde condense to form addition products which depend, initially, upon the ratio of phenol to formaldehyde and whether acid or base catalysts are used.

Phenol and formaldehyde show very little reactivity unless catalyzed by acids or bases. Base catalyzed reactions proceed as follows:



As may be seen, the addition reaction proceeds according to the mole ratio of phenol to formaldehyde. Initially, addition may take place at the ortho position or the para position and in all instances a distribution of isomers does occur.

The methylol group is activated by the phenolic hydroxyl to yield extremely reactive compounds. The reaction is not as simple as indicated above since condensation between these original reaction products can and does occur.

These resins are called resoles and are soluble in alkalies, alcohols and ketones and depending upon the degree of cross-linking either infusible, soluble or dispersible in water.

Acid catalization produces methylene bridges directly, to form thermoplastic resins of low molecular weight, provided the phenol to formaldehyde ratio is greater than 1 to 1:

In one or more moles of formaldehyde are reacted with phenol, the reaction proceeds rapidly to an insoluble infusible product. The thermoplastic resin is called a novolac and is not useful as does formaldehyde. It acts as a three dimensional network connecting parts of molecules between the ortho and para positions of the phenol.

In acid cases the presence of catalyst and its removal or neutralization when the desired degree of reaction is obtained determines stability. Resoles are much less stable than novolacs but are complex and the reactions that the conditions of preparation are the principle determinants of stability.

Foaming Resins

Phenolic foams are made from a commercial casting type resins containing between 1.2 and 1.5 moles of formaldehyde per mole of phenol. After the desired degree of condensation is obtained, the base is usually neutralized with lactic or oxalic acid and concentrated under vacuum to remove water. Aqueous solutions of formaldehyde are used as a starting material, and it is necessary to remove this water and that produced by the condensation reaction. As much as 20% water may remain in the resin to assist in foaming. A combined sodium hydroxide-barium hydroxide catalyst system has been found to produce resoles which are slower to react, thereby allowing greater latitude in foaming. The basic ingredients to foam a resole are: a gas liberating agent, and a catalyst to promote polymerization. Depending upon the foam application and other special requirements ancillary agents are also added.

Foaming

The gas liberating agent may consist of carbonate salt such as sodium, potassium, ammonium, calcium, magnesium, and other carbonates. Those which liberate carbon dioxide upon reaction with the water present in the resole are added just prior to foaming. The resole must be adjusted to a neutral or basic pH to prevent carbon dioxide evolution with the other carbonates. The addition of the acid catalyst promotes and evolution of carbon dioxide.

Metal powders have been used to generate hydrogen in the presence of either acid or alkaline catalysts. Powdered aluminum, zinc, and magnesium suitably treated to prevent premature reaction with water are preferred.

Organic gas liberating agents provide somewhat better control of foaming, especially where higher density foams are desired. Among those utilized have been p,p'-oxybis (benzenesulfonylhydrazide), dibutylene pentamethylenetetramine and diazonium salts such as benzene diazonium sulfate.

Air has been employed to froth the resole previous to catalyst addition. This tends to produce resiliency but leads to lower strength. Gasses such as carbon dioxide, ammonia, hydrogen sulfide, sulphur hexafluoride or halogenated hydrocarbons have been suggested for use in a process requiring special equipment. The acid curing resin is dried and cured after being foamed by the gas.

Catalysts and Stabilizers

Acidic catalysts are preferred for ambient temperature foaming. Mineral acids (hydrochloric, sulphuric, phosphoric) have been widely used, not because of their strong attack upon metal and other materials of construction, other acids which will leave less noxious residues in the foams are preferred. Aromatic sulphonic acids (benzenesulfonic, toluenesulfonic, and phenolsulfonic) are the most popular.

Mixtures of orthophosphoric acid and mineral acids in conjunction with polyvalent aromatic reactants control the reaction rate to produce the more uniform salt structure and improve strength.

Peroxides have also been used as catalysts but require that the mixture be heated to promote reaction in foaming. Calcium peroxide is preferred but other metallic peroxides and urea peroxides are also operative.

Of somewhat different nature are cross linking agents consisting of diisocyanate prepolymers. The prepolymers are reaction products of toluene diisocyanate, pentaerythritol mono-oleate

and pentaerythritol diproponal. When these prepolymers are added to resoles in conjunction with acid catalysts, the exothermic reaction vaporizes the water residual in the resole to form and crosslink the mass. Substantial improvements in compressive strengths and water resistance result.

Surfactants

Organic surfactants are often included in the foam composition to promote uniform cell structure, but this depends upon the nature of the composition. Various surfactants have been reported such as vegetable gums, alkylene oxide-phenol addition products, fatty acid esters, ester phosphatides (lecithin), and aryl aryl sulfates or sulfonates.

Modified Systems

Phenolic foams generally have one basic deficient which, above all other failings, has limited their more widespread use; at low densities (less than 1 lbs/ft^3) they are quite brittle. Considerable research has been directed toward improving this property and has resulted in systems having good compressive strengths.

Mixtures with resol with alcohol hydroxyls or amines possessing reactive hydrogens. The literature indicates that the addition of polyhydric alcohols to the phenolic foam mixture will aid in the production of tougher types. Other polyhydric alcohols, such as ethylene glycol and glycerol are also recommended. Polyamides or natural proteins are also needed as modifiers to substantially improve cell structure, uniformity, and toughness. In this (above), the best means for obtaining improvements is by adding the polyamides, polyamines or polyalcohols to the resole at an elevated temperature (less than 200°F), after the resole condensation is at the desired level.

Fillers such as wood flour, cork, walnut shell flour, mica, diatomite, and calcium silicate have been proposed as modifiers. Very fine particulate materials in low concentrations appear to improve cell structure and uniformity.

Foam Formulation and Preparation

Ingredients: In addition to phenolic resin, there are three basic ingredients used in the formulation of phenolic foams; these are:

1. Surfactant - which is used in order to maintain foam thermal stability during the foaming process. (Tween No. 40 is the recommended surfactant.)

2. Blowing Agent - which is used to obtain a smooth even foaming action which starts at a relatively low

temperature when the low-boiling blowing agent is first vaporized. Without this ingredient, no foaming action would occur until the boiling point of water was reached and foaming action would then be too violent. Isopropyl ether or methylene chloride are recommended blowing agents.

3) Acid Catalyst - is usually used to initiate the resin polymerization action. The acids most commonly employed for this purpose include sulfuric/phosphoric, toluenesulfonic, hydrochloric, or phenolsulfonic. A typical, general purpose formulation composed of these ingredients is as follows:

Ingredient	Parts by Weight
Foaming resin	100
Surfactant	1
Blowing agent	6
Catalyst	8 - 13

Formulation Variables

By varying the ratio of ingredients, changes in foaming characteristics and or foam properties can be achieved. In terms of the basic ingredients these may be catagorized as follows:

Surfactant - Use of the recommended quantity of surfactant results in a uniform, fine cell size distribution. A three-fourths reduction of the recommended quantity of surfactant results in a coarse, thick, cell-wall structure. An increase of up to 30 times the normal amount has a plasticizing effect during foaming and produces a tough, somewhat resilient foam. Small variations are not significant.

Blowing Agent - The use of the recommended quantity of blowing agent results in the optimum foam efficiency (lowest density for a given foam resin reactivity) and cell structure. Significant changes, from elimination to four times the specified quantity, result in a rapid increase in foam density. Minor variations, up to 10%, are not critical.

Catalysis - The type and amount of catalyst used is important to obtaining optimum foam expansion and a minimum foam shrinkage. If less than the recommended amount is used, an insufficient rate of resin cure results and causes serious foam shrinkage. If more than the desired amount of catalyst is used the foam sets before complete vaporization of water and blowing agent can take place. This results in an increased foam density. In any application, thirteen parts per hundred of resin weight of sulfuric/phosphoric acid catalyst is

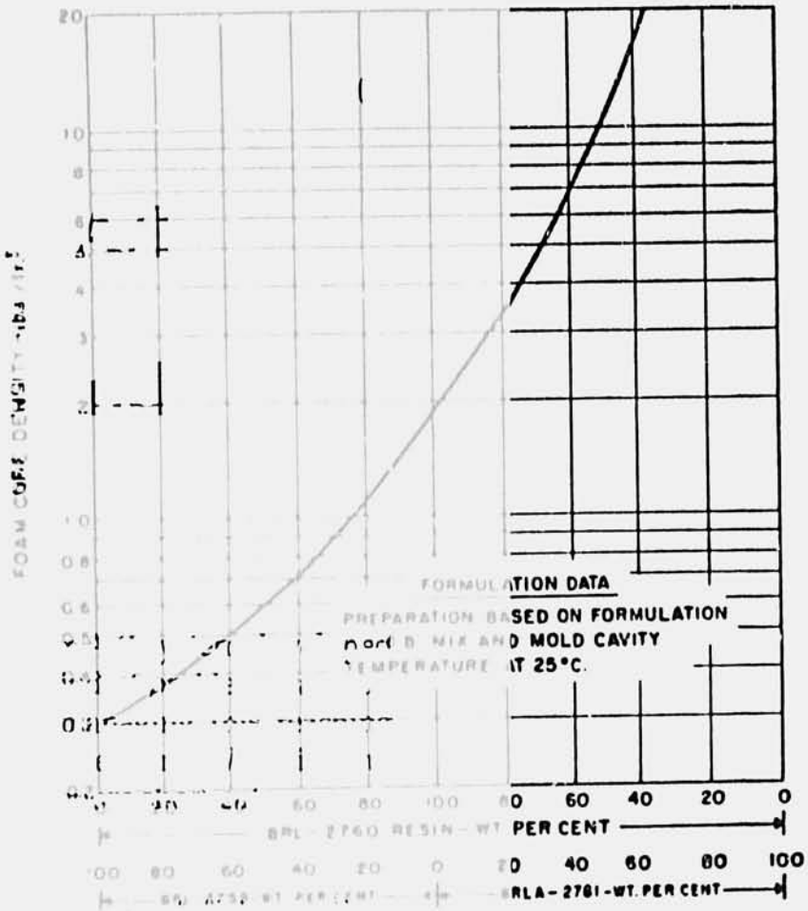
recommended for initial experimental work. This system is one of the easiest to handle, has minimum corrosion, and is used where the finest foam cell size is desired. If foam shrinkage becomes a problem, the amount of catalyst can be increased up to eighteen parts per hundred which will also give a shorter pot life and setting time. In an application where foam shrinkage continues to be a problem, the use of eight to thirteen parts of phenolsulfonic acid (65% concentration) is suggested. A faster pot life and setting time are characteristic of this system. For foams of the highest strength, lightest color, smoothest foam skins, and low shrinkage potential, eight to thirteen parts per hundred of hydrochloric acid (37% concentration) is recommended. This system, however, has a greatest corrosion potential due to the volital nature of the catalyst. Where a relatively long working time of five minutes or more is required, twenty to thirty parts per hundred of p-toluenesulfonic acid (70% concentration) should be used. This system is a slow curing catalyst and leads to a high degree of residual foam shrinkage, sometimes requiring an oven post cure. Because of the long foaming times involved, there is a difficulty in controlling foam density and cell size uniformity.

Control of Foam Properties

Density - Three phenolic foaming resins, each of which produces a specific foam density, are available for commercial use. They are:

Resin	Density of Foam
BRL 2749	[illegible] lb./cu.ft.
BRL 2700	[illegible] lb./cu.ft.
BRLA 2761	[illegible] lb./cu.ft.

In order to obtain intermediate foam density, these resins should be blended as shown in Figure [illegible]. There are a number of other factors which control foam density such as; mass of material foamed, ratio of foam surface area to volume, temperature of mold or cavity in which the foaming occurs, and the amount of restriction which is encountered by the foam when it is expanding. Basically, conditions which remove heat from the foaming mass or increase back pressure on the foam will result in an increased foam density. Thus, for a given foam formulation, minimum density and maximum uniformity would be obtained by foaming a large mass of material in an insulated open top container. Maximum density and a larger density gradient would be obtained by foaming a small mass of material in a cold metal mold having no cross sectional chanels through which the foam would have to travel.



DENSITY-COMPOSITION CURVES FOR BLENDING "BAKELITE" FORMABLE PHENOLIC RESINS

Pot Life - The time from addition of catalyst to onset of foaming is affected by the type and amount of catalyst employed, resins used, temperature of the mix and catalyst when blended, and volume of ingredients involved.

Cell Size - The fine cell size foams are made using isopropal ether as a blowing agent and sulfuric phosphoric acid as the catalyst system. When properly formulated, all systems, regardless of blowing agent or catalyst used, should yield foams of uniform relatively fine cell structure. The methods of producing a relatively large cell size are

1) Reduction of the amount of surfactant
2) Reduction of the amount of catalyst
3) Addition of water up to 15 parts per hundred of resin.

Skin Control - Formation of a "skin" of high-density resin surrounding a foam core is due to the loss of heat which occurs

at the foam surface. Depending on the specific application, the presence of this skin may or may not be desirable. Skin thickness can be reduced by minimizing heat loss during foaming. For example, when foam is generated in a cold metal container, a relatively thick skin is formed. Preheating the metal to 160-180°F markedly reduces the skin thickness. Alternatively, the same formulation foamed in a wooden container will have a relatively thin skin due to the lower heat conductivity of the container wall.

Properties of Phenolic Foams

Physical Strength - Because phenolic foam can be produced over a wide density range, the material exhibits a corresponding wide range of properties. This is essentially true with regard to its strength characteristics. Listed in Table are average values for phenolic foams at densities of 2 and 4 lb./cu.ft.

TABLE

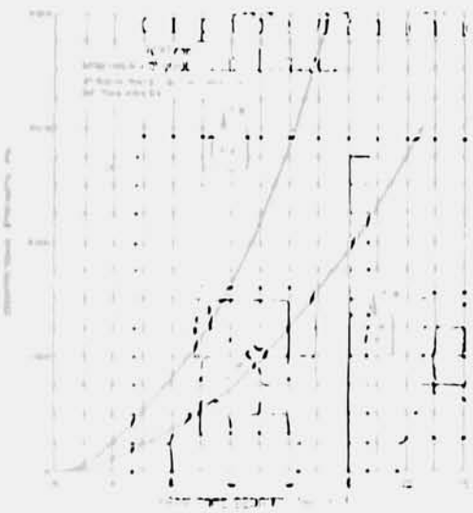
Average Strength Properties of Phenolic Foams

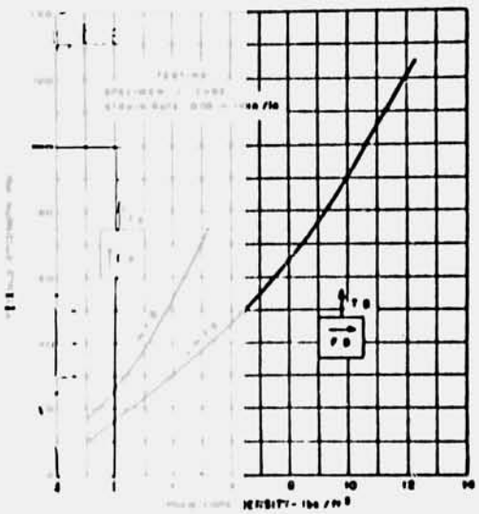
	2 lbs./cu.ft.	4 lbs./cu.ft.
Compressive (p.s.i.)	25	60
Flexural (p.s.i.)	25	65
Shear (p.s.i.)	14	30
Tensile (p.s.i.)	20	42
Shear modulus (p.s.i.)	100	750

These values represent average ultimate strength data obtained on samples of pure foam (no skin, uniform density). In the conversion of liquid resin to finished foam, the vertical rise of the foaming mass results in the elongation of individual cells. Consequently, the strength of phenolic foam will vary depending on whether a property is measured parallel or perpendicular to foam rise.

Figure shows the relationship between compressive strength and core density of phenolic foam. Figure shows the relationship between tensile strength and core density. Figure shows the relationship between flexural strength and core density of phenolic foam and Figure shows the relationship between shear strength versus core density of phenolic foam. Typical load/deflection curves are shown in Figures through

Thermal Conductivity - The thermal conductivity, K-factor, of phenolic foam as measured by ASTM C177-63, varies with foam density as shown in Figure . For practical purposes, the





NGTH (PSI) VS CORE

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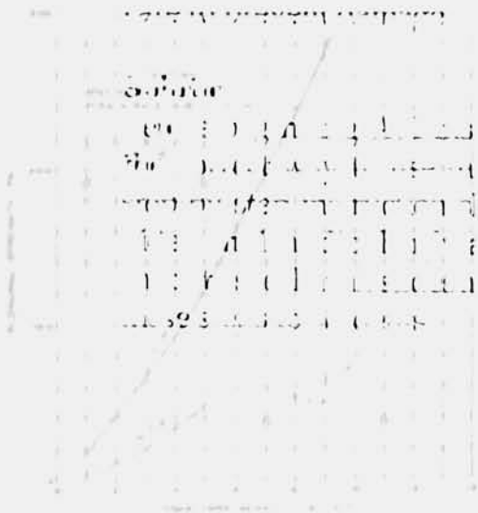

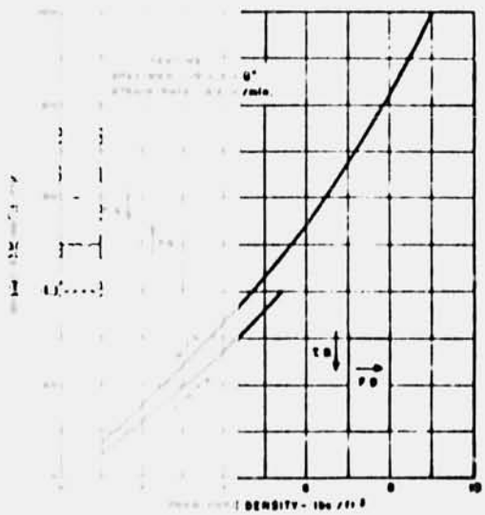

NGTH (PSI) VS CORE

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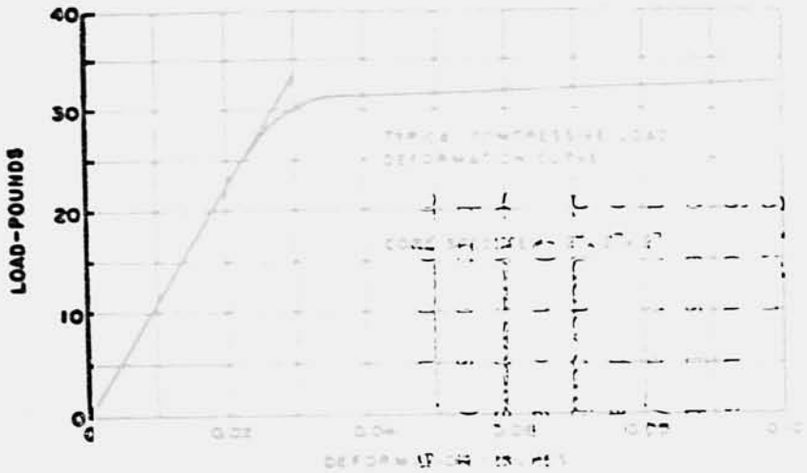
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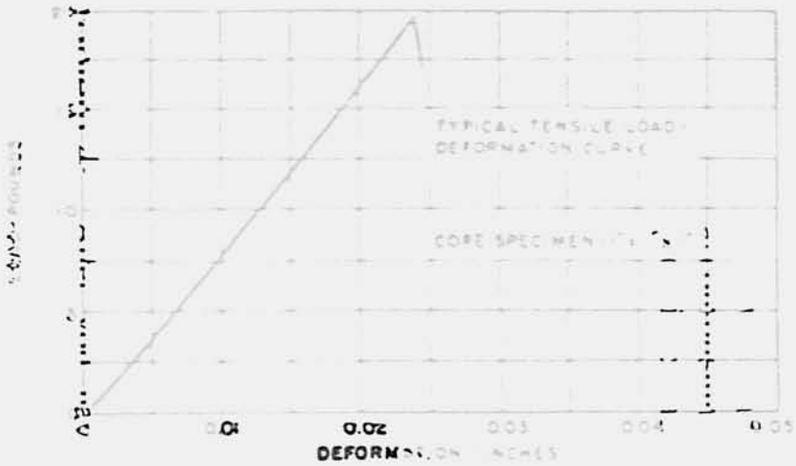
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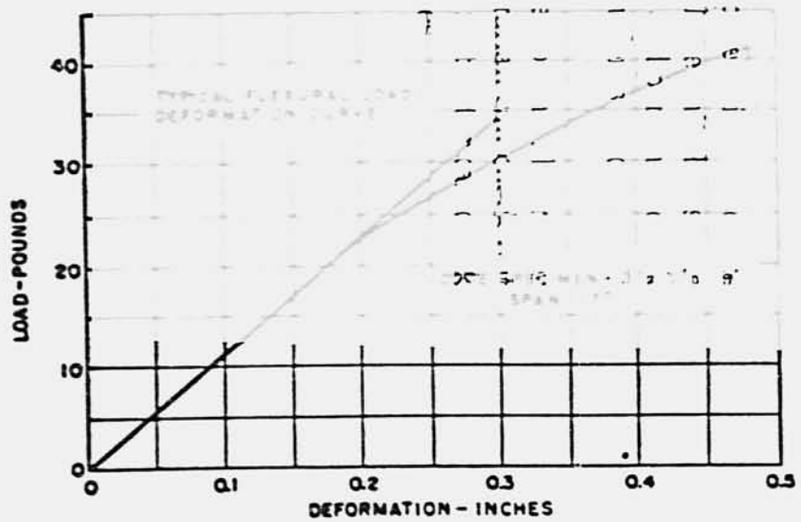
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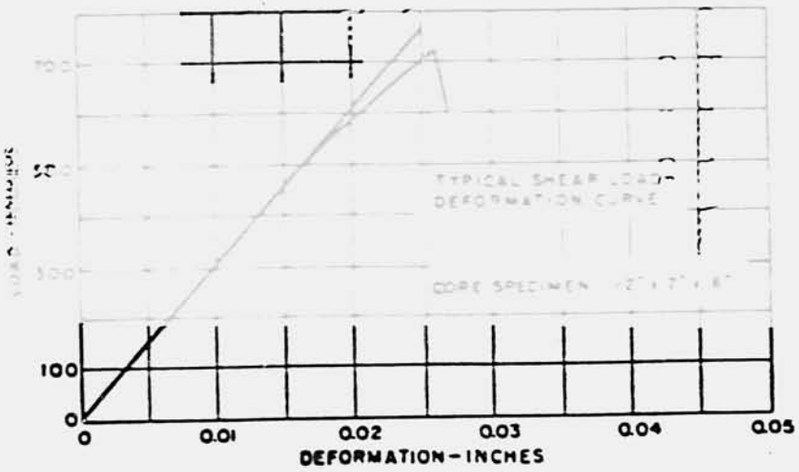
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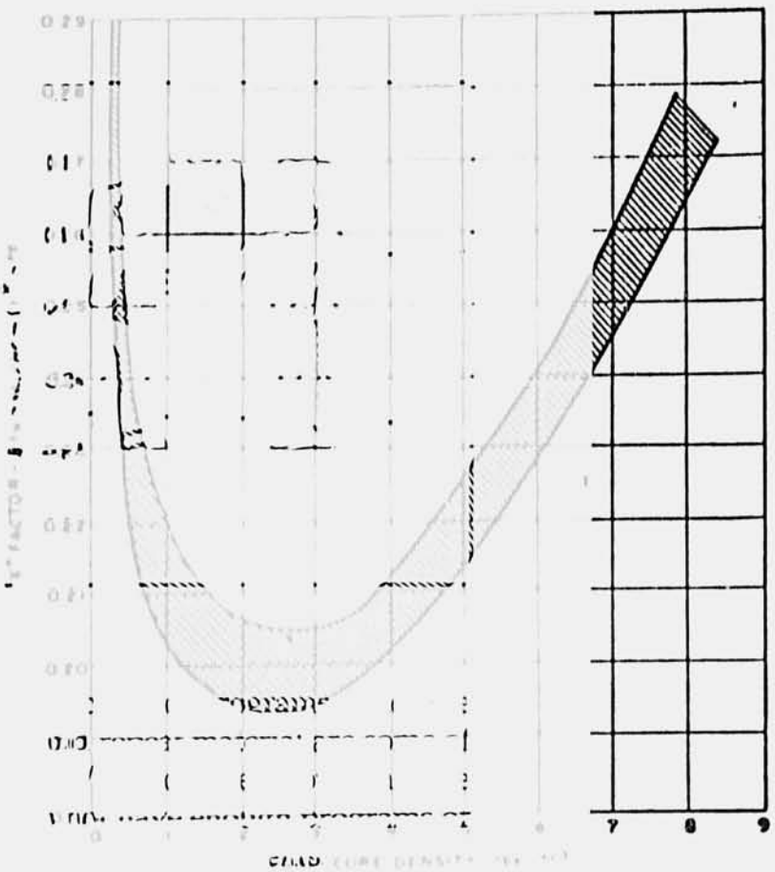


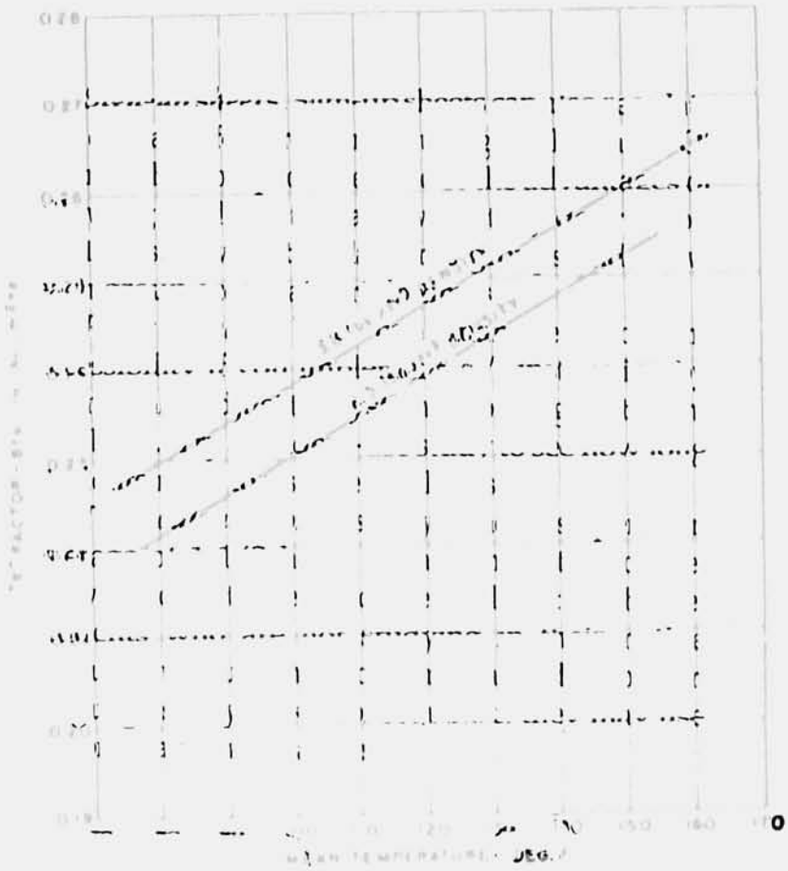
AT MEAN
ITY-(lbs./ft.^{3})
od"

K-factor is at a measurable and reproducible constant at about 0.20 over a density range of 1.5 to 10 lb/ft.^{3}. In order to show, as in Figure , the rate of change of K-factor with temperature is constant from density, the sample was subjected to accelerated aging tests involving six cycles with alternate water immersion, oven exposure, and hot (210°F) and cold (30°F) exposure. This test was used to show relative K-factor values at varied temperatures and does not provide absolute values as does the ASTM test.

Dimensional Stability at Elevated Temperatures

Phenolic foam is a highly cross-linked, thermoset plastic, and its properties are relatively unaffected by heat and moisture.

Table shows that at least 90% of the room-temperature strength is retained when the foam is tested at temperatures



THE [illegible] CONDUCTIVITY [illegible] FACTORS OF PHENOLIC FOAM AT VARIOUS MEAN TEMPERATURES

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Plot [illegible] FOAM CORES AT
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Physical Test and Conditions	Density, lbm/ft³	Strength, psi	Modulus of Elasticity, psi
	Test Parallel to Foam Direction		
Compression			
[illegible]	[illegible]	[illegible]	3900
[illegible]	[illegible]	[illegible]	4210
[illegible]	[illegible]	[illegible]	1540
[illegible]	[illegible]	[illegible]	1640
[illegible]	[illegible]	[illegible]	5940
[illegible]	[illegible]	[illegible]	2550
[illegible]	[illegible]	[illegible]	2480
Tension			
[illegible]	[illegible]	[illegible]	4350
[illegible]	[illegible]	[illegible]	4930
[illegible]	[illegible]	[illegible]	2920
[illegible]	[illegible]	[illegible]	2970
[illegible]	[illegible]	[illegible]	6680
[illegible]	[illegible]	[illegible]	4390
[illegible]	[illegible]	[illegible]	4180
Shear			
[illegible]	[illegible]	[illegible]	502
[illegible]	[illegible]	[illegible]	499
[illegible]	[illegible]	[illegible]	384
[illegible]	[illegible]	[illegible]	658
[illegible]	[illegible]	[illegible]	600
[illegible]	[illegible]	[illegible]	549

Notes:

[illegible] Ion neutralized HCl acid catalyzed foam

[illegible] values are averages of 2 tests. Remainder of data are averages of 5 tests each

The thermal coefficients of expansion over several temperature ranges are shown in Table for phenolic foam.

Moisture and Moisture Vapor Absorption

Phenolic foam has an impervious cell structure that will [illegible] water under conditions of total immersion. Figures and show the volume percentage of water and moisture absorbed at various time intervals up to 1,000 hours.

Flammability Resistance

Phenolic foam is rated as self extinguishing when tested according to ASTM D635-[illegible]. Because it is an organic material, the foam when subjected to flame will [illegible] and finally decompose (without melting), but will not propagate flame by itself.

Adhesion

When foamed in place, phenolic foam adheres well to rough or porous surfaces such as plywood, paperboard, gypsum, plaster, wallboard and similar materials. With such materials, the adhesive bond of the foam to the substrate will generally exceed the cohesive bond of the foam itself. Adhesion to smooth impervious surfaces such as glass or metal is poor and inconsistent. Adhesion to such surfaces is improved by [illegible] and a primer is required to [illegible] against such surfaces.

Corrosion

Acid-catalyzed phenolic foams should be expected to have a high corrosive potential. The most severe corrosion occurs when foam is allowed to contact wet a ferrous metal using hydrochloric acid as the catalyst. Under these conditions, a protective coating should be applied to the metal surfaces before foaming. Foams prepared at least as acidic as using hydrochloric acid and subsequently neutralized to various pH levels have exhibited very little corrosive effects.

Sound Absorption

Sound absorption of phenolic foam is quite good and noise reduction coefficients, measured by ASTM C423-[illegible], range from 0.50 to [illegible].

ration, [illegible] STABILITY OF CORE FOAM* AT

[illegible] ELEVATED TEMPERATURES

	Temperature, °F				
	200	250	300	350	455
First 16 Hr Cycle					
Weight Change (%)	13.2	15.6	14.4	16.5	22.3
Length Dimensional Shrinkage (in./in.)	0.007	0.014	0.014	0.017	0.037
Width Dimensional Shrinkage (in./in.)	0.016	0	0	0.023	0.052
Second 16 Hr Cycle					
Additional Length Dimensional Shrinkage (in./in.)	0.004	0	0.004	0.001	0.013

* Test samples were "neutralized," HCl acid-catalyzed foams of 1.6 lbs/ft³ density. Slab dimensions were 9"x9"x2" thick. Foams wrapped in aluminum foil and placed in dead air oven for testing.

THERMAL EXPANSION COEFFICIENTS*

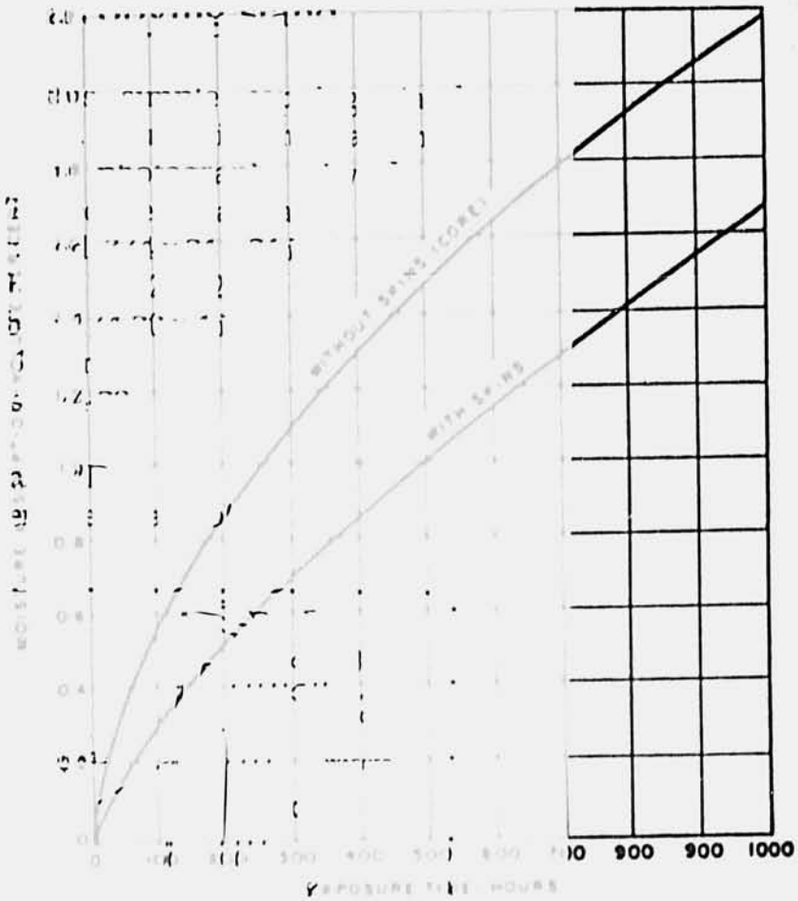
Sample	Test Direction Relative to Foaming Direction	Linear Coefficient of Thermal Expansion	Temperature Range
Core (without skin)	perpendicular	0.14×10^{-5} in./in./°C	-27°C to 60°C
	parallel	0.51×10^{-5} in./in./°C	-27°C to 60°C
	perpendicular	0.67×10^{-5} in./in./°C	-27°C to 93°C
	parallel	0.92×10^{-5} in./in./°C	-27°C to 93°C
Skin (thin phenolic skin formed during foaming-in-place)	perpendicular	1.4×10^{-5} in./in./°C	-27°C to 60°C
	parallel	2.8×10^{-5} in./in./°C	-27°C to 60°C
	perpendicular	3.1×10^{-5} in./in./°C	-27°C to 93°C
	parallel	2.0×10^{-5} in./in./°C	-27°C to 93°C

* Linear coefficients of thermal expansion were determined for 2 lb/cu.ft

Table (cont'd)

density foam, with and without skin. For a 30" span length in a direction both perpendicular and parallel to the foaming direction. Original span length was measured after conditioning samples at 200°F to constant weight and cooling down in desiccator to room temperature.

WATER ABSORPTION (VOLUME PER CENT) VS TIME (HOURS), TOTAL IMMERSION IN WATER AT ROOM TEMPERATURE FOR EIGHTH DENSITY PHENOLIC FOAM WITH AND WITHOUT SKINS



MOISTURE ADDITION (VOLUME PER CENT) AT 100 PER CENT R.H. 23° C STEADY TIME (HOURS) FOR 2 lbs./ft.^{3} OPENING FOAMS WITH AND WITHOUT SKINS

viously discus-
ganic compounds
gen atoms as
rming the silicone
which appear to
he silicone atoms
e resins useful
in rigid foams are polyorganosiloxanes having the general structure:

where R is hydrogen or methyl radical; polymerization is caused by splitting out of water or hydrogen during condensation by heating or by the influence of a catalyst. Mixtures of these systems produce powder or liquid materials containing blowing agents, solvents, or fillers. The powder systems are the oldest and require heating to achieve reaction in foaming. The newer systems require only the addition of catalyst and mixing to initiate foaming. The phenyl siloxanes are preferred for higher temperature resistance, and many modifications such as end blocking and polysiloxane chain may be employed.

Foam Systems

The low foaming temperature silicone foam systems; two powder and one liquid. The expansion of the foaming powders is controlled by adjusting the temperature. The density of the foams varies between 10-12 and 15-16 lbs./cu.ft. for 1 and 18 lbs./cu.ft. respectively. The powders are usually employed in higher temperatures and are usually employed in a cavity, to obtain positive filling and a uniform cell structure. Foaming in place requires special attention to maintain the cavity temperature and a close control of the cavity temperature. Foaming agents are necessary when the foam is to be molded. The liquid system, XR-7131, is prepared by mixing the resin and catalyst for 30 seconds with a mixing [illegible]. The resin portion contains methylene chloride, and care must be exercised in handling because of its hazardous nature. During expansion, a small amount of hydrogen is released which is combustible in operations requires an adequate ventilation be provided. Expansion is complete in about fifteen minutes but the foam is still soft. After 24 hours the foam will have cured sufficiently for handling or working. Oven curing for 15-16 minutes at 200°F. two hours after foaming is complete is adequate for obtaining full cure. The liquid XR-7131 system may also be sprayed with a two component spray gun. Very low pressures and temperatures rarely exceeding 100°F are developed in foaming, therefore light cardboard molds may be used for unconfined foaming.

Table shows the typical properties of silicone foaming powders. Table shows the typical properties of liquid silicone resin XR-7131 based foam.

Urea-Formaldehyde Foam

Chemistry

Urea-formaldehyde resins are prepared in much the same manner as previously described for phenolic resins. Urea and formaldehyde solutions condense on heating with refluxing at a pH of 5 to 6 and 80°C to 100°C to form methylol and methylene ureas and partial polymers thereof. Mole ratios are usually in the range of 1.6 to 2.0 of formaldehyde to one of urea. After sufficient cooking to obtain the desired degree of condensation, the solution is neutralized under vacuum to obtain 60% to 90% resin solids and viscosities of 1 to 4 poises.

Foam Production

Numerous means have been used to produce urea-formaldehyde foams. The liquid resin can be foamed by dispersing air or gas with a high speed agitation, followed by the addition of acid to cure the resin. In another method a solution of water, surfactant, and acid is whipped into a foam and blended with the liquid resin. And in yet another procedure, gas dissolved under pressure in a liquid resin is allowed to foam the mass on appropriate release of pressure. A similar to that technique employed in producing a urethane froth. The foaming agents used in phenolic resins may also be used to liberate gases by addition of acidic curing agents. The exotherm also aids in decomposing such agents.

Two more recent developments concern the emulsification of low-boiling liquids in the liquid resin containing an emulsifier such as dibutyl phenyl phenol sodium disulfonate. Nitrogen, propane under pressure, pentane, and other suitable low-boiling, water insoluble liquids are emulsified in a liquid resin-surfactant solution in low temperatures. Upon addition of catalyst (1% phosphoric acid based upon the weight of resin solids) the heat liberated causes the emulsified liquid to vaporize and foam the mass. Foams of this type are predominately closed-cell, whereas other foaming methods yield open-cell structures. Concentration of liquid blowing agents used are in the range of 30% based upon the weight of resin solids.

Polyoxyalkylene glycols have been used to increase the toughness of foams otherwise brittle foams. Those having intermediate molecular weights (5-25 oxyethylene groups per molecule) provide plasticizing and toughening of the foam. Glycols, from 10% to 35% by weight, may be added to the foamable resins containing high proportions of formaldehyde to urea (5:1), since the hydroxyls and glycol react with the formaldehyde to become a part of the resin.

TYPICAL PROPERTIES OF SILICONE FOAM POWDERS[1]

Properties As Shipped	Type of Foaming Powder R-7002	R-7003
Color	tan	tan
Apparent density, lb./cu.ft.	46	46
Mesh size, approx	20	20
Melting point, °F	160	200
Shelf life, months	79	79
Properties of Silicone Foams		
Density, lb./cu.ft.	14	16
Cell size, inch diameter	<0.08	<0.08
Compressive strength psi (at 10% def.)		
at 77°F	200	325
at 500°F	45	80
Weight loss, % after 1000 hrs. @ 500°F	2.6	2.6
Water absorption, % by weight	2.3	2.1
Maximum service temperature	650°F	650°F
Flame resistance	will not burn	
Dielectric constant @ 10^5 cps	1.25	1.26
Dissipation factor @ 10^5 cps	0.001	0.001
Thermal conductivity, K-factor @ 75°F M.T.	0.3	0.3

TYPICAL PROPERTIES OF LIQUID BOND SILICONE FOAM[2]

Properties As Shipped	
Viscosity, cps, 70°F	500
Mixing proportions, by weight	
Resin	100
Catalyst	7
Properties of Foam	
Density, p.c.f.	3.5
Compressive strength @ 10% def.	
70°F	6.3
500°F	0.5
Weight loss after 200 hrs. @ 500°F, %	6.4
Volume loss after 200 hrs. @ 500°F, %	8.3
Maximum service temperature	650°F
Water absorption, lb./sq.ft. of surface area	0.284
Water vapor transmission, perm-inches	41.2
K-factor @ mean temp. 77°F	0.281
Flame resistance	Does not burn
Dielectric constant at 10^5 cps	1.09
Loss tangent at 10^5 cps	.00032
% closed cells	60

[1] Dow-Corning Chemical Corp.
[2] Ibid.

TABLE

Properties of Urea-Formaldehyde Foam

Physical Properties	Actual Values
Density, lbs./cu.ft.	.35 - .70
Compressive strength	not reported, very friable
Tensile strength	not reported
Elongation	not reported, very friable
K-factor (75°F Mean Temp.)	.34
Capalarity	not reported
Water absorption	not reported (will not retain it's properties if allowed to come into contact with liquid water)
Water vapor transmission (perm-inches)	greater than 50
Flammability characteristics (ASTMD-1692-59T)	self-extinguishing (foam melts away from flame)

Polyvinyl Chloride Foams

Chemistry

Rigid PVC foams have not yet reached a level of commercial significance, but this condition depends upon technological developments. The polymerization and co-polymerization of vinyl chloride is a complex subject, especially in view of recent developments in stereospecific polymerizations. Thus, these studies may result in entirely different classes of polymers which, when applied to foams, could change the entire complexion of the field.

Preparation of PVC foams does not involve the polymerization of vinyl chloride or copolymers. Molecular weights of most commercial resins are believed to be about 50,000 to 150,000. High polymers of this type characteristically have high resistance to solvents and chemicals. In addition, the chlorene content provide non-support of combustion. Two grades of PVC are presently of interest in foams: dispersion resins and low molecular weight, Type 1, resins. Dispersion resins are available as powders having particle sizes of about 1.5 microns and contain vinyl acetate as the comonomer. About 5% vinyl acetate copolymer is used for maximum heat distortion resistance. The Type 1, low molecular rate resins are essentially unmodified PVC exhibiting very good chemical and solvent resistance and high moduli of elasticity. These resins can be obtained from several sources.

Foaming Process

Solvated Gas Process - This process depends upon high-pressure dissolution of gasses and liquids such as plasticizers and solvents for PVC. This method of foaming PVC has been broadly applied to flexible PVC. PVC itself, whether a homopolymer of vinyl acetate copolymer, is very rigid. Plasticizers must be used to make the resin flexible, and absorption of gasses, such as carbon dioxide, by many plasticizers under pressure is the key to this process. The first step of the solvated gas process consists of blending the powdered PVC resin with stabilizers, small amounts of plasticizers, and a solvent. The slurry is delivered to a pressure vessel, and gasses fed to the mixture under pressure of up to 300 atmospheres. The pressure vessel may be fitted with plates, a spray head, or packed with granules to increase the surface of the liquid and thereby speed absorption of the gas which may be carbon dioxide, mitrogen, etc. The pressure tank is connected directly to a heated hydraulic press chamber operating at the same, or slightly higher, pressure as the absorption tank. The chamber is partially filled with the gasseous material and heated to affect fusion of the PVC. The fused mass is then cooled and removed from the mold. The final step in the processing involves heating of the mass to further expand it and to reduce its density.

Several variations of this process have been reported in the literature using methyl ethyl ketone, tetrahydrofuran and similar solvents. These processes bypass the use of a pressure vessel by introducing the mixture directly to the mold, filling the mold with gas, pressurizing it up to about 400 atmospheres, prior to fusion.

Gas Releasing Agent Process - Gas releasing agents have been subjected to considerable study. Efforts have been devoted to determine specific decomposition temperatures and maximum gas (usually nitrogen) evolution per unit weight of agent. The complexities of selection of gas liberating agents is simplified by the use of PVC which required decomposition at about 100°C. Only a few materials have been used commercially.

Utilizing this formulation, the PVC stabilizer and blowing agent must be blended on a cold, two-roll rubber mill. After through blending, the acetone is added and the mixture is passed once, through the cold two-roll mill. The metal mold is then filled with the composition, covered and clamped in a hydraulic press. The mold is then heated for ten minutes with 100 psi steam, followed by cooling for ten minutes. After removal from the mold, expansion is completed by heating the mixture in a circulating oven for fifteen to twenty minutes at 100°C.

TABLE

Typical Rigid PVC Foam Formulation

Raw Materials	Parts by Weight
Polyvinyl chloride dispursion grade resin	100
Acetone	70
Dibasic lead phosphite stabilizer	10
70/30 N,N'dimethyl-N-N'-dinitrosoterephthalamide/ white mineral oil (Nitrosan*)	25

*Trade mark - E. I. duPont deNemours & Co., Inc.

TABLE

Properties of Rigid Polyvinyl Chloride

Property	Value
Densities, lbs., lb./cu.ft.	3 ± 0.5
Compressive strength, 70°F, psi @ 10% def.	80
Shear modulus, 70°F, psi	2500
Thermal conductivity, K-factor, 70°F mean temp.	.198
Combustibility	self-extinguishing
Capalarity	0
Coefficient of linear expansion, in/in/°F	5.4×10^{-5}
Water absorption, lb/sq.ft. of cut surface 24 hrs. under 10 ft. head of water	less than 0.018

Miscellaneous Rigid Cellular Plastics

Almost every plastic which has appeared has been foamed, or, by various means, made into a cellular material. These include such resins as: acrylic polyester, asphalt, and epoxy asphalt copolymers. Inasmuch as these materials are mainly laboratory curiosities and have not reached a level of significant commercial importance, they will not be considered at this time.

Opportunities for Cellular Materials in the Construction Industry

Introduction

The use of cellular plastics as materials of construction has been considered for most of the past decade. Many new and novel ideas utilizing expanded plastics are currently being field tested to determine performance as compared to the more conventional building materials. Six major problem areas which have been encountered are discussed briefly:

1) Building Codes - In dealing with the building and construction industry the major barrier to increased market penetration by cellular materials is that of building code acceptance. There are numerous separate codes governing building with each small municipality adhering to local codes. There is no code which is widely accepted, although considerable effort has been expended in recent years to develop and obtain acceptance of a National Building Code. This situation, therefore, makes a large scale educational effort necessary in order to promote the use of new materials such as cellular plastics.

2) Flammability Characteristics of Cellular Plastics - A major problem facing the cellular plastics industry is the combustible nature of many commercially available rigid foams. Because of the desirability, and in many areas, the necessity of obtaining approval by regulatory agencies, the development of fire retardant foams will have an important effect on the growth rate. The author believes the following minimum requirements presented in Table must be achieved if cellular plastics are to gain widespread acceptance.

3) Heat Distortion - Another property of cellular plastics which has been receiving increasing attention is that of heat distortion. Service requirements have been gradually raised due to the temperatures developed within the core of sandwich panels when exposed to ambient temperatures in excess of 90°F. Thus, cellular plastics must be capable of withstanding continuous exposure to 150°F without significant loss of physical properties.

4) Moisture Resistance - A fourth problem area is that of long-term moisture resistance by the rigid foams. Since it is not expected that hermetically-sealed panels are economically feasible, some moisture will be introduced into the panel during "breathing" from outdoor temperature changes. Thus, the foam core must not swell or shrink as a result of exposure to moisture.

TABLE

Flammability Requirements for Cellular Plastics

Test Method	Property	Requirement
U. L. Tunnel Test[1]	Propagation of flame spread	less 25
U. L. Tunnel Test	Smoke density	min. acceptable 100; desired less 50
U. L. Tunnel Test	Fuel contribution	less 25
U. L. Wall or Ceiling Test[2]	Fire endurance	min. acceptable 1 hr.; desired 2-3 hours

[1] ASTM - E - 84T

[2] ASTM - E - 119

5) Design Engineering Criteria - A serious lack of basic design engineering data exists covering rigid cellular plastics. The development of an engineering design manual for use by architects and builders is essential if the growth rate of cellular plastics is to meet industry expectations.

6) Economics - The installed cost of construction must be considered rather than the cost of the cellular plastics per se. As foam raw material production facilities are expanded within the United States an overcapacity of certain major foam ingredients will be encountered. This factor will aid in reducing present price structures. However, major developments in fabricating techniques must be made to allow cellular plastics to compete with low cost insulating materials such as fibrous glass. The superior insulating properties of cellular plastics, the use of adhesive characteristics developed during in-situ applications are but a few of the many properties of cellular plastics which should be considered for potential building and construction applications.

Roof Insulation

Cellular plastics have gained recognition as insulating materials in the roof construction field. The total 1963 market for industrial roof insulation was estimated to be 34 - 35 million dollars. The approximate market participation by commercially available insulating materials is indicated in Table

A comparison of the properties and economics of roof insulating materials is presented in Table .

The requirements for structural roof deck plank insulation are shown in Table

TABLE

Industrial Roof Insulation - 1963

Insulation	Volume
Fibrous glass	$ 15 MM
Wood fiber products	$ 15 MM
Cellular insulation	$ 5 MM
	$ 35 MM

TABLE

Comparison of Economics and Properties of Roof Insulation

Property	Urethane Foam	Polystyrene Foam	Fibrous Glass	Wood Fiber
Mfg. Cost B. F.	7¢	5¢	5¢	4¢
"K"-Factor	.130	.260	.270	.340
Mfg. Cost/R	.925	1.300	1.350	1.30-1.40
Compressive strength (p.s.i.-yield)	20	20	15	50
Flame spread (U. L. Tunnel)	40+	15 - 100+	25	25
W.V.T.R. (perm-inch)	2 - 3	1 - 2	--	--
Handability	Fair	Fair	Good	Good
Dimensional stability	Fair	Poor	Good	Poor
Resistance to hot asphalt	Fair	Very Poor*	Good	Good

* Must be protected by paper skin.

TABLE

Requirements for Structural Roof Deck Plank Insulation

Property	Specifications
Thermal Conductivity ("K"-Factor @ 75°F M.T.)	Maximum - .400; desired - less .200
Spanability	The product must be capable of spanning an evenly divided increment of 20 feet.
Flammability Classification[1]	Non-combustible
Flame spread	0 - 25
Fuel contribution	0 - 25
Smoke developed	Maximum 100; desired - less 50
Fire Endurance[2]	Minimum 1 hr. endurance with 40 p.s.f. design load
Weight	If product weights more than 140 lbs., it should be capable of being handled by suitable mechanical equipment.
Wind Uplift Resistance	A system must be devised for attaching the deck to the structure so that it will resist uplift pressures of 30, 45, and 60 p.s.f. for 1 minute.
Nail Holding Power	A practical means must exist whereby nails will develop the required uplift resistance in the deck.
Thermal Coefficient of Expansion	Must not exceed 0.57 expansion
Wet Strength Retention	The product must maintain 50% of its physical strength when exposed to a one foot head of water for 30 days.
Impact Resistance	The product must withstand the impact of a 60 lb. bag dropped successively from a height of 6" to 36" in 6" increments at the center of the span without failure.
Compressive Strength	Minimum 50 p.s.i.
Deflection Under Load	Maximum deflection allowed is 1/240 of the span under a 40 p.s.f. design load.
Abuse Resistance	The product should possess good abrasion and impact resistance. It must have sufficient strength to withstand normal shipping and handling abuses without damage.

1 ASTM - E - 84T
2 ASTM - E - 119

Roof Systems Based on Cellular Plastics

Figure shows a workman laying a cellular slab product on a metal roof deck. This insulation may be applied to the deck without the use of an adhesive or it may be spot-adhered. Figure illustrates a large roof section with rigid slab insulation in place. A vapor barrier is not normally required under urethane or polystyrene foam applied to a metal deck. However, over areas where the relative humidity exceeds 75% a vapor barrier is recommended to eliminate moisture migration through the joints. If more than one layer of insulation is to be applied, the joints should be staggared to reduce water transmission (Figure). If a polystyrene-based foam is used it should be encased in an asphalt-laminated kraft paper so that it can be hot mopped without damage. When there is no vapor barrier, moisture will migrate through porous insulations to the underside of the roofing. If a cellular type insulation is used, this migration will occur at the insulation joints. Upon reaching the first felt at the joint between the boards, the moisture is absorbed by working into the felt and expands it until a ridge is formed. After the ridge is formed, the bitumen on the outside surface will flow off during heat of the summer, exposing bare felt. This is the start of a roof leak or roof blister (Figure). When a vapor barrier is installed on the warm side vapor cannot enter through the insulation or through the joint system to reach the cold side of the roofing. Therefore, there will be no blistering or ridge growth. However, if a roof leak occurs because of rupture in the roofing or flashing, water will enter porous insulation and ridge growth will again take place since the vapor barrier prevents the wet insulation from drying out through the deck. When the vapor barrier has been eliminated and the first ply of roofing is a coated base sheet, the moisture migrates from the warm side toward the cold side, however, it can only pass through the joint system since the insulation is a closed cell product. Upon reaching the cold side, the moisture cannot enter the roofing system as the first ply is a coated base sheet. The coated base sheet, a 15 or 30 pound saturated felt which has been factory coated with asphalt resulting in a 33 or 43 pound coated base sheet, may be applied dry by the "kick-out" technique. (Figure)

When subsequent layers of felt are mopped into place, Figure the heat of the asphalt melts the asphalt coating on the back of the base sheet. This effects a strong bond between the insulation and the first layer of felt. Figure shows the machine application of a coated base sheet. Hot asphalt is applied to the coated base sheet by means of a roller as the equipment is pushed over the insulation. Figure , a diagramatic sketch, presents a cross-sectional view of a built-up roof system. Figure shows a cross-sectional view of a polyethylene vapor

barrier joint system developed for built-up roof by Dow Chemical Corporation. This expansion joint would be covered with roofing felt as described previously.

The use of cellular plastics as core materials in sandwich panels has increased many fold in the past three years. Figures and illustrate a single story residential roof system based on a polystyrene foam core and a fiber glass reinforced plastic skin sandwich panel. Figure shows a residential roof system based on a similar sandwich panel supported on wood studs. Segments of the roof of the West Virginia Pavilion (1964 World's Fair) were constructed of sandwich panels utilizing an urethane foam core and fiber glass reinforced plastic skins. Figures and show a view of the semi-completed dome. Figure shows the ring attachment used to provide additional strength in the completed dome. Polymeric caulks and sealants were used to seal the joints thus preventing migration of water or vapor. Figure through show the erection of the canopy using foam-filled sandwich panels. Figure shows the domes and canopies completely installed.

Curtain Wall Panels

Rigid cellular plastics are increasing their market penetration as core materials for curtain wall non-load bearing panels. When enclosed by metal skins, present fire-retardent foam systems are gaining wider acceptance by local code officials.

Figures and show polystyrene foam filled curtain wall panels being installed in the Inland Steel Building, Chicago, Illinois. The five inch thick panels are sheathed with 1/16" stainless steel on the exterior face. The standard panel size was five feet by twelve feet. Figure shows a section of a Monsanto Building during errection. The curtain wall panels are constructed with metal skins and urethane foam cores. Additional examples showing the use of curtain wall panels with cellular plastic cores may be seen in Figure , The Hong Kong Hilton Hotel, Figure , Alitalia Terminal Building, and Figure , The University of Michigan Press Box.

Exterior Load Bearing Wall Panels

The exterior facing of the 42 inch by 84 inch wall panels shown in Figures and is quarter inch exterior grade redwood plywood. The interior facing is quarter inch paint grade gum plywood. These panels were used in both load bearing and curtain wall capacity throughout the house. Figure shows the installation of metal faced, load bearing sandwich panels as the exterior wall of a large warehouse. Figure shows the complete exterior wall. Figures through show the installation of large concrete faced polystyrene core exterior wall panels. The use of prefabricated techniques, illustrated by these photographs, allows the major reduction in the total labor cost incurred during errection.

Cavity Wall Insulation

Cellular plastics have increased their penetration in recent years in the cavity wall insulation market area. These materials provide permanent comfort and economy for heated and air conditioned buildings. Most foams absorb little or no water, thus reducing or eliminating moisture penetration into the inner wythe. The polystyrene and urethane foams have no food value and therefore do not sustain rot or fungus or attract insects or rodents. Figure shows urethane foam being applied in a cavity wall void by means of the froth technique.

Perimeter Insulation

F.H.A. Minimum Property Standards require the perimeter insulation shall be installed to limit the heat loss from heated and unheated concrete slab floors to not more than 5 B.T.U.'s per hour per square foot of floor area.

Figure is a diagramatic sketch of a cross-section of a residential home showing the installed perimeter insulation. Figure shows a workman installing polystyrene foam perimeter insulation on the gravel substrate prior to errection of the side walls. Styrene based foams have captured the bulk of this market area as they are presently competitive with conventional materials on an insulating effectiveness basis.

Application of Cellular Plastics to Masonry Walls

Cellular plastic slab stock may be bonded directly to masonry wall surfaces. The "push-box" technique, illustrated in Figure may be used to apply a portland cement mortar to the insulation prior to installation. Interior finished such as gypsum wallboard, shown in process of installation using spot adhesive in Figure , plaster shown in Figure , ceramic tile, wood paneling and decorative hardboard may be applied over cellular plastics. The finished wall is constructed at an obvious savings over conventional methods because furring and lathing may be eliminated.

Spray-Applied Urethane Foam

A number of electrically heated single family dwellings have been insulated by means of spray applied urethane foam (Figures Initial evaluation of economic studies conducted during these test applications has indicated that foam applied to a thickness allowing for equal thermal efficiency as compared with conventional insulations such as fibrous glass cannot compete economically. However, if the foam is allowed to completely fill the wall voids, thus purposely over-insulating, savings realized by reductions in the heating plant and air conditioning units may compensate for the previously unattractive economic comparison.

Cold Storage Insulation

Considerable controversy exists covering the prescribed methods for construction of cold storage facilities. A variety of materials have been used as insulation. Historically these have included cork, fibrous glass, polystyrene foam, and urethane foam. The cellular insulating materials are gaining acceptance as they may be specified for the entire structure. The older materials such as cork and fibrous glass were lacking in compressive strength to provide sufficient strength to support the floor wearing surface. Figure shows rigid slab stock being installed on the wall of a cold storage room. The first layer is adhered to the substrate by an application of hot mastic. The second layer is applied dry with treated wood skewers where needed to hold it in place. Figure illustrates the application of rigid urethane foam in a cold storage wall by means of the pour-in-place technique. The transite wearing surface was attached to urethane studs, cut from slab stock, which were adhered to the concrete block wall.

Pipe Insulation

Cellular insulations dominate the low temperature (below 32°F) industrial and commercial pipe insulation markets. These materials are also gaining acceptance in the chilled water range (32°F to 50°F), at the expense of fibrous glass insulation. Figure shows the installation of a molded cellular plastic pipe section. Figure illustrates a typical section of piping showing molded cellular plastic straight sections, elbows, and tees.

Foaming Thin Shells

The thin shell construction technique using polystyrene foam in conjunction with mortar materials: as a plaster base, as a core material for concrete sandwich panels, and as a form liner for the in-situ coating of concrete roofs has been the basis for many novel construction applications. Figure shows a completed hyperbolic paraboloid tilt-up panel being raised into position during construction of a Milwaukee church. Styrene foam planks 1½ inches thick, served as a form liner, permanent insulation, and a base for plaster. Figure shows the styrene based foam positioned in a mold. Figure illustrates a typical casting step in the fabrication of curtain wall concrete sandwich panels. Figure shows a completed auditorium erected in Anderson, Indiana. The 268 foot diameter lightweight concrete dome was constructed over 38,000 cubic yards of dirt and gravel mounded to form a mold. Slabs of rigid polystyrene foam were laid over the mold. Reinforcing steel was placed over the foam, resting on chairs with steel metal feet. The post-tensioned ring beam was placed at ground level with steel collars at each column, spaced 20 feet on center around the periphery of the dome. Hydraulic jacks mounted on the top of each column lifted the nearly

60,000 square feet of concrete dome 24 feet up the columns to its final position. The polystyrene foam remained bonded to the underside of the dome as it was lifted, providing a permanent insulation and vapor barrier, ready to receive the plastered interior finish. The structural portion of the building including foundations, columns, and concrete dome cost slightly more than $3.00/square foot. The total cost of the building was $6.50/square foot.

In many cases the cellular plastic materials can be used as a total structural form, eliminating almost completely the need for forming or falsework. Figure shows a novel folded-plate roof which was constructed in Houston, Texas. The roof elements were folded-plate segments formed with polystyrene foam, reinforcing rods, and wire mesh and lifted into position. They were then sprayed with concrete on top and bottom. The building costs were about 15% less than conventional. Other unique structures erected by similar techniques are illustrated in Figures and .

A projection of potential markets (1961-1966) for rigid board insulation in the Construction Market is presented in Table An estimate of rigid urethane foam consumption in the 1970 Construction Market is presented in Table .

Conclusions

The area for greatest potential sales for rigid cellular plastics is the building and construction market. Increased market acceptance of cellular materials, refinements in processing of raw materials, advancement of application techniques, design of more reliable and more functional equipment will permit a continuation of a general downward trend in the cost of foam insulations. However, major penetration of cellular plastics into areas governed by such factors as building codes and specifications set by regulatory agencies will not become a reality until the flammability characteristics of foams are improved to meet the severe requirements regarding propagation of flame spread, smoke density, fuel contribution, and fire endurance properties. It is the author's opinion that composites based on extension of present foam systems with inorganic, non-burning fillers must be developed using the cellular plastics as binders before this new class of materials will achieve their greatest sales potential. The final and perhaps most important factor which will determine the growth rate of cellular materials will be the development and dissemination of engineering data to architects, builders, and others responsible for design and specifications of new applications.

Note: Figures will be submitted with Final Report.

Industrial Sources and Production Processes For Urethane Raw Materials

Commercial Production of Diisocyanates

Raw Materials Required

Toluene (or benzene)	- Coal (coke - coal tar) Petroleum (Hydroforming)
Sulfuric Acid	- Sulfur dioxide (sulfur, zinc, C_u, P_b ore)
Nitric Acid	- Oxide of nitrogen NH_3 (Ostwald process to NO and NO_2)
H_2	- Decomposition of Hydrocarbons (natural gas) - Steam and coke (coal) - Hydrocarbons and steam (oil)
Phosgene	- Carbon monoxide and chlorine

Production of Raw Materials For Urethane Foam

Industrial Source of Alkylbenzenes

There are two large reservoirs of organic material, petroleum and coal, and aromatic compounds are obtained from both. Aromatic compounds are separated as such from coal tar, and are synthesized from the alhones of petroleum.

Production of Aromatic Compounds From Coal

The largest portion of coal that is mined today is converted into coke, which is needed for the smelting of iron to steel. When coal is heated in the absence of air it is partially broken down into simpler volatile compounds which are driven out, the residue is coke. The volatile liquids consist of coal gas, and a liquid known as coal tar. Table presents a representative breakdown of the compounds obtained from the coking process.

While 0.5 lbs. of toluene does not represent a high percentage yield, more than 70 million gallons were provided in 1963. Approximately 280 million gallons of benzene were also produced. It is relatively easy to convert benzene to toluene if needed.

TABLE

Coal (2000 lbs.)

heat, absence of oxygen

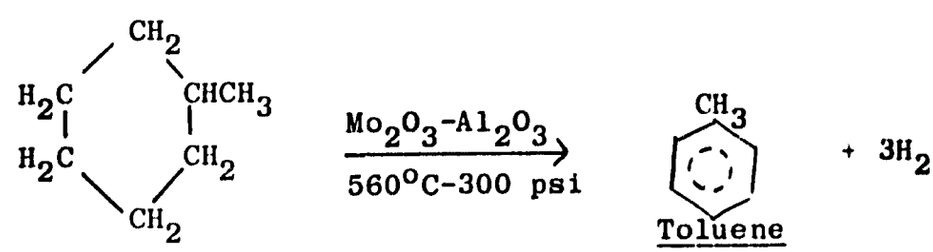
residue (coal)	volatiles (coal gas)	liquids (coal tar) (120 lbs)

Coal tar

benzene	2.0 lbs
toluene	0.5 lbs
xylenes	0.1 lbs
phenol	0.5 lbs
cresols	2.0 lbs
naphthalene	5.0 lbs

Production of Aromatic Compounds From Petroleum

During World War II, the need for toluene for TNT production greatly exceeded the yearly production obtained from coal tar. A process, hydroforming, was developed to obtain toluene from the aliphatic hydrocarbons of petroleum. This process involves the dehydrogenation of the methylcyclohexane which is abundant in some crude petroleums. The methylcyclohexane is passed at high temperature and pressure over certain oxide catalysts.



Methylcyclohexane

Since the War this synthesis of aromatic compounds from the aliphatic compounds of petroleum has been continued and is one of the major sources of these aromatic compounds.

Production of Sulfuric Acid

Sulfuric acid was first prepared on a commercial scale about the middle of the eighteenth century. At present the nation's annual production of sulfuric acid is in excess of 16 MM tons of the 100% acid.

Sulfuric acid is manufactured by two different methods, both of which involves the catalytic contact oxidation of sulfur dioxide.

The first of these consists in the conversion of sulfur dioxide, produced by the contact process, to sulfuric acid. The gas from the catalytic chamber is passed into concentrated sulfuric acid, which reacts with the sulfur trioxide to form pyrosulfuric acid.

$$H_2SO_4 + SO_3 \rightleftharpoons H_2S_2O_7$$

This substance is then treated with the quantity of water required to give sulfuric acid solution of the desired concentration.

$$H_2S_2O_7 + H_2O \rightleftharpoons 2H_2SO_4$$

In practice, these two steps are carried out simultaneously to make a continuous process. Water is run into the absorbing acid at a regulated rate, so the concentration of the acid is maintained at a constant level. This method is used to obtain sulfuric acid of high purity and of any concentration desired.

Lead-Chamber Process

Sulfur dioxide, oxygen, water vapor, and the oxides of nitrogen are mixed in large lead-lined chambers. A complicated series of reactions ensue, the net result of which is the combination of sulfur dioxide, oxygen, and water to form sulfuric acid. The oxides of nitrogen function as a catalyst and are later recovered. A compound called nitrocyl sulfuric acid $SO_2(OH)(NO_2)$ is formed as an intermediate step. In the presence of an excess of water, this compound is hydrolyzed giving sulfuric acid.

$$2SO_2(OH)(NO_2) + H_2O \rightleftharpoons 2H_2SO_4 + NO + NO_2$$

Since the oxides of nitrogen are relatively expensive, it is essential for economic reasons, to recover them. This is accomplished by their absorption on leaving the chambers in concentrated sulfuric acid.

Ordinary chamber acid has a concentration of 60 to 70% H_2SO_4 by weight and contains a considerably larger proportion of impurities than acid made by the contact process. Where relatively dilute acid is required and the presence of small quantities of impurities is of no consequence, the less expensive chamber process is used.

The sulfur dioxide used in these processes is obtained either from the burning of sulfur or from the roasting of pyrite, F_eS_2; some sulfur dioxide, however, comes from the roasting of sulfide ores of zinc, copper or lead, and hence sulfuric acid is sometimes obtained as a by-product of the metallurgy of these metals.

Manufacture of Nitric Acid

For many years the chief source of nitric acid was the reaction at elevated temperatures of sodium nitrate with concentrated sulfuric acid.

$$NONO_3 + H_2SO_4 \rightleftharpoons N\ HSO_4 + HNO_3$$

The natural supply of sodium nitrate is found only in Chile. Thus, the discovery of methods for the preparation of nitrogen compounds directly from nitrogen in the air led to more suitable methods for the production of nitric acid. A high-temperature process was developed for the manufacture of nitric oxide, and the Haber and Cyanamide processes for the manufacture of ammonia.

The chief source of nitric acid today is from the oxidation of ammonia. The 8 stuold process for the catalytic oxidation of ammonia to nitric oxide is widely used. The nitric oxide, after being cooled, is mixed with oxygen to convert it to the dioxide.

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The product is then passed into warm water with which it reacts according to the equation

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The nitric oxide is recovered and recycled. A 60% solution of nitric acid is obtained by this process. More concentrated solutions can be prepared by distillation from a mixture of the dilute acid and concentrated sulfuric acid.

Industrial Production of Hydrogen

A number of industrial processes are available for the production of hydrogen needed for the reduction of dinitrotoluene to toluenediamine. These include:

1) Decomposition of Hydrocarbons (natural gas) Some hydrogen is obtained by the catalytic decomposition at high temperature of compounds carbon and hydrogen such as those found in natural gas.

$$CH_4 \rightleftharpoons C + \underline{2H_2}$$

2) Reaction of Steam with Coke (coal) - When steam is passed over hot coke (1000°C) carbon monoxide and hydrogen are formed.

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Phosgene, $COCl_2$, a highly poisonous gas, is manufactured by the reaction between carbon monoxide and chlorine.

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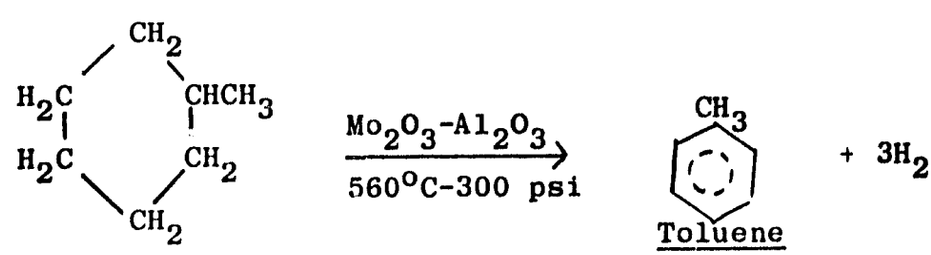

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I. Properties and Economics of Insulating Materials

A. Scope

A detailed analysis of the physical properties and economics of the following commercially available insulating materials is presented:

1. Polyurethane Foam

   a. Rigid slab stock
   b. Foamed-in-place rigid foam
   c. Spray-applied rigid foam

2. Polystyrene Foam

   a. Expandable polystyrene foam (bead foam)
   b. Expanded polystyrene foam (extruded foam)

3. Polyethylene Foam

4. Urea-formaldehyde Foam

5. Foam Glass

6. Fibrous Glass

7. Epoxy Foam

Special emphasis is placed on a comparison of the insulating effectiveness of cellular materials vs. fibrous glass insulation.

Projections of expected or possible changes in the properties and cost of insulating materials within the next three to five years is discussed.

B. Foam Economics

The cost of insulating materials vs. density for the years 1960 (actual) and 1965 (projected) are presented in Table The cost of additional insulating materials are listed below:

Material	Density (p.c.f.)	$ Cost/Bd.Ft. (1965)	$Cost/Bd.Ft. (1965)
Fibrous glass	6.0	.082	.075
Fibrous glass	2.5	.031	.031
Fibrous glass	1.5	.093	.080
Foamglas	9.0	.143	.143
Polyethylene Foam	2.0	.220	.200
Urea-formaldehyde Foam	35-.70	---	.143

TABLE

Foam Costs vs Density (1960 - 1965)

Density (p.c.f.)	2.0			3.0	
Materials	1960	1965	$/Bd.Ft.	1960	1965
Urethane Foam (sprayed, purchased prepolymer)	.230	.170		---	.260
Urethane Foam (poured, purchased prepolymer)	.160	.130		.235	.195
Urethane Foam (sprayed, manufactured prepolymer)	.145	.110		.225	.170
Urethane Foam (slab stock)	.145	.105		.190	.145
Urethane Foam (poured, manufactured prepolymer)	.105	.080		.155	.125
Styrene Bead Foam purchased beads)	.075	.075		.115	.115
Styrene Extruded	.060	.060		.075	.075
Styrene Bead Foam	.048	.048		.065	.065

C. Properties of Insulating Materials

1. Insulating Effectiveness - Insulating effectiveness is defined, following the trade practice, as the product of K-factor and the price per unit volume of material. Inasmuch as low K-factor and low price are desirable, a low insulating effectiveness is more desirable than a high one. Except in noise-control and air-filter applications, the prime requirement for materials is the most important single characteristic of these materials. Tables , , and present the insulating effectiveness of the materials considered in this study.

   A review of Tables , , and shows that the foam with the most favorable insulating effectiveness at present is urea-formaldehyde foam. Since this material has no structural value, and has not been widely evaluated it cannot be considered to be an important commercial product at this time in the market areas covered by this study. The material possessing the next best insulating effectiveness is rigid urethane foam. Because of declines in raw material prices coupled with technological advances this situation should continue. Polystyrene bead foam is next in insulating effectiveness. In common with all other foams covered, except in-situ applied urethane foams and urea-formaldehyde foams, this material is made in slab form and then cut to shape. Following bead foam in insulating effectiveness are rigid urethane slab, extruded polystyrene foam, spray-applied urethane foam, and foam glass. For the future, spray-applied urethane foam will become directly competitive with bead polystyrene foam. Polyethylene foam is so poor in insulating effectiveness that the author does not believe it constitutes a serious threat to any large volume insulating market.

   The insulating effectiveness of fibrous glass products declines as density increases. It is quite apparent from Tables , , and that a number of organic foam products are already better in insulating effectiveness than many fibrous glass products. The competitive positions of foams will improve in the future.

2. Strength Properties - In most of the markets considered in this study, strength of the insulating materials is primarily important during handling and installation and in resisting damage in use rather than in contributing structural strength. There are exceptions, such as cold storage floors in which the insulating material itself becomes a part of the structure and is expected to carry a load. In most of these cases compressive load-bearing strength is the important characteristic. So far as the

TABLE

Insulating Effectiveness of Cellular Plastics - 1.5 p.c.f.

(1960 - 1965)

Materials	1960			1965		
	"K"	$/Bd.Ft.	I.E.	"K"	$/Bd.Ft.	I.E.
Urethane Foam (sprayed, purchased prepolymer)	.154	.170	.026	.154	.130	.020
Urethane Foam (poured, purchased prepolymer)	.121	.120	.015	.121	.100	.012
Urethane Foam (sprayed, manufactured prepolymer)	.154	.110	.017	.154	.085	.013
Urethane Foam (slab)	.154	.110	.017	.154	.085	.013
Urethane Foam (poured, manufactured prepolymer)	.121	.075	.009	.121	.060	.007
Styrene Bead Foam (purchased beads)	.260	.065	.015	.260	.065	.015
Styrene Extruded Foam	.285	.050	.014	.285	.050	.014
Styrene Bead Foam (manufactured beads)	.260	.045	.012	.260	.045	.012

TABLE

Insulating Effectiveness of Cellular Plastics - 2.0 p.c.f.

(1960 - 1965)

Materials	1960 "K"	1960 $/Bd.Ft.	1960 I.E.	1965 "K"	1965 $/Bd.Ft.	1965 I.E.
Urethane Foam (sprayed, purchased prepolymer)	.140	.230	.032	.140	.170	.024
Urethane Foam (poured, purchased prepolymer)	.110	.160	.018	.110	.130	.014
Urethane Foam (sprayed, manufactured prepolymer)	.140	.145	.020	.140	.110	.015
Urethane Foam (slab)	.140	.145	.020	.140	.105	.015
Urethane Foam (poured, manufactured prepolymer)	.110	.105	.012	.110	.080	.009
Styrene Bead Foam (purchased beads)	.260	.075	.020	.260	.075	.020
Styrene Extruded Foam	.285	.060	.017	.285	.060	.017
Styrene Bead Foam (manufactured beads)	.260	.048	.012	.260	.048	.012

TABLE

Insulating Effectiveness of Miscellaneous Insulating Materials

(1960 - 1965)

Materials	1960 "K"	1960 $/Bd.Ft.	1960 I.E.	1965 "K"	1965 $/Bd.Ft.	1965 I.E.
Polyethylene Foam (2.0 p.c.f.)	.350	.220	.077	.330	.200	.066
Foamglas (9.0 p.c.f.)	.400	.143	.057	.400	.143	.057
Urea-formaldehyde Foam (.35 - .70 p.c.f.)	---	---	---	.240	.013	.003
Fibrous Glass						
(6.0 p.c.f.)	.240	.082	.020	.240	.075	.018
(2.5 p.c.f.)	.260	.031	.008	.260	.031	.008
(1.5 p.c.f.)	.227	.093	.021	.227	.080	.018

author can determine, tensile and flexural strengths have no value except in contributing to toughness and workability of the material. In terms of strength, all of the foam except urea-formaldehyde -- which serves only as a low cost bulk filler -- are generally superior to fibrous glass products. Structural strength is not a controlled property of fibrous glass products and when required must be built in, the cost then becomes very high. The high costs of these fibrous glass products are reflected by their poor insulating effectiveness. Current foams have strength properties superior to fibrous glass for any insulating effectiveness. In the case of urethanes, when foamed-in-place they bond tightly to the walls of the space in which the reaction takes place. This bond, plus the high strengths possible in the foams, opens the possibility of utilizing the foams as structural elements as well as insulating materials.

3. Permeability - The cellular structure of most of the foams considered in this report is largely closed, and the materials are comparatively good water vapor barriers. Fibrous glass and urea-formaldehyde foams, on the other hand, have very open porous structures, and thus are highly permeable to water v apor. In all low-temperature insulating applications (below room temperature) a vapor barrier must be used on the warm side, if the insulation itself is not a vapor barrier, in order to prevent the insulation from becoming wet and its insulating value from being reduced. It was thought for some time that the unicellular foams would not require a water vapor barrier in order to perform efficiently at low temperatures, but field experience with a number of installations has indicated that a barrier is necessary. Inasmuch as a barrier is also required with fibrous glass insulations it is reasonable to assume that the cost of providing a barrier with foam is not greater than providing fibrous glass products a similar barrier; and in fact may be somewhat less because the foams themselves are tougher and may not require so tough a barrier to resist damage during installation and under use conditions.

4. Operating Temperature Range - As organic materials, foams have a distinct disadvantage in comparison with inorganic materials such as fibrous glass or foam glass. Polystyrene based foams are low-melting thermoplastic materials and are not recommended for continuous services at temperatures in excess of 140°F. Current urethane foams are somewhat better; properly formulated foams will operate continuously at 200-250°F, but at the high end only if not subjected to loading. Fibrous glass products will operate continuously at 350°F, and if the organic binder customarily used on them is eliminated, will operate up to

1000°F. Fibrous glass insulation must be protected by multi-layer vapor barriers if specified for use below 0°F. Multi-layers of insulation are required with the joints staggered and vapor barriers applied between each layer. Thus urethane foams, poured-in-place, will develop a monolithic structure and should operate more efficiently at very low temperatures than all other foams considered in this study.

5. Flammability Characteristics - This is the property value in which the organic foams are most generally deficient for construction uses at present. While progress has been made in reducing the flame spread values of organic foams, this has been done at the expense of increasing the smoke density properties to a range which is not acceptable by most code agencies. The urethane foams can be made self-extinguishing by formulation with special resins and additives, but whether the flame spread value thus obtained is satisfactory has not been established. To date not a single urethane foam has been listed by Underwriter's Laboratory. It is understood by the author that the flammability characteristics of the special self-extinguishing polystyrene foams is marginal after aging. Several styrene based foams have qualified for a U.L. label (flame spread). This label is qualified for use in thickness of one inch or less. Polystyrene foams have smoke densities in excess of 300 and thus are not accepted by many code groups. In view of the history of development of organic foams during the past few years it does not seem unreasonable to forecase improvement in the flammability characteristics of cellular plastics. How soon improvements may appear and how significant they will be is impossible to predict.

D. Projections of Future Developments in Cellular Materials of Construction

Increased market acceptance of cellular materials, refinements in processing of raw materials, advancement of application techniques, design of more reliable and more functional equipment will permit a continuation of a general downward trend in the cost of foam insulations. However, major penetration of cellular plastics into the areas governed by such factors as building codes and specifications set by underwriting agencies will not become a reality until the flammability characteristics are improved to meet the severe requirements regarding propagation of flame spread, smoke density, fuel contribution, and fire endurance properties.

It is the author's opinion that composites based on extension of present systems with inorganic, non-burning fillers must be developed using the cellular materials only as binders before this new class of materials are accepted as specified

building components. Once the necessary physical requirements have been met it will be necessary for the cellular plastics industry to develop standards and a method or system, such as an independent testing facility, to certify and award a seal of approval to materials which qualify for service under these standards.

The final and perhaps most important factor which will determine the specification of cellular materials will be the development and dissemination of engineering data to architects, builders, and others responsible for design and specifications of new applications.

PROPERTIES OF COMMERCIALLY AVAILABLE INSULATING MATERIALS

Polyurethane Foams

Manufacturer / Trade name	Typical foams selected		
Physical Characteristics	**Slab Stock***	**Foam-in-Place**	**Spray Applied**
Physical Properties			
Density (p.c.f.)	1.5 - 2.0	2.25	1.8 - 2.0
Compressive strength (p.s.i. yield)	25 - 50	25	20 - 48
Compressive modulus (p.s.i.)	750 - 1000	700	430
Flexural strength (p.s.i.)	40 - 60	40 - 60	40
Flexural modulus (p.s.i.)	40 - 60	---	---
Shear strength (p.s.i.)	20 - 30	37	29
Shear modulus (p.s.i.)	350 - 500	420	300
Tensile strength (p.s.i.)	15 - 70	54	50
Thermal Properties			
"K"-factor ($70^{o}F$) unaged	.110	.110	.140
aged cut	.165	.130	.170
Coefficient of expansion	3.0×10^{-5}	3.5×10^{-5}	4.0×10^{-5}
Service temperature limit	$+250^{o}F$	$+250^{o}F$	$+180^{o}F$
Water Resistance Properties			
Capillarity	none	none	none
Water absorption (% vol. 1" head of water 20 weeks)	less 2%	less 2%	less 2%
Water vapor transmission (perm-inches)	less 2.5	less 1.8	less 1.9

Polyurethane Foams (cont'd)

Physical Characteristics	Slab Stock*	Foam-in-Place	Spray Applied
Flammability Characteristics (U.L. Tunnel Test-Unofficial)			
Flame spread	35	---	---
Smoke density	+400	---	---
Fuel contributed	10w	---	---

Electrical Properties (2.0 p.c.f.)

Frequency cps	Dielectric Constant	Dissipation Factor
10^3	1.06	0.0003
10^4	1.06	0.0005
10^5	1.06	0.0009
10^9	1.04	0.0013

Economics

Foam Costs (1960 - 1965)

Density (p.c.f.) 2.0

Type of Foam	$/Bd. Ft. 1960	$/Bd. Ft. 1965
Urethane Foam (sprayed) purchased prepolymer	.230	.130
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Urethane Foam (sprayed) manufactured prepolymer	.145	.110
Urethane Foam (slab stock)	.145	.105
Urethane Foam (poured) manufactured prepolymer	.105	.080

*Hetrofoam 250, a self-extinguishing rigid urethane foam based on a chlorinated polyester polyol and a polymeric isocyanate.

Expandable Polystyrene

Manufacturer Dow Chemical Company

Trade Name Pelaspan

Physical Characteristics

Physical Properties		
Density (p.c.f.)	1.0	2.0
Compressive strength (p.s.i. at 5% defl.)	10.0	23.0
Tensile strength (p.s.i.)	---	40.0
Flexural strength (p.s.i.)	32.0	60.0
Thermal properties (mean 70°F)	.240	.240
Coefficient of expansion	4.0×10^{-5}	4.0×10^{-5}
Resistance to Heat		
Maximum service temperature	120°F	170°F
Water Resistance Properties		
Capillarity	none	none
Water absorption (volume - 10 foot head, 48 hours)	less 1%	less 1%
Water vapor transmission (perm-inches)	2.0	0.5
Flammability Characteristics (U.L. Tunnel Test - 2.0 p.c.f.)		
Flame spread 1" thick	---	10
Flame spread 2" thick	---	40-80
Smoke density	---	greater 400
Fuel contribution	---	low

Expandable Polystyrene (cont'd)

Electrical Properties

Dielectric constant	---	1.030
Dissipation factor	---	0.0007

Economics

Foam Costs (1960 - 1965)

Density (p.c.f.) 2.0

Type of Foam	$/Bd.Ft. 1960	$/Bd.Ft. 1965
Styrene Bead Foam purchased beads	.075	.075
Styrene Bead Foam manufactured beads	.048	.048

Expanded Polystyrene Foam

Manufacturer Dow Chemical Corporation

Trade Name Styrofoam

Physical Characteristics

Physical Properties	Styrofoam 22	Styrofoam 33	Styrofoam HD-1
Density (lb/cu.ft.)	1.6 - 2.0	1.7 - 2.3	2.8 - 3.2
Compressive strength (yield p.s.i.)	16 - 32	16 - 38	50 - 80
Tensile strength (p.s.i.)	45 - 61	65 - 95	95 - 115
Shear strength (p.s.i.)	27 - 36	30 - 40	53 - 62
Flexural strength (p.s.i.)	42 - 61	48 - 99	70 - 90
Compressive modulus (p.s.i.)	1200-1700	1500-2000	2750-3350
Bending modulus (p.s.i.)	1000-1285	1250-1760	1850-2150
Shear modulus (p.s.i.)	700 -1600	1000-1300	1600-2000
Thermal Properties			
"K"-factor (40°F)	.280	.280	.280
Coefficient of expansion (in/in/F.) 0°F - 80°F	3×10^{-5}	3×10^{-5}	3×10^{-5}
Specific heat (B.T.U./lb/F.) at 40°F	0.27	0.27	0.27
Resistance to heat (maximum service temp.)	170°F	160°F	170°F
Water Resistance Properties			
Capillarity	none	none	none
Water absorption (volume 90°F, 90% R.H.-15 days)	less .03%	less .03%	less .03%
Vapor Transmission			
Perm-inches (frains/hr/sq/Hg)	1.0 - 2.0	1.0 - 2.0	less 1.5

Expanded Polystyrene Foam (cont'd)

Flammability Characteristics

Burning rate (1" thick) U.L.	tunnel test rating 10
(2" thick) U.L.	tunnel test rating 40 - 80
Smoke density	greater than 400
Fuel contribution	low

Economics

Foam Costs (1960 - 1965)

Density (p.c.f.) 2.0

Type of Foam	$/Bd.Ft. 1960	$/Bd.Ft. 1965
Styrene extruded foam	.060	.060

Polyethylene Foam

Manufacturer	Dow Chemical Company
Trade Name	Ethafoam

Physical Characteristics

Physical Properties

Density (p.c.f.)	1.8 - 2.2
Compressive strength (p.s.i.-10% def.)	8
Tensile strength (p.s.i.)	20 - 30

Thermal Properties

"K"-factor (mean 70°F)	.350
Service temperature range	-120°F - 160°F

Water Resistance Properties

Water absorption (1% volume)	
submerged 1 day	less 1%
submerged 48 days	less 4%
Water vapor transmission rate (perm-inches)	
without surface skin	less than .40
with surface skin	less than .40

Flammability Characteristics

Burning Rate (ASTM D-1692-59T)	2.5 in/min

Electrical Properties

Dielectric constant (10^9 c.p.s.)	1.05
Dissipation factor (10^9 c.p.s.)	0.0002

Economics

Foam Costs (1960 - 1965)

Density (p.c.f.) 2.0

Type of Foam	$/Bd.Ft. 1960	$/Bd.Ft. 1965
Polyethylene flexible foam	.220	.200

Urea-Formaldehyde Foam

Manufacturer Barrett Division, Allied Chemical Corp.

Trade Name Barrett Insulation Foam 404

Physical Characteristics

Physical Properties	404 Foam
Density (p.c.f.)	.35 - .70
Compressive strength	not reported, very friable
Tensile strength	not reported
Elongation	not reported, very friable

Note: Urea-formaldehyde foam is used as a low cost, low density bulk filler.

Thermal Properties	
"K"-factor (75°K)	.240

Water Resistance	
Capillarity	not reported
Water absorption	not reported (will not retain its properties if allowed to come into contact with liquid water)

Vapor Transmission	
Perm-inches (grains/hr/sq. ft./1 in./Hg)	greater than 50

Flammability Characteristics	
ASTM D-1692-59T	self-extinguishing (foam melts away from flame)

Economics

Foam Costs (1960 - 1965)

Density (p.c.f.) 0.35 - .70

Type of Foam	$/Bd.Ft.* 1960	1965
Urea-formaldehyde foam (poured-in-place)	----	0.016-0.030

*Includes application labor

Foamed Glass

Manufacturer Pittsburgh Corning Corporation

Trade Name Foamglas

Physical Characateistics

Physical Properties	Foamglas
Density (lbs/cu.ft.)	9.0
Compressive strength (ult.)(p.s.i.)	100
Shear strength (p.s.i.)	40
Flexural strength (p.s.i.)	75
Thermal Properties	
"K"-factor (50°F)	.380
(75°F)	.400
Coefficient of expansion (in/in/F)	4.6×10^{-6}
Specific heat (B.T.U./lb./F)	.20
Water Resistance Properties	
Capillarity	none
Water Absorption (C-240-61)	0.2% by volume
Hygroscopicity (24g days in air 90% RH)	no weight increase
Vapor Transmission	
Perm-inches (grains/hr/sq.ft./1"/Hg.)	0.0
Flammability Characteristics	
Burning rate	will not burn
Smoke density	N.A.
Fuel contribution	N.A.

Economics

Foam Costs (1960 - 1965)

		$/Bd.Ft. 1960	$/Bd.Ft. 1965
Density (p.c.f.)	9.0		
Foamglas blocks		.143	.143

Fibrous Glass Insulation

Manufacturer Owens-Corning Fiberglas Corporation

Trade Name Fiberglas

Physical Characteristics	PF 615	PF 612	PF 338
Physical Properties			
Density (p.c.f.)	6.0	2.5	1.5
Compressive strength (p.s.i. 5% defl.)	1.4	flexible materials	
Flexural strength (p.s.i.)	---	---	---
Thermal Properties			
"K"-factor (mean 75°F)	.240	.260	.227
Service temperature range	-120-400°F	-120-400°F	OF-250°F
Water Resistance Properties			
Water absorption (%)	high	high	high
Water vapor permeability (perm-inches)	high	high	high
Flammability Characteristics			
(U.L. Tunnel Test)			
Flame spread	10-15	---	---
Fuel contribution	25-30	---	---
Smoke density	0-5		
Misc. Properties			
Dimensional stability	good	good	good
Chemical resistance	excellent	excellent	excellent
Noise reduction coef.	0.6-0.8	---	---

Economics

Foam Costs (1960 - 1965)

Density (p.c.f.) 1.5 - 6.0

	$/Bd.Ft. 1960	$/Bd.Ft. 1965
Fibrous glass (1.5 p.c.f.)	.093	.080
Fibrous glass (2.5 p.c.f.)	.031	.031
Fibrous glass (6.0 p.c.f.)	.082	.075

Epxoy Foam

Manufacturer Shell Chemical Company

Trade Name Epon-Foam Spray 175

Physical Characteristics

Physical Properties	Epon-Foam 175
Density (p.s.i.)	1.8 - 2.0
Compressive strength (p.s.i.)	13 - 17
Tensile strength (p.s.i.)	26 - 31
Elongation % (77°F)	34 - 44
Thermal Properties	
"K"-factor (75°F)	.11-.12 (initial) .16-.17 (aged)
Coefficient of expansion (cm/cm/C)	15×10^{-6}
Heat stability	300°F
Water Resistance Properties	
Water absorption (lbs/sq.ft.)	0.03 - 0.05
Vapor Transmission	
Perm-inches (grains/hr/sq.ft/1"/Hg)	0.9 - 1.2
Flammability Characteristics	
Burning rate	not reported
Smoke density	not reported
Fuel contribution	not reported

Economics - Price information is not available as most epoxy foams are still in the product development phase. Shell Chemical Company has recently withdrawn their foam from the market.

Japanese Isocyanate and Urethane Foam Production

1. Japanese Ministry of International Trade and Industry Reports.

2. Information Received from Masoya Nisheda
   Chief Technical Section
   Organic Cehmical Department
   Mitsubishi Chemical Ind. Ltd.
   Kurosohi Plant

Japanese Production of Foam Raw Materials

Toluene Diisocyanate (MM Lbs.)

	Nippon Polyurethane	Mitsui	Takeda	Mitsubishi	Nippon Soda	Sumitowa	Total
1963	12.0	8.0	6.7	2.0	3.9	-	32.6
1964	16.0	9.6	10.7	4.0	6.7	5.3	53.3
1965	24.0	16.0	16.0	10.7	6.7	8.0	81.4

Technical Background

Bayer Dupont Allied Self developed ---

Polypropylene Glycol (MM Lbs.)

	Asahi Denka	Dainihon Ink	Sanyo	Mitsui	Nippon Soda	Nippon Yushi	Takeda	Daiichi	Total
1963	10.7	53.0	21.0	27.0	12.0	16.0	--	8.0	101.0
1964	14.7	16.0	21.0	42.0	8.7	16.0	12.0	16.0	153.0

Polyurethane Supply - Demand Balance in Japan*

TDI Demand (MM Lbs.)

	Flexible Foam	Rigid Foam	Other	Total
1963	23.4	0.3	0.09	23.8
1964	34.6	0.7	0.13	35.5
1965	48.5	1.1	0.18	45.7
1966	47.0	1.7	0.29	48.7
1967	53.7	2.6	0.44	56.5

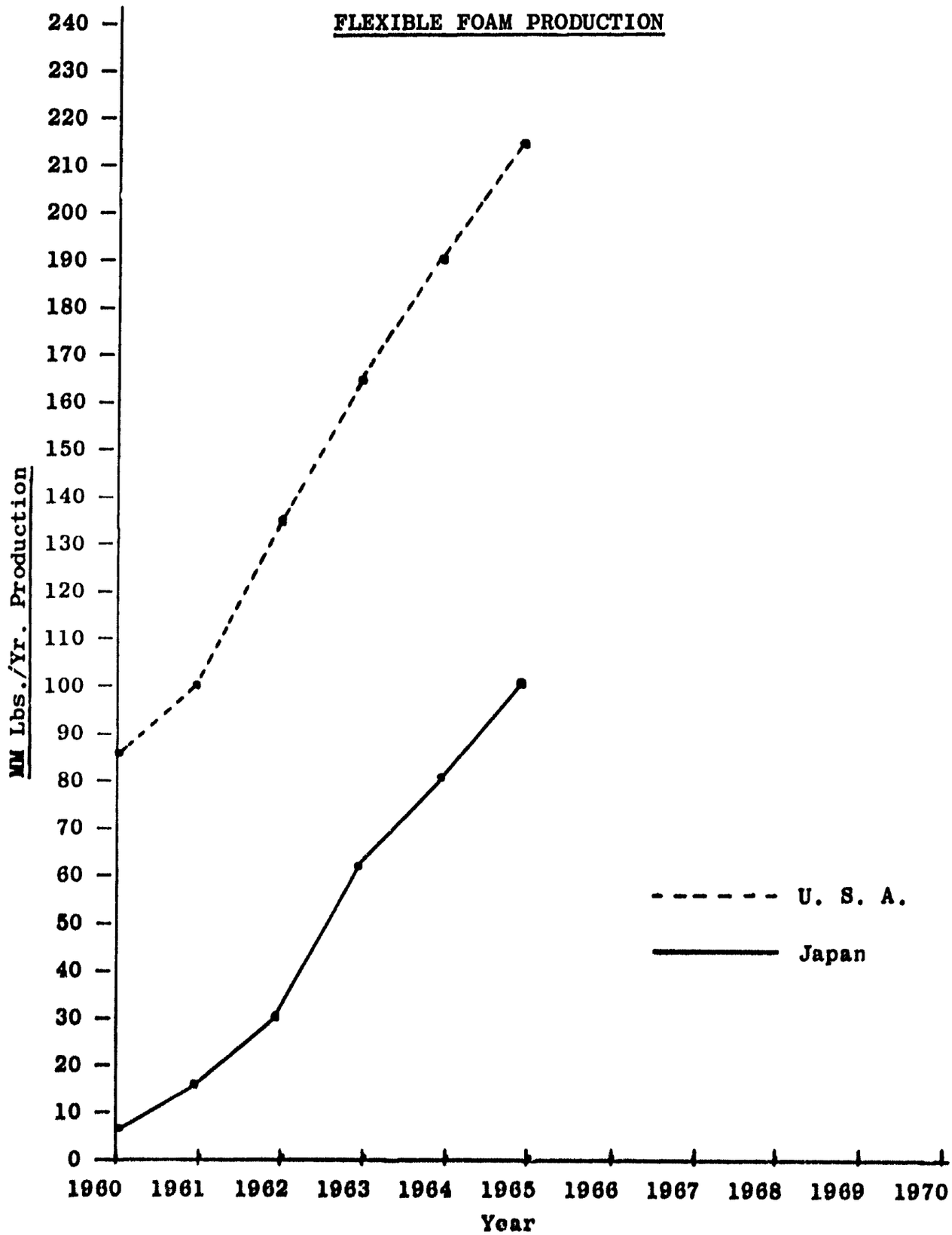
TDI Supply (MM Lbs.)

	Production Capacity	Production Rate
1963	32.6	72
1964	52.0	68
1965	81.4	56
1966	81.4	60
1967	81.4	70

* Japanese Ministry of International Trade and Industry

Japanese Polyurethane Foam Production (1963)

Bayer Facilities	MM Lbs.
MTP Chemical Industries	14.7
B. S. Tire Industries	20.0
Yokohama Tire Industries	10.7
Toyo Rubber Chemical Industries	8.0
DuPont Facilities	
Toyo Rubber Industries (Gen. Tire)	13.3
Kokoku Urethane Corp. (Philips)	2.6
Kurasiki Fiber Industries (ICI)	5.3
Nisshin Fiber Industries (Mitsui)	1.3
Total Production	84.0


FLEXIBLE FOAM PRODUCTION
MM Lbs./Yr. Production
240
230
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
1960
1961
1962
1963
1964
1965
1966
1967
1968
1969
1970
Year
U. S. A.
Japan

European Isocyanate and Foam Production and Economics

TABLE

European Isocyanate Production

Year	Total Production	Production/Demand Ratio
1963	70,000 tons	Production equals demand
1964		Production 2 x demand

TABLE

Review of Toluene Diisocyanate Prices

1961	$/Lb. TDI
France	0.73
Belgium	0.70
Great Britain	0.63
Italy	0.61
Germany	0.54

1964

Average European price for TDI - $0.45 - $0.50

TABLE

Analysis of European Foam Market

	1963	1964	1965
Flexible Foam Production (tons)	70,000	90,000	Not reported
Rigid Foam Production (tons)	2,000	7,000	21,000

TABLE

Urethane Foam Consumption/Per Capita Basis - 1963

Germany	1.32 lbs.
Scandinavia	0.89 lbs.
Great Britain	0.77 lbs.
France	0.60 lbs.
Italy	0.44 lbs.
Benelux	0.44 lbs.
Spain	0.04 lbs.
Portugal	0.04 lbs.

TABLE

European Application of Flexible Foam - 1963

Market Application	Germany	Great Britain	France	Italy
Automotive	10-15	45	50-60	3
Furniture	40-50	30	30-40	35-45
Bedding	10-15	*	*	45-50
Foam laminates	10-15	5-10	*	*
Miscellaneous (household, packaging, etc.)	20	15-20	10-15	10-15

* Relatively small production, exact figures unknown.

TABLE

Flexible Foam Markets - Europe

Automotive Seating

1964	Predicted total 20-30 metric tons flexible urethane foams
1968	Predicted total 70-80 metric tons flexible urethane foams

Furniture Industry

1965	Predicted penetration - flexible urethane foam 50%
1968	Predicted penetration - flexible urethane foam 65%

TABLE

Flexible Foam - Raw Material Costs

1962	
Germany	4.0¢/Bd.Ft.
Great Britain	4.25¢/Bd.Ft.
France	5.5¢/Bd.Ft.
1964	
Average European Raw Material Cost	3.5¢/Bd.Ft.*

* Flexible Polyether based urethane foam, (1.3 p.c.f., 7% Ccl_3F blowing agent).

TABLE

Western Europe - Total Urethane Foam Production

(Metric Tons)

	1962	1963	1964
West Germany	25,000	30,000	35,000
Great Britain	15,000	19,000	21,000
Italy	6,000	11,000	14,000
France	6,000	10,000	13,000
Benelux	3,600	6,000	8,000
Other Countries	4,400	9,000	12,000
	60,000	85,000	103,000

TABLE

Rigid Foam Markets - Europe

1964	
Predicted market	5 - 7 M metric tons
1965	
Predicted market*	20 M metric tons

* Will not reach projection goals in 1965 because of cost, flammability characteristics, competition of glass wool, styrofoam, etc.

TABLE

European Production of Refrigerators
(Number of Units Built)

	1960	1961	1962	1963
France	1,015,000	970,000	830,000	950,000
Germany	2,400,000	1,970,000	1,700,000	1,300,000
Italy	977,000	1,530,000	1,750,000	2,100,170
Great Britain	1,100,000	200,000	835,000	880,000
	5,492,000	5,320,000	5,115,000	5,230,000

Urethane Foam

Urethane foams are produced as the reaction products of polyisocyanates and polyhydroxyl compounds. The use of catalysts, blowing agents, surfactants, and miscellaneous additives such as pigments, fillers, fire-retardants, etc. are incorporated into the foam formulation in order to obtain desired product modifications.

Polyisocyanates

A variety of polyisocyanates are used for the production of urethane foams. The 80/20 mixture of 2,4 isomer and 2,6 isomer of tolylene diisocyanate is the predominant material used in the production of flexible foam. A variety of crude isocyanates, polymeric isocyanates as well as tolylene diisocyanate (80/20 isomer mixture) are used in the production of rigid foams. Table lists a summary of the U. S. producers of isocyanates together with an estimate of total capacity.

Table presents a summary of isocyanates used in total urethane markets.

A comparison of Tables and will indicate a growing overcapacity for isocyanate materials. This has been the prime factor leading to a continuing downward trend in foam raw materials costs. The more favorable material price structure together with improved application techniques is opening many market applications for cellular plastics.

Considerable difference of opinion exists as to the market potential for cellular materials, thus several sources will be presented. Table indicates the forecast for flexible foam consumption by market areas for the years 1961 through 1966. Table forecasts rigid foam consumption for 1966. Additional market estimates are presented in Tables and .

Polyols

A wide variety of polyfunctional hydroxyl components (polyesters and polyethers) are used in the production of urethane foams. These materials are based on the polyethylene and polypropylene adducts trimethylol propane, glycerine, sorbitol, methylglucoside, sucrose, etc. Table shows the estimate of polyol consumption in the rigid foam market area.

An additional source of information comparing urethane foam raw material capacity vs. consumption for U. S. producers (1963) is presented in Table . The figures for polyols capacity are inherently nebulous, since most companies have production units that can be diverted from making other products as needed.

TABLE

Isocyanates - U.S. Producers and Capacity (MM Lbs)

Company/Plant Location	1960	1961	1962	1963
Mobay	25	40	50+	70
New Martinsville, W.Va.				
DuPont	25	30	50+	70
Deepwater, N.J.				
Allied	10	15	30	30
Moundsville, W.Va.				
Southern California	--	--	--	20
Nopco	--	--	10	10
Linden, N.J.				
Carwin				
North Haven, Conn.	1	3	0.5	0.5
Houston, Texas	--	--	3.0	4.5
Ott	--	--	3.0	3.0
Muskegon, Mich.				
Olin-Mathieson				
Ashtabula, Ohio	--	--	--	25
Brondenburg, Ky.	--	--	--	10
Union Carbide	--	--	--	25
Institute, W. Va.				
TOTAL CAPACITY	61	88	146.5	268
			168	
Estimated Demand			57	87

Note: Kaiser Chemical, Wyandotte Chemicals Corporation, and U. S. Rubber Company have since announced decisions to become producers of isocyanates.

TABLE

U.S. End Use Summary - Isocyanate (MM Lbs)

Foam End Use	1961			1963			1966		
	TDI	MDI	Other	TDI	MDI	Other	TDI	MDI	Other
Flexible Foam	34.0	- -	- -	48.0	- -	- -	69.0	- -	- -
Rigid Foam	8.0	0.1	0.1	19.0	1.2	0.4	44.0	4.0	0.9
Elastomer	0.8	0.9	0.1	1.7	2.4	0.4	2.6	5.8	0.7
Spandex Fibers	0.1	0.3	- -	0.4	1.5	- -	0.7	3.4	- -
Binders	1.2	- -	- -	2.1	- -	- -	3.2	- -	- -
Surface Coatings	2.7	- -	- -	5.8	- -	- -	13.9	- -	- -
Miscellaneous	- -	0.2	0.1	- -	0.2	0.1	- -	0.3	0.2
Sub-Total	46.8	1.5	0.3	77.0	5.3	0.9	133.4	13.5	1.8
Export	8.0	- -	- -	4.0	- -	- -	- -	- -	- -
TOTAL	54.8	1.5	0.3	81.0	5.3	0.9	133.4	13.5	1.8

TABLE [illegible]

Forecasts For Flexible Foam Consumption

Flexible Foams (Total Market)	1961	1966
Furniture Industry		
Rubber latex	49 MM Lbs	80 MM Lbs
Urethane	49 MM Lbs	50 MM Lbs
Vinyl	2 MM Lbs	10 MM Lbs
	100 MM Lbs	140 MM Lbs
Market Breakdown (Flexible Foams)		
Bedding Industry		
Rubber latex	25 MM Lbs	40 MM Lbs
Urethane	10 MM Lbs	60 MM Lbs
Carpet Cushioning		
Rubber latex	-----	10 MM Lbs
Urethane	-----	15 MM Lbs
Chemically-blown sponge rubber	-----	20 MM Lbs
Automotive Seats		
Rubber latex	10 MM Lbs	10 MM Lbs
Urethane	20 MM Lbs	40 MM Lbs
Misc. Automotive Applications (arm rests,		
Rubber latex	-----	5 MM Lbs
Urethanes (flexible)	-----	25 MM Lbs
(rigid)	-----	10 MM Lbs
Chemically-blown sponge rubber	-----	25 MM Lbs
Vinyl	-----	15 MM Lbs
Textile Industry		
Foam/fabric combination (urethane)		15 MM Lbs
Luggage (vinyl)		5 MM Lbs

TABLE

Forecasts For Rigid Foam Consumption

	1966
Building and Construction	
Polystyrene	55 MM Lbs
Urethane	30 MM Lbs
Mobile Homes	
Polystyrene	10 MM Lbs
Urethane	
Low Temperature Applications	
Polystyrene	5 MM Lbs
Urethane	20 MM Lbs
Epoxy	5 MM Lbs
Domestic Refrigerators	
Urethane	35 MM Lbs
Polystyrene	10 MM Lbs
Epoxy	5 MM Lbs
Industrial Insulation	
Urethane	5 MM Lbs
Polystyrene	5 MM Lbs
Epoxy	5 MM Lbs
Chemically-blown sponge rubber	5 MM Lbs
Vinyl	3 MM Lbs
Polyolefins	2 MM Lbs
Wire Insulation	
Vinyl	10 MM Lbs
Polyolefins	20 MM Lbs
Packaging	
Flexible urethane	5 MM Lbs
Rigid urethane	5 MM Lbs
Polyolefins	5 MM Lbs
Polystyrene	15 MM Lbs
Marine Flotation	
Urethane	10 MM Lbs
Polystyrene	7 MM Lbs
Rigid vinyl	4 MM Lbs
Polyolefins	3 MM Lbs
Misc. Applications	
Urethane (flexible)	10 MM Lbs
Urethane (rigid)	5 MM Lbs
Rubber latex	5 MM Lbs
Flexible vinyl	5 MM Lbs
Polystyrene	20 MM Lbs
Rigid vinyl	3 MM Lbs
Chemically-blown sponge rubber	30 MM Lbs
Polyolefins	5 MM Lbs
Epoxy	5 MM Lbs
Silicone	2 MM Lbs

TABLE

Estimate Total Rigid Foam Market (MM Lbs)

Year	60	61	62	63	64	65	70
Appliances	5.0	8.0	15.0	40.0	45.0	50.0	75.0
Disp. cases	.5	1.0	2.0	3.0	4.0	5.0	7.0
Cold storage	2.0	2.0	8.0	10.0	14.0	16.0	25.0
Bldg. trades	1.0	1.0	5.0	9.0	13.0	20.0	500.0
Transportation	.5	1.0	3.0	5.0	6.0	7.0	15.0
Packaging	0	.5	1.0	2.0	5.0	10.0	500.0
Military	1.0	1.0	1.0	1.5	1.5	1.5	2.0
Mining	0	0	1.0	3.0	4.0	5.0	10.0
Misc.	1.0	1.0	6.0	8.0	10.0	10.0	20.0
	11.0	15.5	42.0	81.5	102.5	124.5	1154.0

TABLE

Rigid Urethane Foams and Isocyanates Used Therein

Foam End Use	1961	1963	1966
Refrigeration	5.0	16.0	40.0
Transportation	3.5	8.0	12.0
Construction	2.5	11.0	35.5-36.0
Flotation	2.0	3.0	5.0
Others	3.0	5.0	10.0
Total Rigid Foam	16.0	43.0	102 - 103
Isocyanates			
Used	6.1	16.8	40.8
Scrap, Experimental, Inventory	2.1	3.8	8.1
Total Isocyanates	8.2	20.6	48.9
TDI Types	8.0	19.0	44.0
MDI & Others	0.2	1.6	4.9

TABLE

Estimate of Polyol Consumption - Rigid Urethane Foam Markets (MM Lbs. Polyether/Polyester)

	1959	1960	1961	1963	1965
Refrigerators	1.3	1.5	2.1	18.0	23.0
Industrial Insulation	0.5	1.0	2.2	5.4	9.0
Building and Construction	- -	0.4	1.0	6.0	14.0
Transportation	0.2	0.5	1.0	3.5	6.5
Miscellaneous	0.9	1.1	1.2	1.7	3.0
Total	2.9	4.5	7.5	34.6	55.5

One company, for example, could increase its polyols capacity by a factor of four or five, if market conditions warrented diversion of certain plant equipment from production of other materials.

A summary of urethane foam raw materials capacity vs. consumption for Europe and Japan (1963) is presented in Table .

A projection of total urethane industry statistics (worldwide estimate) for the year 1965 is presented in Table .

A summary of total capital investment in the worldwide urethane industry is presented in Table .

The major components of urethane foam systems, based on total volume, would be polyol, isocyanate, and blowing agent. Other raw materials such as catalyst, surfactant, flame-retardants, pigments, etc., are used in limited quantities in foam formulation. A projection of current vs. 1965 raw materials costs is shown in Table .

The reactions by which foams are produced can be carried out in a single stage or in a sequence. Three methods are available:

1) In the "one-shot" method, all the ingredients (polyol, blowing agent, isocyanate, and catalyst) are mixed simultaneously, and the resulting mixture is allowed to foam.

2) In the "prepolymer" method (batch-mix or continuous), the polyol and isocyanate are reacted to yield a prepolymer, and the catalyst is subsequently mixed into the prepolymer to effect foaming.

TABLE

Urethane Raw Materials - Capacity vs Consumption

(U.S. Producers)

Company	1963 Capacity-Millions of Pounds Polyol	Isocyanate
Allied	20	30
Atlas	35	- -
Carbide	120	30
Carwin	- -	7
Dow	60	- -
Du Pont	- -	70
Jefferson	20	- -
Olin	25	35
Ott	- -	3
Nopco	- -	10
Mobay	- -	70
Witco	20	--
Wyandotte	90	--
Others	10	--
Total Capacity	390	255
Total Consumption (approximate)	80	120

TABLE

Urethane Raw Materials - Capacity vs Consumption

(Europe and Japan)

European Producers Company	1963 Capacity-Millions of Pounds Polyol	Isocyanate
Bayer	40	35
Carbide, U.K.	10	-
Carbochemique	25	-
Celene	20	-
Dokachimie	-	12
Dow	15	-
Du Pont	-	22
ICI	20	20
Kuhlmann	20	-
Lankro	20	-
Naphtachimie	20	-
PBU	20	26
Pfizer	10	-
Tolochimie	-	13
Total Capacity	220	128
Japanese Producers		
Mitsubishi	8	4
Mitsui	8	5
Nippon P.I.	6	8
Nippon Soda	8	4
Sumitomo	-	8
Takeda	8	3
Others	4	4
Total Capacity	42	36
Total Consumption	60	130

TABLE

1965 Urethane Industry: Raw Materials, Foam Producers, % of Capacity

1965	Raw Mat'ls Capacity MM/lb	All Foams Est.Use, MM/lb	% of Chem. Capacity	Number of Foamers, Flexible Only*	Median Output per Foamer(lb.)	Est.% of Capacity
North America	700	300	43	40	3,000,000	25
Europe	348	225	70	90	1,000,000	50
Asia	78	31	40	16	550,000	20
Oceania	--	14	--	11	500,000	25
South America	--	10	--	16	300,000	10
Africa	--	3	--	3	1,000,000	50
Soviet bloc	--	10+	--	5	2,000,000	?
TOTALS	1126	593+	52**	181	800,000**	33**

* Number of semirigid and rigid foamers difficult to predict, due to the largely captive nature of the business.

** Not additive

TABLE [illegible]

Total Capital Investment Since 1937 Runs High in Urethane Industry

Estimated Capital Costs from 1937 to 1963 (millions of dollars)

	Raw Material Producers			Foam Producers			Total	
Area	Development	Plant + Working Capital	Revenue	Development	Plant + Working Capital	Revenue	Capital	Revenue
North America	$30	$220	$85	$15	$95	$175	$360	$175
Europe	12	155	77	5	92	164	264	164
Asia	3	30	7	2	9	16	44	16
Oceania			3	1	5	12	6	12
Other			4	1	16	11	17	11
World Totals	$45	$405	$176	$24	$217	$378	$691	$378

TABLE

Prices of Urethane Foam Raw Materials

Material	Price, May 1964 $/lb	Future Price (1965) $/lb
Tolylene Diisocyanate (Bulk)	0.60	0.48
Crude Tolylene Diisocyanate (Bulk) (National Aniline 4040)	0.51	0.40
Polymeric Isocyanate (Bulk)		
(Mobay MR)	0.51	0.38
(Carwin PAPI)	0.51	0.38
Polypropylene Ether Polyols (Bulk) for - Rigid Foams	0.28-0.35	0.24-0.31
Polyester Resins (Bulk) for - Rigid Foams	0.50-0.60	0.48-0.56
Amine Catalysts (Drum)	2.00-7.50	2.50-7.00
Organotin Catalysts (Drum)	1.75-2.00	1.50
Silicone Oils (Drum)	2.50	2.00
Flurocarbon Blowing Agents (Bulk)	0.206	0.200

TABLE

Typical One-Shot Formulation (May 1964)

	Wt %	$/Lb	$/Lb-Material
Component A			
Crude TDI	40.4	.510	.206
Component B			
Sorbitol Polyol	42.0	.290	.122
Flurocarbon-11	16.0	.206	.033
Silicone Oil	0.5	2.500	.013
DMEA	0.5	1.500	.001
Tin Catalyst	0.6	1.69	.001
	100.0%		.376
2% Process Loss			.008
			.384

3) The "quasi-prepolymer" method is a combination of the two methods previously mentioned. The polyol vehicle is reacted with diisocyanate to form one component, additional polyol, catalyst, surfactant, and blowing agent are mixed to form the second component. The two components are then blended with desired agitation to initiate foaming.

The present and future economics of a typical one-shot formulation based on crude tolylene diisocyanate and a sorbitol polyol are compared in Tables and .

The economics of a typical quasi-prepolymer system is presented for comparison purposes. The following calculations are used to develop the assumed foam formulation based on a total NCO/OH ratio of 1.05/1.0.

Calculations:

Component A

Sorbitol prepolymer

Polyol properties

OH No. = 496

Acid No. = 0.5

H_2O = 0.1% max.

Equivalent weight resin

$$E\ resin = \frac{56.1 \times 1000}{OH\ w + Acid\ No.}$$

$$E\ resin = \frac{56000}{496.5} = 112.8$$

Equivalent weight of TDI = 87

Polymer NCO/OH = 4.5/1.0

$$\text{thus, } \frac{100\ g\ resin}{112.8\ g/eq.} = .887\ eq.\ resin$$

$$\text{for } \frac{NCO/OH + 4.5/1.0}{(4.5)(.887)(87)} = 347.3\ g\ TDI$$

Note: Compensation for H_2O in polyol

$$100\ g \times .001 = 0.1\ g\ H_2O$$

$$\frac{.1\ g}{9\ g/eq.} = .01\ eq.\ H_2O$$

$$87 \times .01 = .87\ g\ TDI$$

hence 348.2 g TDI
100.0 g Polyol Prepolymer

The economics of a typical quasi-prepolymer system is presented for comparison purposes. Table presents the economics of this system based on May 1964 raw material prices, while Table presents the economics of this system based on future raw material prices.

TABLE

Economics of a Typical Quasi-Prepolymer System (May 1964)

Component A	Wt %	$/Lb	$/Lb-Material
Tolylene diisocyanate	77.69	.56	.435
Sorbitol polyol	22.31	.29	.065
	100.00		.050
2% Process Loss			.010
			.510
Component B			
Sorbitol polyol	65.6	0.290	.190
Flurocarbon-11	32.3	0.206	.067
Silicone oil	0.9	2.500	.023
TMBDA	0.4	3.000	.012
Triethylene diamine	0.4	6.950	.028
TMG	0.4	3.000	.012
	100.0		.332

System Cost (NCO/OH = 1.5/1.0)

100 g Component B = 65.6 g polyol

$$\frac{65.6\ g}{112.8\ g/eq} = .582\ eq.$$

$$4.5 = (1.05)(x)$$

$$x = 4.29 \text{ OH equivalents}$$

$$\frac{100}{.582} = \frac{x}{4.29}$$

$$x = 737.1 \text{ g Component B}$$

System	Weight	Wt %	$/Lb	$/Lb-Material
Component A	448.2	37.70	.510	.192
Component B	737.1	62.30	.332	.206
	1185.3	100.00		.398

Polystyrene Foam Economics

There are two bead manufacturing processes: 1) the conventional batch process developed by Badische, Anilin, and Soda Fabrik (BASF), and 2) a new continuous extrusion process developed by

TABLE

Economics of a Typical Quasi-Prepolymer System (Future)

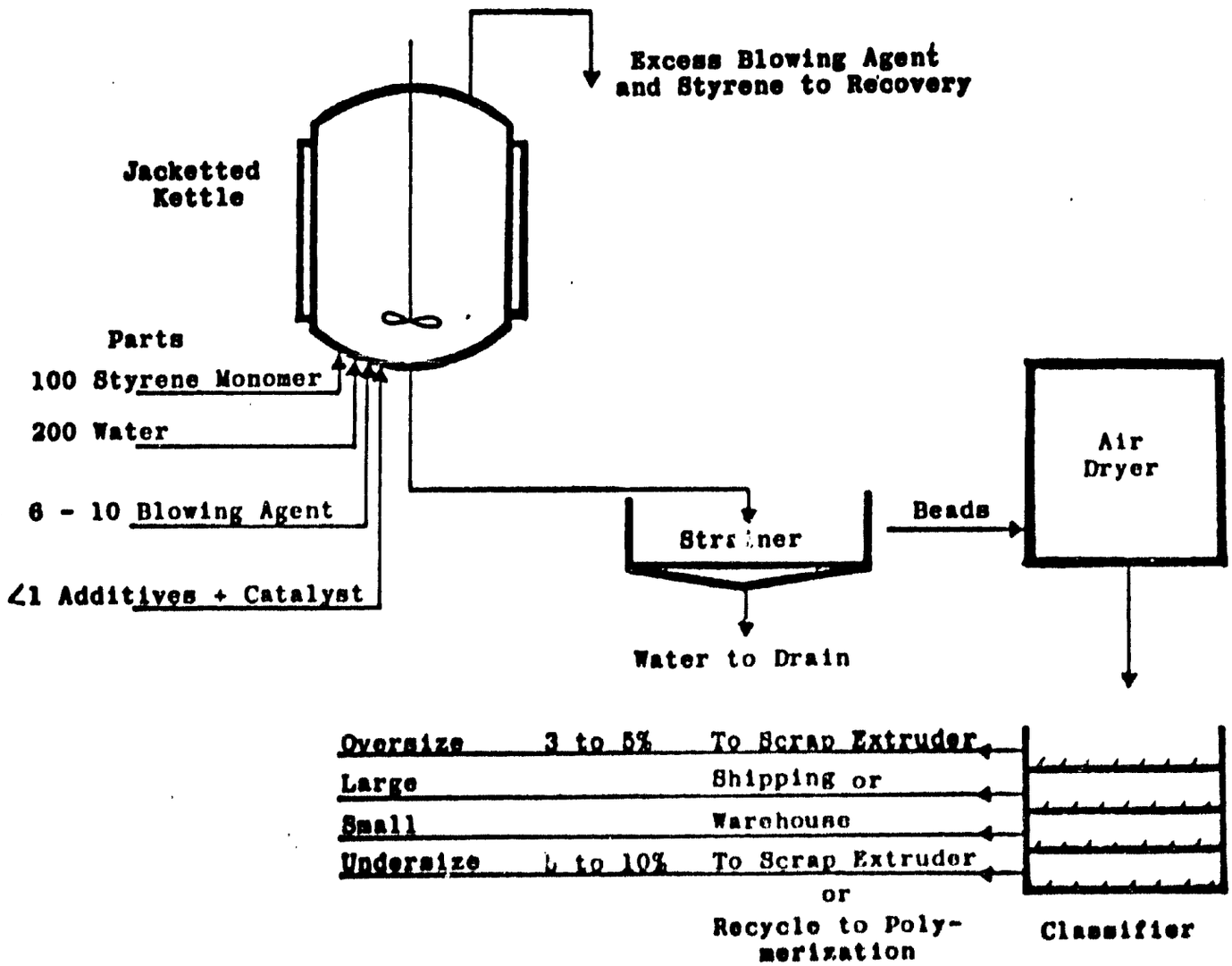
	Wt %	$/Lb	$/Lb-Material
Component A			
TDI	77.69	.40	.311
Polyol	22.31	.23	.051
	100.00		.362
2% Process Loss			.007
			.369
Component B			
Sorbitol Polyol	65.6	.230	.151
Flurocarbon-11	32.3	.200	.065
Silicone oil	0.9	2.000	.018
TMBDA	0.4	2.500	.010
Triethylene diamine	0.4	5.000	.020
TMG	0.4	2.500	.010
	100.0		.274
System Cost			
Component A	37.70	.369	.139
	62.30	.274	.172
	100.00		.311

Dow. It is understood that the total cost of manufacturing beads (excluding royalties) is about the same by the extrusion process as it is by the BASF process, but capital costs for the extrusion process per unit capacity is about 1.3 times that for the BASF process. The extrusion process would therefore appear to lead to a lower return on investment.

BASF Batch Process (Bead Manufacture)

This is a batch process in which styrene monomer is charged to jacketed kettles of 500 to 1000 gallons capacity with blowing agents, catalyst, and additives. Water is charged to the kettle, it is sealed, and the mixture is agitated at a constant temperature of about 100°C. After four hours, the temperature is reduced to 40°C, the pressure released, and the water-bead mixture discharged to strainers. After drying, the beads are classified and off-sizes cycled to a scrap extruder. There is a raw material loss of about 5% in the form of scrap.

EXPANDABLE STYRENE BEAD MANUFACTURING FLOW DIAGRAM:
BASF BATCH PROCESS



Figure

Dow Process (Bead Manufacture)

In the Dow extrusion process the starting material is polystyrene rather than monomer. Polystyrene, additives, and blowing agents are charged to an extruder. From the extruder, the blend passes to a mixer-cooler. The mix is then passed through a cutter, and the resulting beads are then conditioned in hot water to relax them.

Manufacture of Bead Foam Board

In the manufacture of bead foam board, the beads are pre-expanded and then allowed to relax and cool for some time before being charged to block mold. Blocks as large 12' x 4' x 24' have been molded by this process. After expansion in the mold, the foam blocks are allowed to cure, usually exposed to weather, for four to eight days. Most fabricators cut the blocks to shape by means of a hot wire to reduce dusting.

Expanded Polystyrene Foam

The Dow Process involves the continuous production of buns by injecting a volatile liquid, such as methyl chloride, into the polymer melt which is being forced through an extruder. As the mixture of polystyrene and volatile liquid, which must be only partially soluble in the polystyrene melt, emerge from the orifice of the extruder, the melt expands upon release of pressure and cools rapidly (because of expansion) to produce a low density cellular product.

An estimate of styrene monomer capacity (1961) is presented in Table .

TABLE

Styrene Monomer Capacity

Process	Capacity MM lbs.
Ethylene Process*	
Dow Chemical	800
Foster Grant	150
Koppers Chemical	175
Monstant Chemical	560
Odessa Styrene	40
Shell Chemical	210
Union Carbide	110
Koppers - Sinclair Oil	70
Ethylene Benzene Process**	
Cosden Petroleum	60
Sunray Chemical	60
	2235

* Synthesize the styrene from benzene and ethylene

** Removes ethyl benzene intermediate by fractional distillation from catalystic reforming system.

EXPANDABLE STYRENE BEAD MANUFACTURING FLOW DIAGRAM:
DOW'S EXTRUSION PROCESS

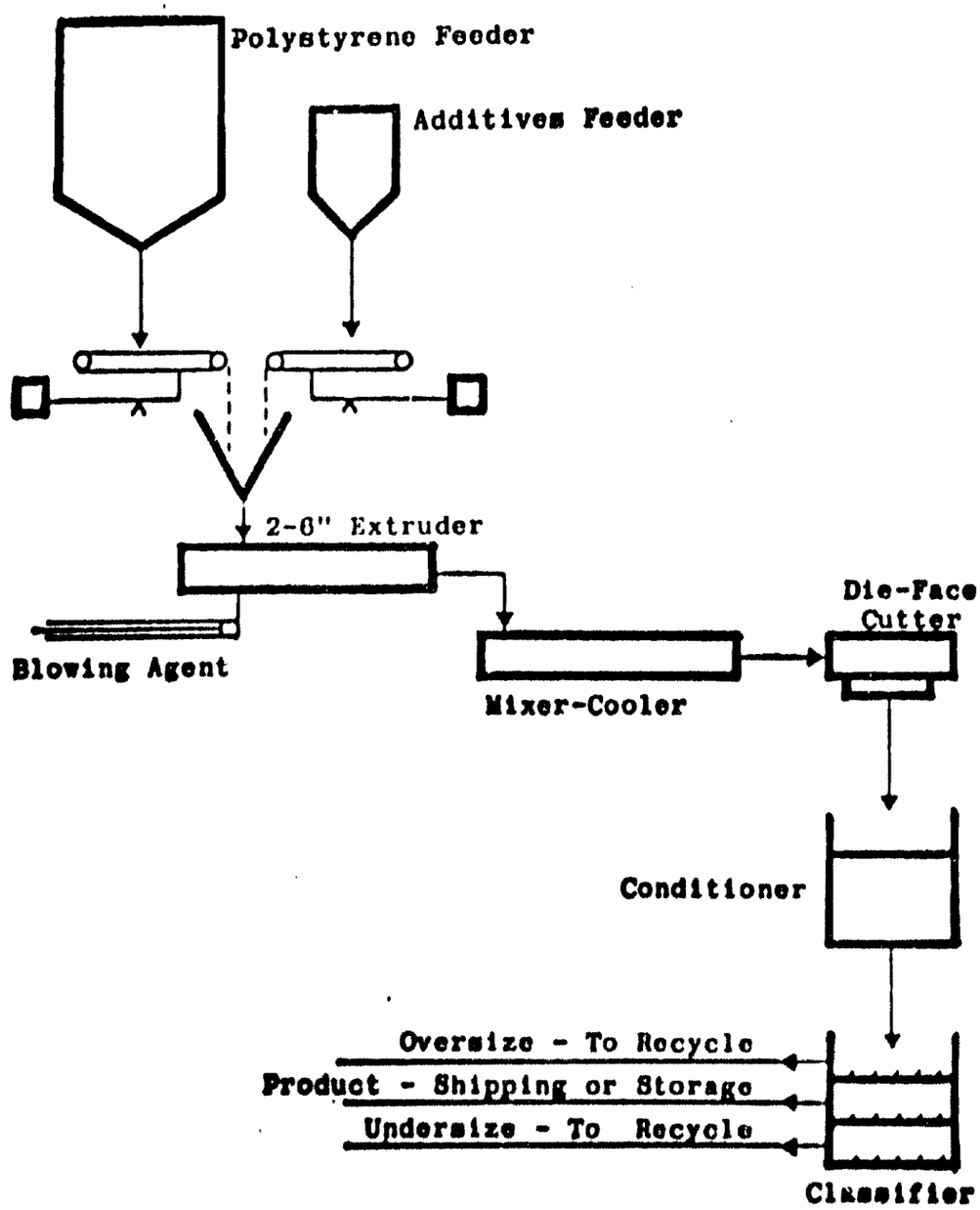
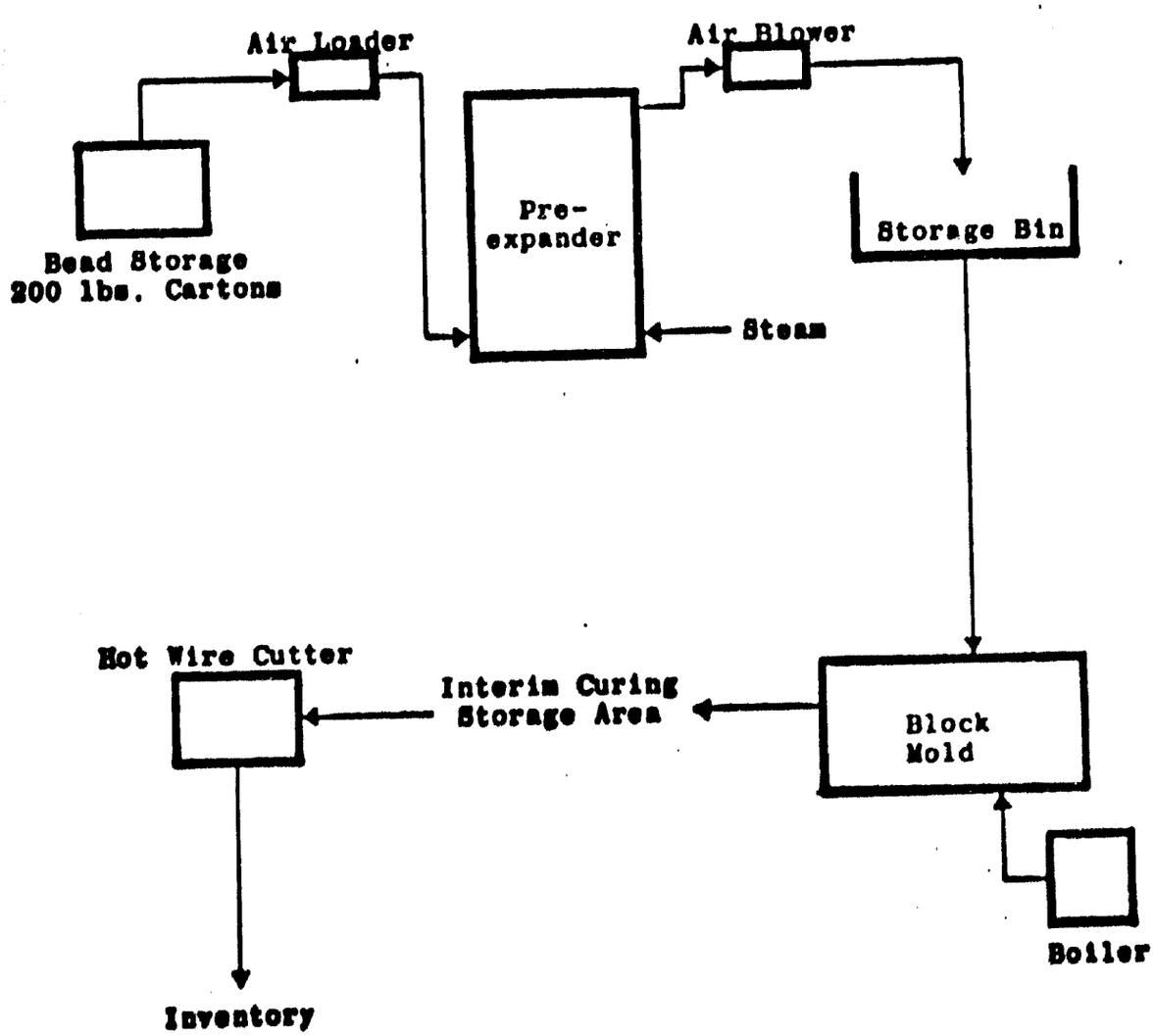


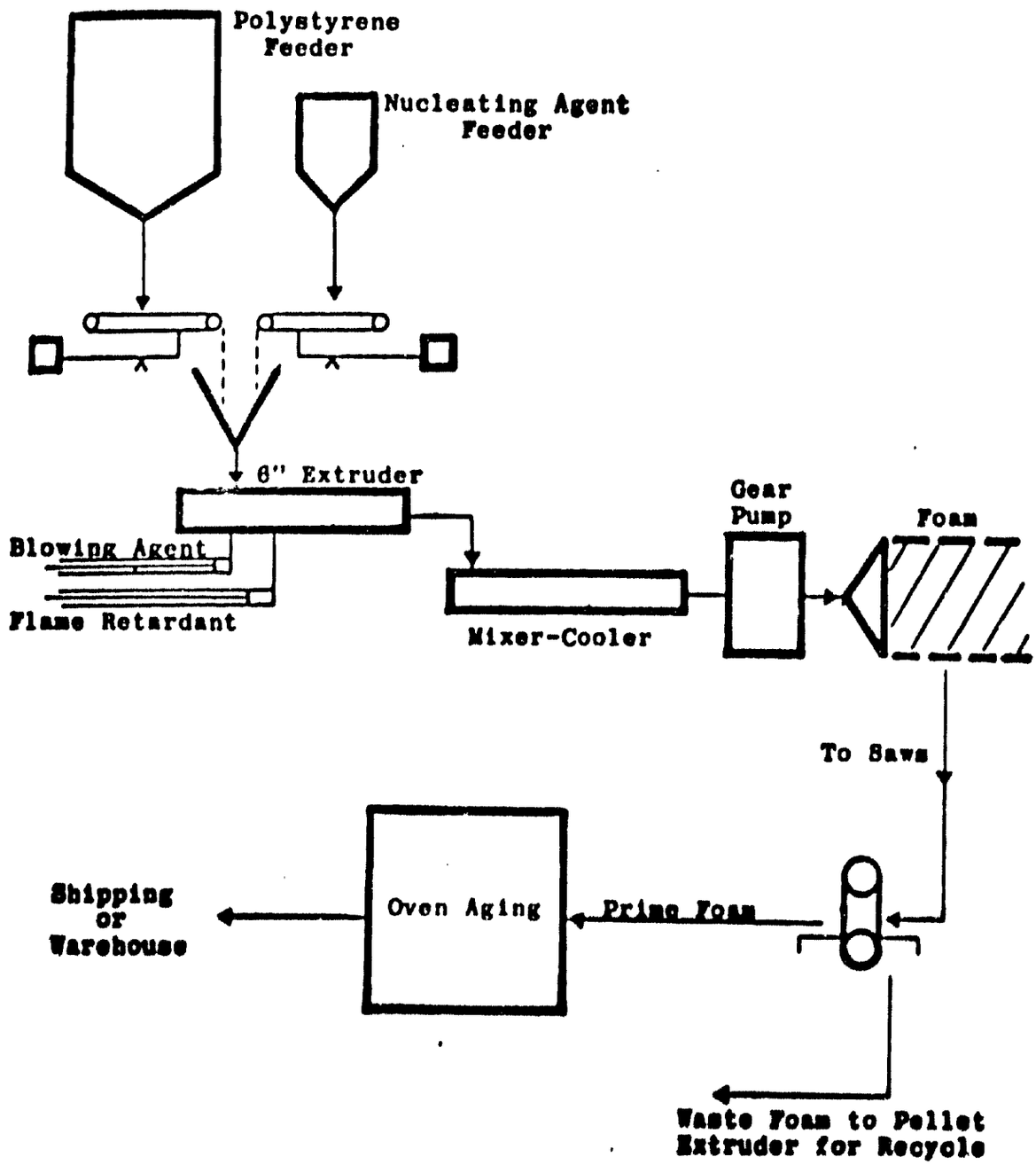
Figure 1

EXPANDABLE STYRENE BEAD FOAM MANUFACTURING FLOW DIAGRAM



Figure

EXTRUDED POLYSTYRENE FOAM MANUFACTURING FLOW DIAGRAM
"Styrofoam"



Figure

Economics of Styrene Monomer and Polystyrene (1961 figures)

A styrene monomer facility possessing a plant capacity of 75 million pounds/year could produce this product for 10.04¢/pound. The 1961 average cost selling price for styrene monomer was 12.00¢/pound resulting in an approximate 6.1% return on investment after taxes.

A polystyrene facility possessing a plant capacity of 50 million pounds/year could produce this product for 17.2¢/pound. The 1961 average cost selling price for polystyrene was 21.00¢/pound resulting in an approximate 6.7% return on investment after taxes.

Economics of Styrene Bead Production (1961)

An expandable styrene bead manufacturing plant (BASF Batch Process) possessing a plant capacity of 400/pounds/hour could produce this product for an estimated total manufacturing cost of .200-.244 pound.

Economic Aspects - Polystyrene Bead Foam

A summary of the economics of polystyrene bead foam manufacture is presented in Table .

TABLE

Economics of Polystyrene Bead Foam Production

	Purchased Beads (37¢/lb)	Manufactured Beads (22¢/lb)
Poundage Sales	515,000	515,000
Board Foot Sales (1.2 pcf)	6.15 MM	6.15 MM
Total Cost of Product Sold	4.83¢/Bd.Ft.	3.55¢/Bd.Ft.
Sales Price/Bd.Ft.	7.8¢	7.8¢
Return on Investment, % yr.	21.4%	44%

Economic Aspects - Polystyrene Extruded Foam

A summary of the economics of polystyrene foam (extruded process) is presented in Table .

Review of Markets for Cellular Plastics

Industrial Insulation Market

Low Temperature Pipe Insulation - The low temperature pipe insulation market is divided into two distinct segments, namely industrial and commercial construction. The total present market potential for low temperature pipe below 250°F is approximately $25 MM.

TABLE

Pipe and Equipment Insulation 1965 Market ($M)

Materials	to 32°F	%	32°F-250°F	%	250°F-400°F	%	Total($M)	%
Fibrous glass	100	1.1	10,900	58.0	24,000	100	35,000	68.0
Flexible closed cell tubing	1,200	13.9	3,900	20.5	- - -	0	5,100	9.9
Foamglas	2,000	23.1	2,200	11.7	- - -	0	4,200	8.2
Polystyrene Foam	3,500	40.5	1,200	6.4	- - -	0	4,700	9.1
Polyurethane Foam	1,850	21.4	650	3.4	- - -	0	2,500	4.8
Total	8,650	100.0	18,850	100.0	24,000	100	51,500	100.0

TABLE

Pipe and Equipment Insulation 1970 Market ($M)

Materials	to 32°F	%	32°F-250°F	%	250°F-400°F	%	Total($M)	%
Fibrous glass	75	0.4	11,500	52.5	26,125	100	37,700	59.0
Flexible closed cell tubing	1,100	6.9	4,400	20.1	- - -	0	5,500	8.5
Foamglas	2,200	13.8	2,400	10.9	- - -	0	4,600	7.2
Polystyrene Foam	7,200	45.0	2,000	9.2	- - -	0	9,200	14.4
Polyurethane Foam	5,400	33.9	1,600	7.3	- - -	0	7,000	10.9
Total	15,975	100.0%	21,900	100.0%	26,125	100%	64,000	100.0%

TABLE

Pipe and Equipment Insulation 1965 Market ($M)

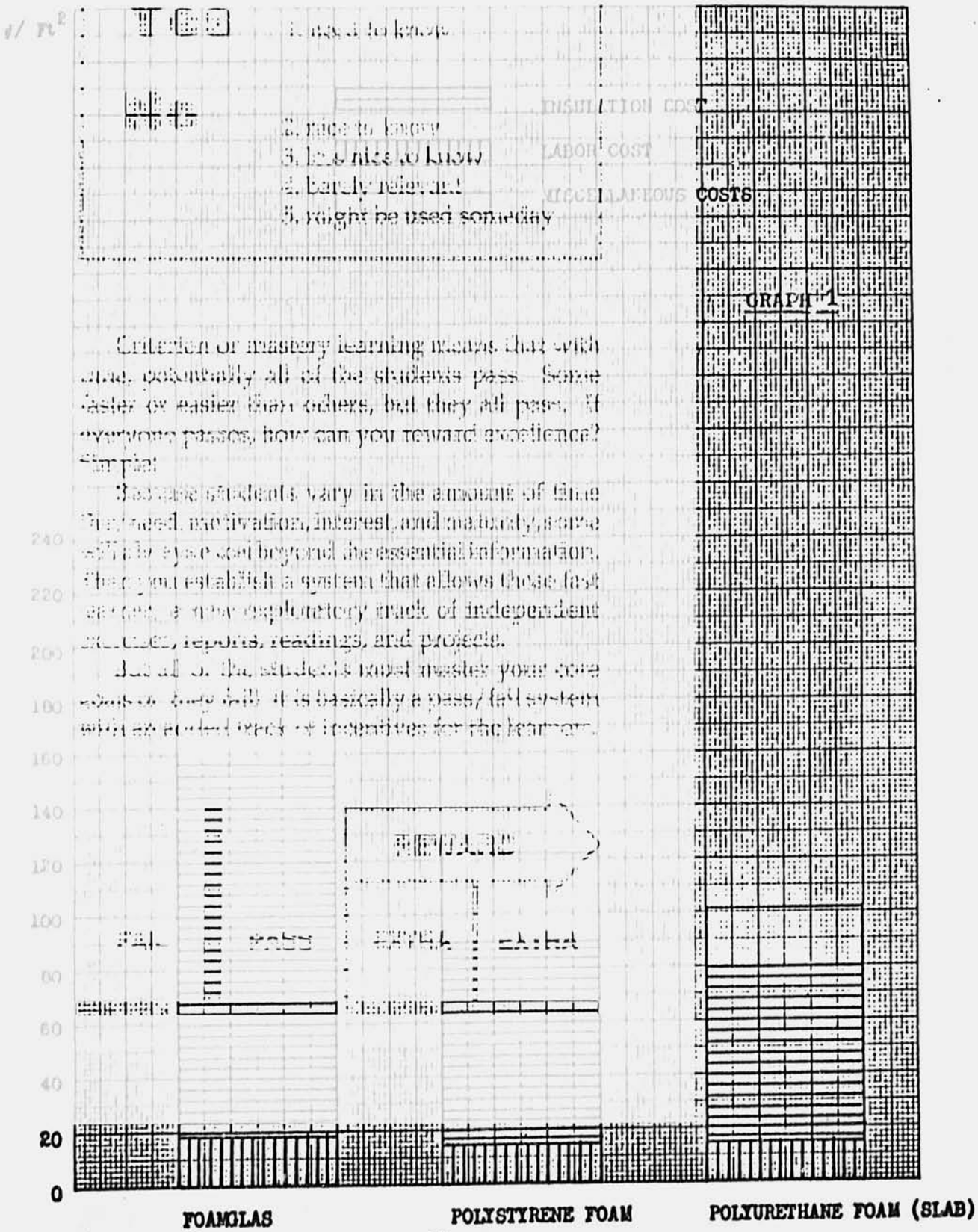
Materials	to 32°F	%	32°F-250°F	%	250°F-400°F	%	Total ($M)	%
Fibr[illegible] glass	100	1[illegible]	1[illegible]	58.0	24,000	100	35,000	68.0
Flex[illegible] closed cell tubing	1,200	13.8	3,800	20.5	- - -	0	5,100	9.9
Foam[illegible]	2,000	23.1	2,200	11.7	- - -	0	4,200	8.2
Poly[illegible] Foam	3,500	40.5	1,200	6.4	- - -	0	4,700	9.1
Poly[illegible] Foam	1,850	21.4	650	3.4	- - -	0	2,500	4.8
Total	8,650	100.0	18,850	100.0	24,000	100	51,500	100.0

TABLE

Pipe and Equipment Insulation 1970 Market ($M)

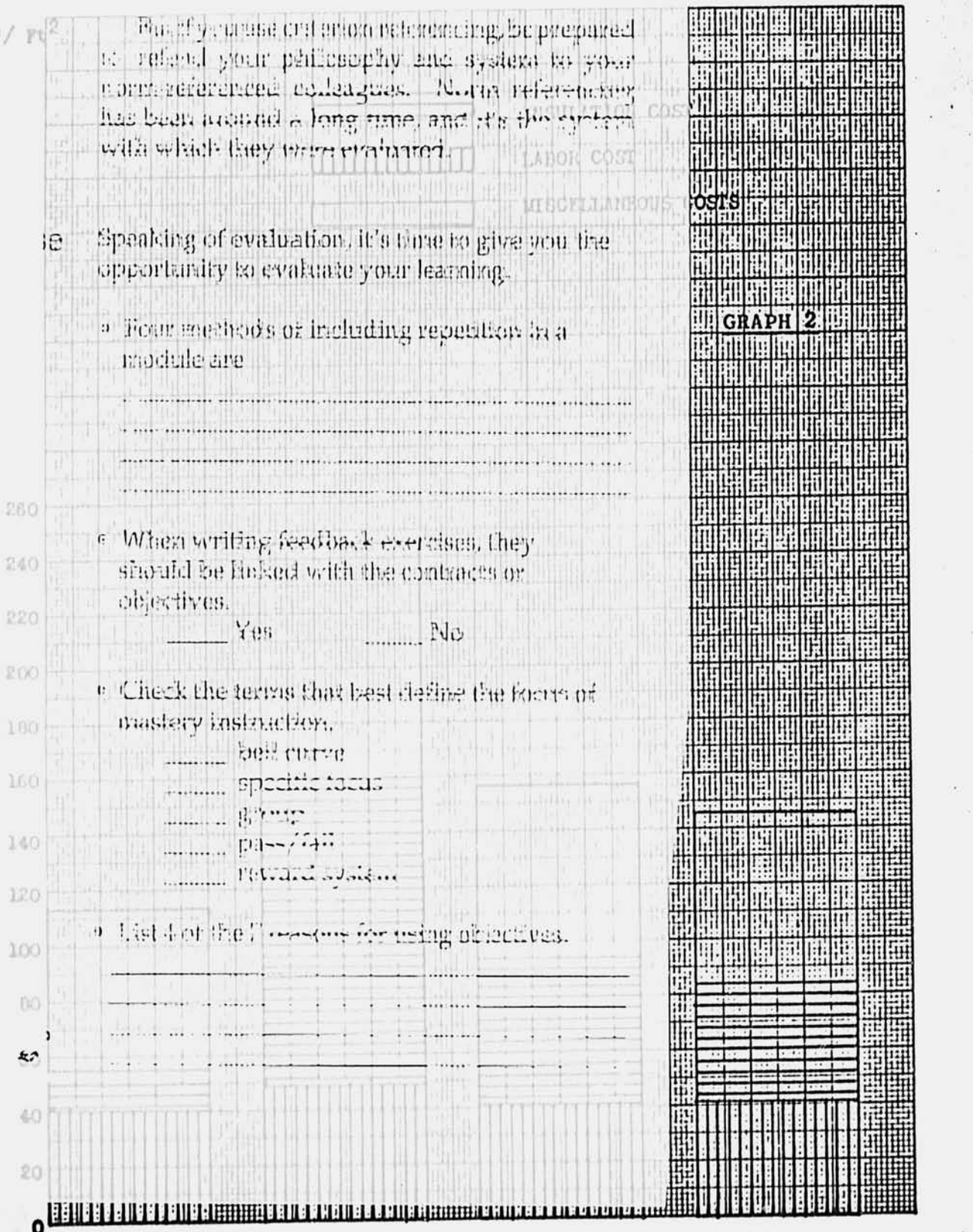
Materials	to 32°F	%	32°F-250°F	%	250°F-400°F	%	Total ($M)	%
Fibr[illegible] glass	[illegible]	[illegible]	[illegible]	52.5	26,125	100	37,700	59.0
Flex[illegible] closed cell tubing	[illegible]	[illegible]	[illegible]	[illegible]	- - -	0	5,500	8.5
Foamglas	2,200	13.8	2,400	10.9	- - -	0	4,600	7.2
Polystyrene Foam	7,200	45.0	2,000	9.2	- - -	0	9,200	14.4
Polyurethane Foam	5,400	33.9	1,600	7.3	- - -	0	7,000	10.9
Total	15,975	100.0%	21,900	100.0%	26,125	100%	64,000	100.0%

COLD STORAGE APPLICATION - FLOOR INSULATION



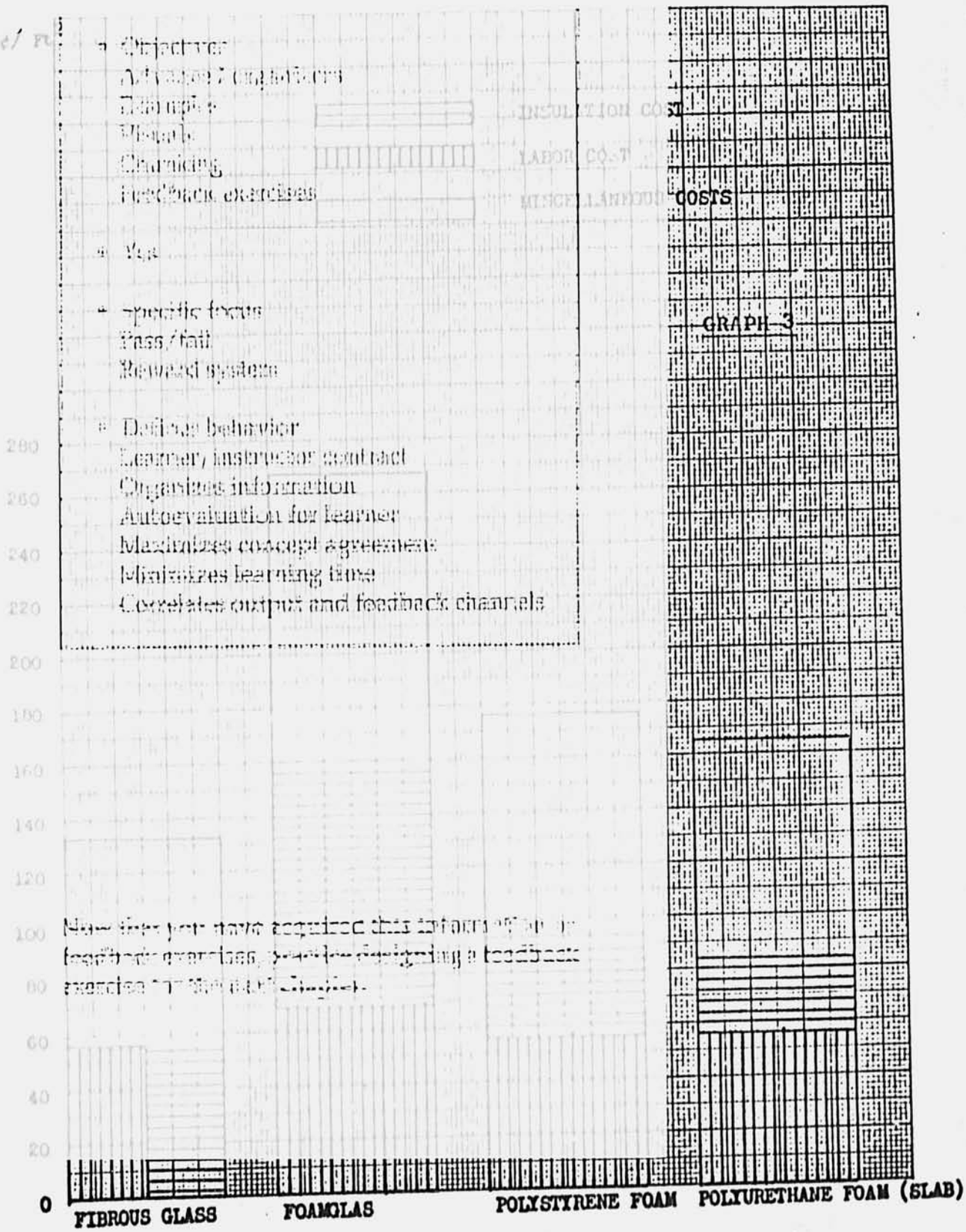
Figure

COLD STORAGE APPLICATION - WALL INSULATION



Figure

COLD STORAGE APPLICATION - CEILING INSULATION



Figure

TABLE

[illegible] Cost employed anchor [illegible] - Insulating Materials

(Dollars [illegible])

Insulation	% Application	$ MM
Styrofoam	61	10.8
Foamglas	32	5.8
Fibrous glass	5	.9
Urethane foam	2	.5
Total	100	18.0

Note: The cellular plastics market position will continue to grow as temperature limits and fire resistance increases and as manufacturing costs and selling price decreases.

Appliance Insulation

The rate of growth of rigid cellular plastics in the appliance industry has not met the predicted growth rate because:

1) Excessive optimism
2) Increase price estimates for the [illegible]nate component
3) High cost of foam systems
4) High cost of automation
5) [illegible]

Industry emphasis on the short term basis has been directed toward the original equipment manufacturer molding continued slab stock. Long range desirability of foam in-place depends on process development. A comparison of the advantages and disadvantages of hand block vs foam in place insulation is presented in Table

The relationship between foam material costs and raw material price for rigid urethane foam in the appliance market is presented in Table

Thus by using the information presented in Table , it is possible to compare cellular plastics vs fibrous glass insulation on the basis of insulating effectiveness. This comparison is presented in Table

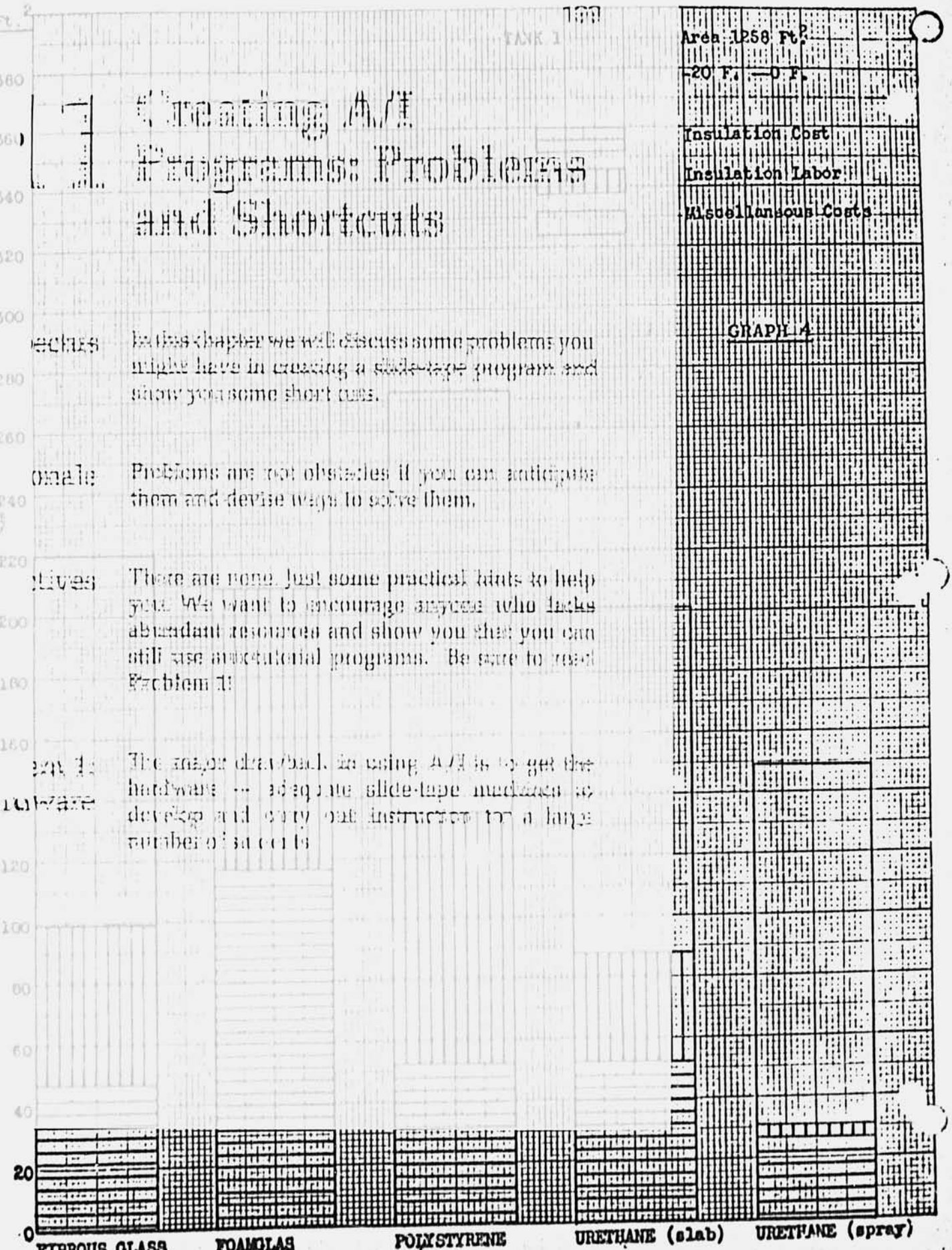
7. Creating A/V Programs: Problems and Shortcuts

echnics — In this chapter we will discuss some problems you might have in creating a slide-tape program and show you some short cuts.

omals — Problems are not obstacles if you can anticipate them and devise ways to solve them.

tives — There are none. Just some practical hints to help you. We want to encourage anyone who lacks abundant resources and show you that you can still use audiovisual programs. Be sure to read Problem 1!

ean I — The major drawback in using A/V is to get the hardware — adequate slide-tape machines to develop and carry out instruction for a large number of students.



Figure

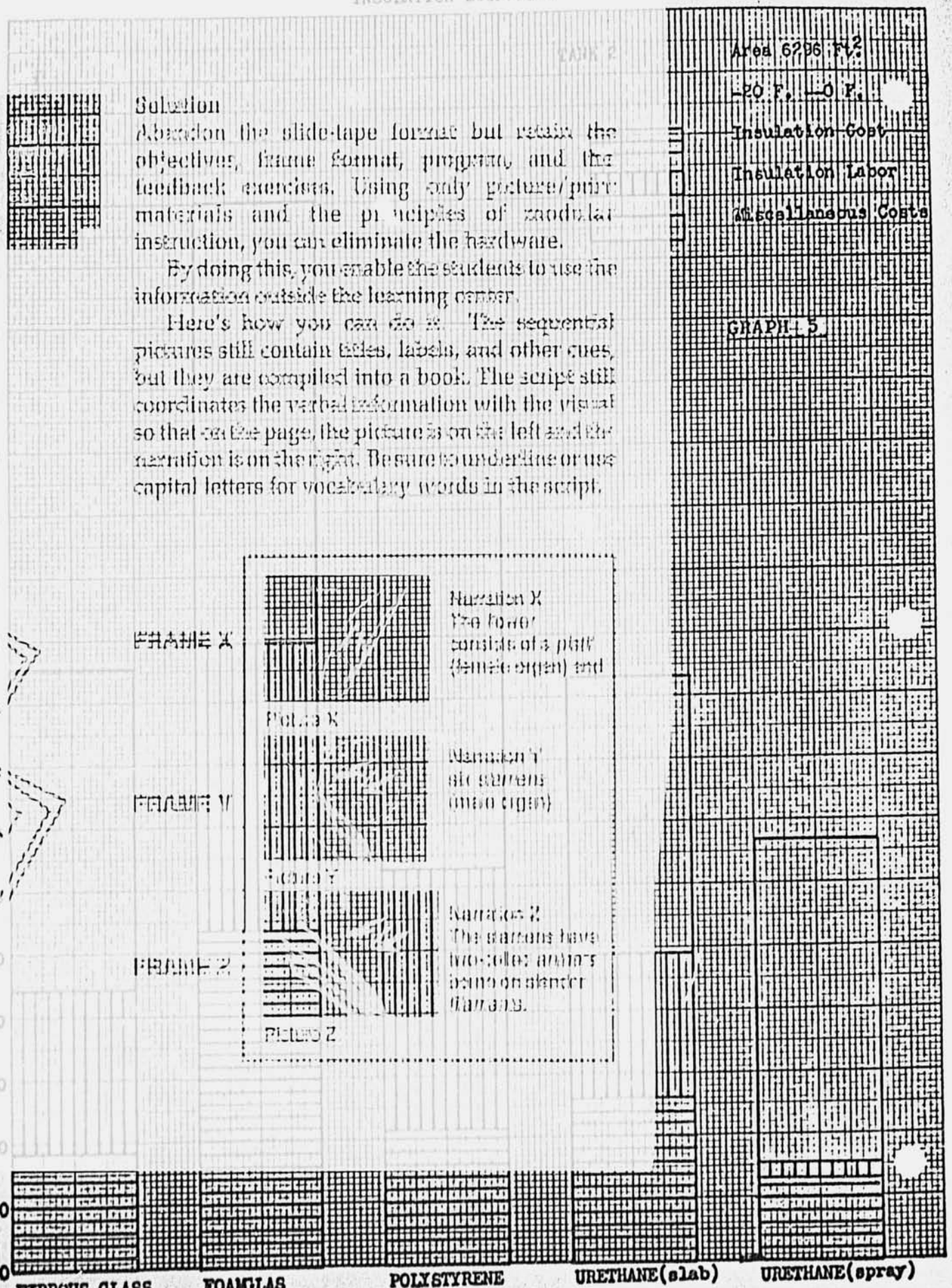
EFFECT OF APPLICATION SIZE AND SERVICE TEMPERATURE RANGE ON APPLIED INSULATION ECONOMICS

Solution

Abandon the slide-tape format but retain the objectives, frame format, programs and the feedback exercises. Using only picture/print materials and the principles of modular instruction, you can eliminate the hardware.

By doing this, you enable the students to use the information outside the learning center.

Here's how you can do it. The sequential pictures still contain titles, labels, and other cues, but they are compiled into a book. The script still coordinates the verbal information with the visual so that on the page, the picture is on the left and the narration is on the right. Be sure to underline or use capital letters for vocabulary words in the script.



Figure

Disadvantages are that you do not have the voice and music that go with listening. Also, it is expensive to print pictures. You might compromise by using black and white instead of color.

If you can afford it, use this method of instruction in addition to the slide-tape format. It assists learning because learners can read the script and hear it at the same time.

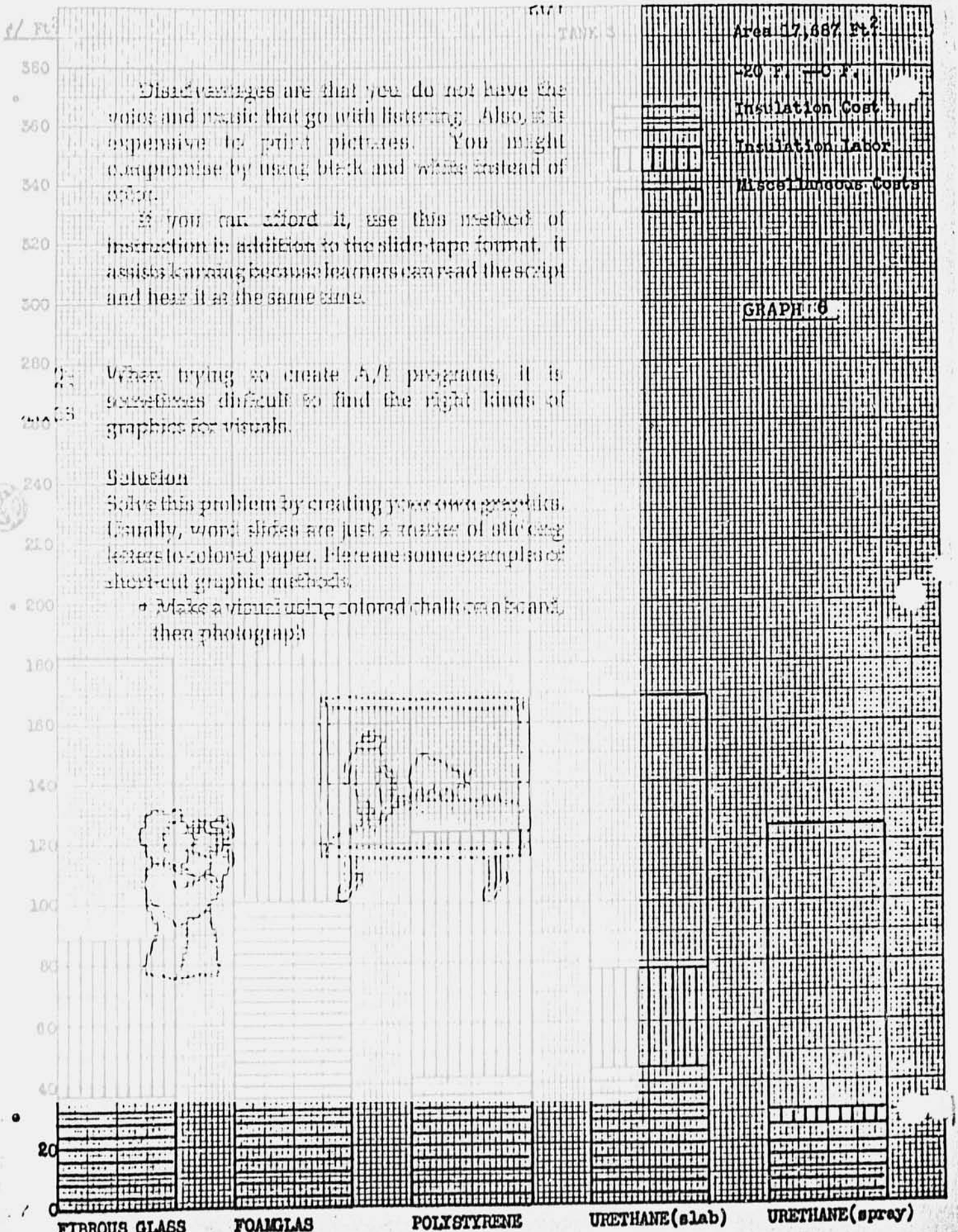
When trying to create A/V programs, it is sometimes difficult to find the right kinds of graphics for visuals.

Solution

Solve this problem by creating your own graphics. Usually, word slides are just a matter of sticking letters to colored paper. Here are some examples of short-cut graphic methods.

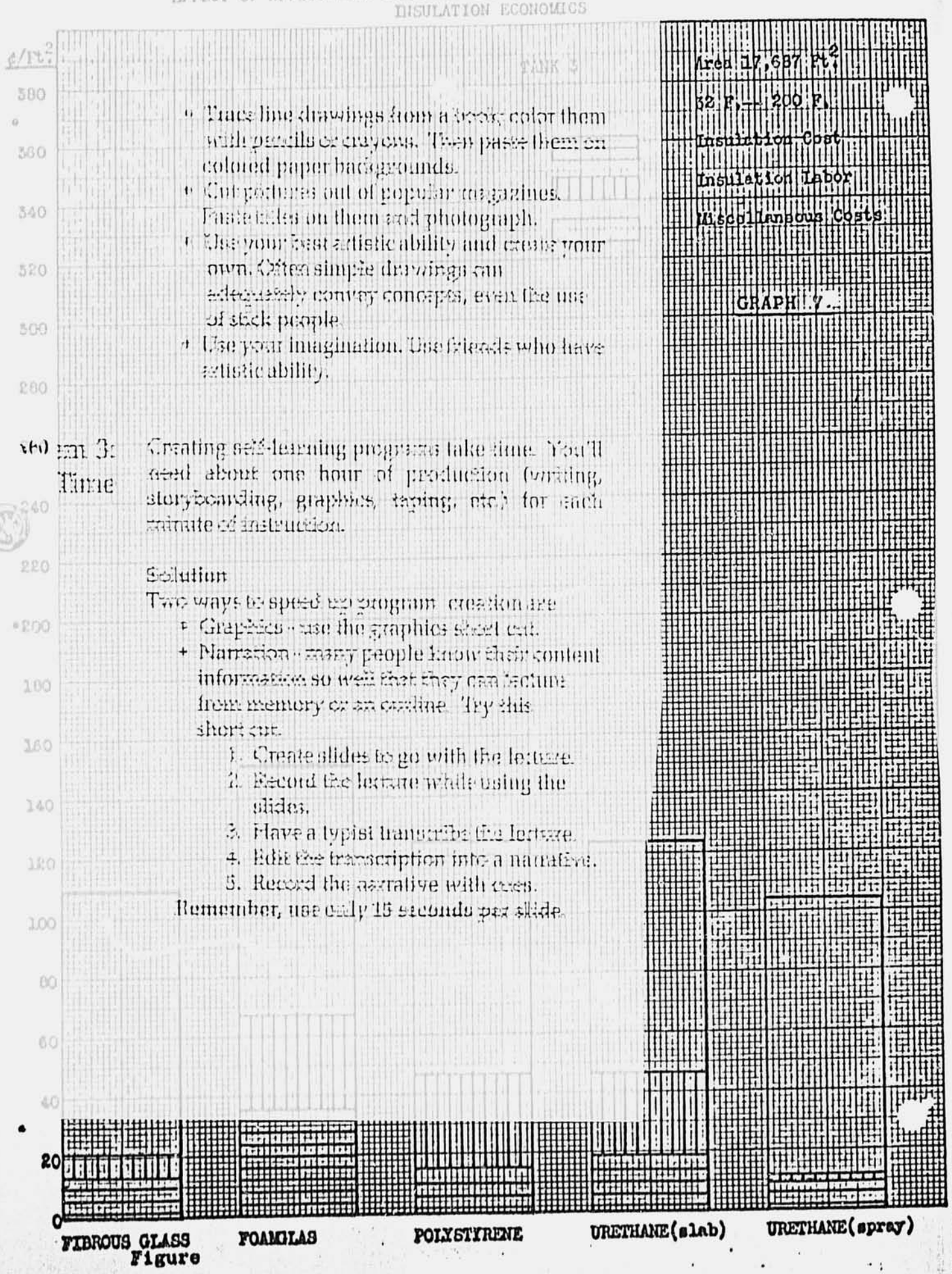
- Make a visual using colored chalk on a board, then photograph

EFFECT OF APPLICATION SIZE AND SERVICE TEMPERATURE RANGE ON APPLIED INSULATION ECONOMICS



Figure

EFFECT OF APPLICATION SIZE AND SERVICE TEMPERATURE RANGE ON APPLIED INSULATION ECONOMICS



- Trace line drawings from a book, color them with pencils or crayons. Then paste them on colored paper backgrounds.
- Cut pictures out of popular magazines. Paste titles on them and photograph.
- Use your best artistic ability and create your own. Often simple drawings can adequately convey concepts, even the use of stick people.
- Use your imagination. Use friends who have artistic ability.

Time

Creating self-learning programs take time. You'll need about one hour of production (writing, storyboarding, graphics, taping, etc) for each minute of instruction.

Solution

Two ways to speed up program creation are

- Graphics - use the graphics sheet cut.
- Narration - many people know their content information so well that they can lecture from memory or an outline. Try this short cut.
  1. Create slides to go with the lecture.
  2. Record the lecture while using the slides.
  3. Have a typist transcribe the lecture.
  4. Edit the transcription into a narrative.
  5. Record the narrative with cues.

Remember, use only 15 seconds per slide.

Figure

EFFECT OF APPLICATION SIZE AND SERVICE TEMPERATURE RANGE ON APPLIED INSULATION ECONOMICS

Often, high speed and multitape duplicating facilities are not available.

Solution

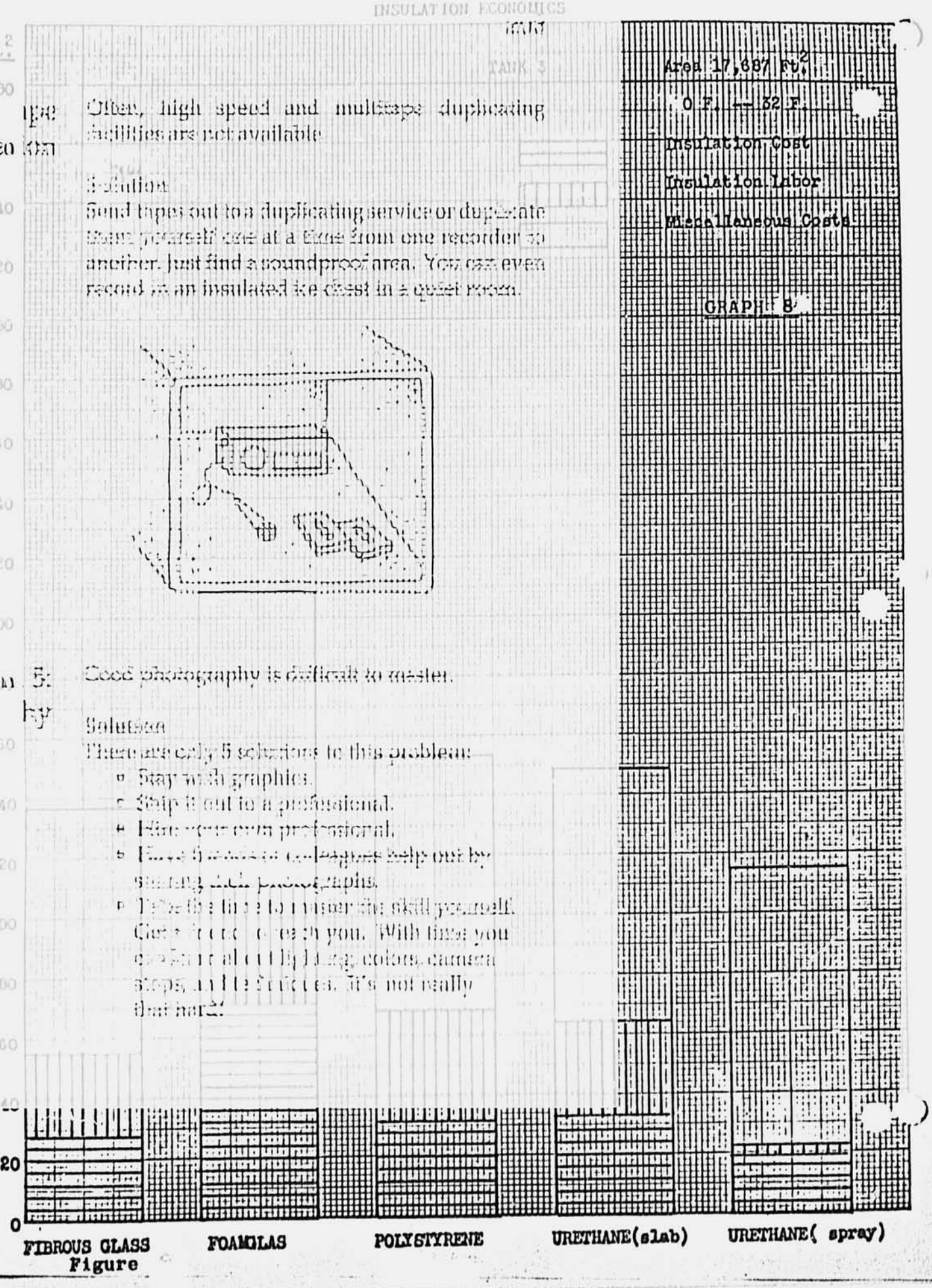
Send tapes out to a duplicating service or duplicate them yourself one at a time from one recorder to another. Just find a soundproof area. You can even record in an insulated ice chest in a quiet room.

Good photography is difficult to master.

Solution

There are only 5 solutions to this problem:

- Stay with graphics.
- Ship it out to a professional.
- Hire your own professional.
- Have friends or colleagues help out by shooting their photographs.
- Take the time to master the skill yourself. Get a good camera. With time you can learn all the tricks, colors, camera steps, and the practice. It's not really that hard.



Figure

TABLE

Rigid Foam Slab Stock vs Foamed-In-Place Insulation

Slab Stock (Purchased)	Foamed-In-Place Insulation
No tooling costs	High tooling costs
No equipment costs	High tooling costs
Moderate time	High cycle time
Semi-skilled personnel required	Skilled personnel required
Design "K"-factor .16 - .17	Design "K"-factor .14 - .15
Density 1.8 - 2.1 p.c.f.	Density 2.25 - 2.50 p.c.f.
Material cost 14¢-16¢/bd.ft.	Material cost 8.3¢-9.2¢/bd.ft.
Insulating effectiveness .0224 - .0272	Insulating effectiveness .0113 - .0138
Adhesive required	No adhesives required

TABLE

Relationship Between Foam Material Cost and Raw Material Price

Isocyanate Cost ¢/lb.	54	54	51	42	36
Resin Cost ¢/lb.	29	29	25	25	21
Foam Density p.c.f.	2.5	2.6	2.0	2.0	1.8
Foam Cost ¢/lb.	39	39	37	33	30
Foam Cost ¢/Ft.^{3}	97	78	74	66	54
Foam Cost ¢/Bd.Ft.	8.7	6.4	6.1	5.5	4.5

TABLE

% Premium Cost of Foam vs Fibrous Glass
Based on Insulating Effectiveness

Foam Cost $/cu.ft.	Foam	0.12	0.14	0.16
	Fibrous glass	0.24	-.24	0.24
97		+37	+63	+86
78		+11	+29	+49
74		+ 6	+23	+40
66		- 6	+11	+26
54		-20	- 9	+ 3

Transportation Market

The rate of market penetration for rigid foams in the Transportation Market has exceeded most projections. A summary of rigid foam usage in the Transportation Market is presented in Table .

TABLE

Rigid Foams in Transportation Market Areas

Year	R.R. Refrig. Cars			Refrig. Truck Trailers			Total Potential M lbs P-ether	% Foam Pene-tration	Probable Potential M lbs P-ether
		Potential*			Potential*				
	No. of Units	M lbs Foam	M lbs P-ether	No. of Units	M lbs Foam	M lbs P-ether			
1960	3,000	6,750	3,000	6,000	5,000	2,700	5,700	-	-
1961	3,000	6,750	3,000	6,600	5,600	2,960	5,960	16.8	1,000
1962	3,000	6,750	3,000	7,250	7,250	3,250	6,250	33.6	2,100
1963	3,000	6,750	3,000	7,950	7,950	3,580	6,580	53.0	3,500
1964	**3,000**	**6,750**	**3,000**	**8,750**	**8,750**	**3,950**	**6,950**	**72.0**	**5,000**
1965	**3,000**	**6,750**	**3,000**	**9,600**	**9,600**	**4,300**	**4,300**	**89.0**	**6,500**

* **Estimates of potential if all units produced were insulated with rigid foam.**

TABLE

Potential Markets for Rigid Board Insulation in Construction

(MM Bd. Ft.)

	1961	1966
Low temperature space insulation	200	300
Pipe and equipment covering	50	100
Cavity wall and insulation plasterbase	60	200
Perimeter and floor slab insulation	40	70
Roof insulation	200	600
Backerboard for metal siding	40	180
Nonresidential panels	20	125
Residential panels	Nil	125
Panels for low temperature space insulation	Nil	150
Thin shell construction	Nil	50
Floating structures	25	80
Miscellaneous	Nil	20
Total	635	2000

TABLE

Estimate of Rigid Urethane Foam Consumption - 1970

Construction Market

(MM lbs Rigid Foam)

	Total	Slab Foam	In-Situ Foam
Residential			
Sandwich panels	50	25	25
Electric heated homes	10	-	10
Perimeter insulation	3	1.5	1.5
Prefab cores	2	-	2
Non-Residential			
Roof insulation	15	15	--
Curtain wall	6	6	--
Masonry cavity wall	5	-	5
Perimeter insulation	1	0.5	0.5
Plaster base	1	-	1
Total	93	48	45

DuPont

TABLE

Soybean Meal Manufacturing Cost

Plant Capacity - 73 million lb/yr

Plant Investment - $10.4 million

	$/year	¢/lb
Sales [illegible]	$9,000,000	12.0
Manufacturing Cost		
[illegible]	1,225,000	1.63
[illegible]	2,918,400	3.89
[illegible]	793,600	1.06
[illegible]	265,000	0.35
Laboratory	50,000	0.07
Operating labor, supervision and clerical	203,900	0.27
Plant administration and overhead expense at [illegible]	203,900	0.27
Maintenance at [illegible] of investment	416,800	0.56
Taxes and insurance at [illegible] of investment	261,000	0.35
Royalties	156,000	0.18
Working expense allocation of [illegible]	18,000	0.02
Depreciation [illegible]	1,042,000	1.39
Cost of Goods Sold	7,853,600	10.04
Gross Profit		
Selling expenses [illegible]	36,090	0.05
Administrative expenses [illegible]	90,225	0.12
Net [illegible]	1,320,100	1.76
Net Profit After Federal Income Tax	633,640	0.84
Return on Investment	6.1%	

Note: The [illegible] presented [illegible] manufacturing cost are based on 1961 production figures.

TABLE

Polystyrene Resin (Regular Grade)

Plant Capacity - 50 million lb

Plant Investment - $10 million
(Equipment and building excluding working capital)

	$/Year	¢/lb
Sales (24¢/lb)	10,000,000	
Manufacturing Cost		
Raw materials (12¢/lb)	6,000,000	12
Operating labor (90-100 men)	500,000	1
Utilities	500,000	1
Maintenance	150,000	0.3
Plant administration, overhead (cost of labor)	500,000	1
Taxes, insurance, other fixed investment cost (working capital)	200,000	0.4
Depreciation (10 years straight line)	750,000	1.5
Cost of Goods Sold	8,600,000	17.2
Gross Profit	1,400,000	
Less G&AWD exp (7% sales)	525,000	1.05
Net Profit before taxes	875,000	2.75
Net Profit after taxes (assuming 1 year tax free period of the new investment)	666,000	1.33
Return on investment	6.7%	

TABLE

Financial Aspects: Styrene Monomer and Polystyrene

Styrene Monomer

Plant Capacity	75 MM lb/yr	
Investment	$10.4 million	
Profit and Loss	$ MM/yr	¢/lb
Sales	9.0	14
Less cost of goods sold	7.6	12
Gross Profit	1.4	2
Less estimated S. G&A, R&D expenses	1	.2
Net profit before taxes	1.3	1.8
Net profit after taxes	0.6	0.8
Return on Investment	6.1%	

Polystyrene Resin - Crystalline

Plant capacity	50 MM lb/yr	
Investment	$10 million	
Profit and Loss	$ MM/yr	¢/lb
Sales	10.5	21
Less cost of goods sold	8.6	17.2
Gross Profit	1.9	3.8
Less estimated S. G&A, R&D expenses	.6	1.1
Net profit before taxes	1.3	2.7
Net profit after taxes	0.7	1.3
Return on Investment	6.7%	

Note: Vacuum charged to polymer process @ 12¢/lb market price; if charged at cost, 10¢ lb. cost of polymer would be 15.2¢ lb

TABLE

Expandable Styrene Bead Manufacture **BASF**

Batch Process

Estimated Capacity - 100 lb/hr

(Continued)

I	Estimated Equipment Costs	
	1 Jacketed Autoclave (1000 gallons carbon steel)	10,000
	1 Strainer	4,000
	1 Rotary Dryer	8,000
	1 Classifier	5,000
		27,000
II	Estimated Installation Costs	
	Installation @ 20% of equipment	6,500
	Piping @ 15%	4,000
	Electrical @ 10%	2,700
	Instrumentation @ 10%	2,700
	Miscellaneous @ 10%	2,700
		18,600
III	Estimated Total Equipment Costs	45,600
IV	Estimated Total Manufacturing Cost (excluding Royalty)	.20 - .244/lb

Note: The information presented on expandable styrene manufacture is based on costs obtained in 1961.

TABLE

Expandable Styrene Bead Manufacture
Under Bulk Polymerization Process
(Accommodating 2 Reactors)

Estimated Capacity 600-700 lb/hr

	(Dollars)
I. Estimated Equipment Costs	
2 Storage bins	3,000
2 Weight spouts	7,000
1 [illegible] Extruder and drive	40,000
1 Mixer feeder	8,000
1 Die face cutter	5,000
1 Conditioner	4,000
1 Classifier	5,000
	72,000
II. Estimated Installation Costs (Includes unit use part of the time as the installation is a set of equipment)	10,500
Piping [illegible]	7,000
Electrical [illegible]	7,000
Instrumentation [illegible]	3,500
Miscellaneous [illegible]	3,500
	31,500
III. Estimated Total Equipment Cost	103,500
IV. Estimated Total Manufacturing Cost	.20 - .24/lb

Note: The information presented on expandable styrene manufacture is based on costs obtained in 1961.

Table

Expanded Polystyrene Mold Foam Investment
(Million)

I. Equipment	
Pre-expander	3,000
Air loader	200
Water system to expanded beads factory	700
Storage silos (2) bead	400
Block mold (12' x 4' x 22').	34,000
Boiler and auxiliary equipment	18,000
Block molding equipment	2,500
Hot wire cutter	9,000
Installation and handling	2,000
	69,800
II. Manufacturing Vehicles	
Electric forklift, 8,000 sq. ft.	75,000
III. Storage Capacity	
7,200 new material storage	24,000
IV. Total Investment	168,800

Note: Based on [illegible] 316,000 board feet, 8.15 million board feet as a density of 1 p.c.f. Assumes outside storage area for waste material.

TABLE

Economical Aspects Polystyrene Bead Foam

	BASF Batch Process	Dow Extrusion Process
Bead Manufacture		
Plant capacity	300 lb/hr	600-700 lb/hr
Equipment investment (rough estimate)	$40,000	$104,000
Building fixed	37¢/lb	37¢/lb
Expected cost of capital	20-24¢/lb	20-24¢/lb
	(no royalty)	(no royalty)
	Purchased Bead	Manufactured Bead
Foam Manufacture		
Plant capacity		
M lb/yr	15 @ 1 pcf -	
MM bd ft/yr	15 @ 1 pcf -	
Investment $M		
Equipment	[illegible]	104 (bead mfg)
Manufacturing	[illegible]	169 (foam mfg)
Working capital	24	—
	[illegible]	273
Profit and Loss		
Net sales	392	392
Less cost of goods	296	218
Gross Profit	[illegible]	174
Less S, G&A, R&D expenses	20	20
Net profit before taxes	[illegible]	154
Net profit after taxes	[illegible]	74
Net profit on total invest	24%	27%
Net profit on total invest (excluding building)	[illegible]	37%

Notes: (Explanation of assumptions used in preparation of Table)

1. Estimate of total cost of bead manufacture of 20-24¢/lb is based on information from a source believed to be reliable. I have not been able to check this completely within the scope of the survey.

2. It is understood that polystyrene is charged to Dow's extruded process at approximately 15¢/lb - about cost. If so, this means that profit for the entire operation from monomer through beads is taken on the beads - or foam. If foam is made from the manufactured beads, and charged at cost.

3. Nominal working investment for bead foam ($75,000) is a building.

4. Working (accounts receivable and finished products) capital is that required for a 30 day raw material supply.

5. Naphtha - bead feed is considered at 6½¢/bd.ft. (current price is larger a some coal-based).

6. Beads are charged at 15¢/lb to purchased bead column, 22¢/lb to manufactured bead column. No royalty would have to be added in this cost in computing return because I have used the investment for the Dow extrusion process which includes the royalty.

7. Selling, general, administrative and research and development expenses are assumed to be 5% of gross sales, close than in the case of urethanes because of the lower technological requirements for bead foam manufacture.

TABLE

Profit and Loss - Expanded Polystyrene Bead Foam

	Purchased Bead (37¢/lb)		Manufactured Bead (22¢/lb excl Royalty)	
	$/Year	¢/bd.ft	$/Year	¢/bd.ft
Poundage S		[illegible]	[illegible]	
Board Foot				
Gross Sale		[illegible]	[illegible]	[illegible]
Less fr	[illegible]		2,000	
Net Sales		[illegible]	[illegible]	
Raw mat	[illegible]	[illegible]	[illegible]	[illegible]
Operati	[illegible]	[illegible]	31,000	[illegible]
Plant a				
(175	[illegible]	[illegible]	34,000	[illegible]
Mainten	[illegible]	[illegible]	2,800	[illegible]
Taxes a				
tota				
work	[illegible]	[illegible]	3,600	[illegible]
Depreci				
10%/	[illegible]	[illegible]	7,000	[illegible]
5%/	[illegible]	[illegible]	3,800	[illegible]
Total C	[illegible]	[illegible]	218,200	[illegible]
Gross Prof		[illegible]	[illegible]	
Less GA	[illegible]		20,000	
Net Profit Before Taxes		[illegible]	[illegible]	
Less 52% Federal Tax	38,800		80,000	
Net Profit After Taxes		36,000		73,000
Total Capital Investment	168,800		168,800	
Return on Investment, %/yr		21.4%		44%

Notes: 1. Sales at 6.5/bd.ft. for 1 p.c.f. foam.

2. Raw Materials:
   528,000 lb/yr consumed
   (2.8% absolute loss of raw materials takes into account 15% re-use of trim & scrap)
   Beads at 37¢/lb = $195,000
   Beads at 22¢/lb (excluding royalty) = $116,000.

3. Labor:
   6 men at $2/hr, 1 shift, 250 days/yr.
   1 supervisor at $7,000/yr.

Bead For

Styrene

Blowing
tane

Additive

Bead Mar

Bead Cos
Mater
Estim

Bead Sel

Foam Mar

Cost per

Material

Foam Mfc

Selling Prices (¢/bd.ft.)

	Regular	Self-extinguishing
1.25 pcf List	.116 - .123	.120 - .128
Contractors	.090 - .098	.095 - .103
Large volume end-users	.065 - .070	
1 pcf Contractors	.080 - .085	.085 - .095

TABLE

Styrofoam

I.	Estimated Equipment Costs	
	1 Storage bin (polystyrene)	2,000
	1 Storage bin (other)	1,000
	2 Weight spars	7,000
	1 6" extruder and drive	40,000
	1 Mixer cooler (assume jacketed pipe with mixing screw)	8,000
	1 Metering pump for product	2,000
	2 Feeders (blowing and flame retardant systems)	4,000
	1 Forming belt	1,500
	1 Truck type oven (tray)	20,000
		89,500
II.	Estimated Installation Costs	
	Installation @ 15% of equipment	13,000
	Piping @ 10%	9,000
	Electrical @ 10%	9,000
	Instrumentation @ 5%	4,500
	Miscellaneous @ 5%	4,500
		40,000
III.	Estimated Plant Costs (excludes building)	
IV.	Estimated Total Cost of Manufacture (4-5¢/bd.ft.)	129,500

TABLE

Financial Aspects: Polystyrene Extruded Foam (Styrofoam)

Plant Capacity - 5.2 MM lb/yr or 35 MM bd.ft./yr (1.8 pcf)

Equipment Investment (rough estimate) - $130,000

Profit and Loss	Polystyrene charged @ market	Polystyrene charged @ market
$/bd.ft.		
Selling price	.085 average	.085 average
Estimated cost of goods	.045	.054
Gross Profit	.040	.031

TABLE

Financial Aspects: Polyethylene Foam

Plant Capacity - 3.1 MM lb/yr or 19 MM bd.ft/yr (2.0 pcf)

Equipment Investment (rough estimate) - $130,000

Profit and Loss	$/bd.ft.
Selling price	.22
Estimated cost of goods sold	.153
Gross Profit	.067

TABLE

Costs and Prices of Extruded Polystyrene Foam (Styrofoam)

Formulation Material	Parts by Weight	% by Weight	Price ($/lb) Dow's est. cost	Price ($/lb) Market	Cost ($/lb) Dow's est. cost	Cost ($/lb) Market
Polystyrene resin	100	92	.15	.21	.138	.193
Blowing agent (methyl chloride)	6.5	6	.12	.12	.007	.007
Nucleating agent (TiO_2)	2.2	2	.14	.14	.003	.003
	108.7	100			.148	.203

Foam Manufacturing Processes Losses 5%

Costs per Unit of Foam Produced

	$/lb Cost	$/lb Market	1 pcf Cost	1 pcf Market	1.5 pcf Cost	1.5 pcf Market	1.8 pcf Cost	1.8 pcf Market	2.5 pcf Cost	2.5 pcf Market
Materials	.156	.214	.013	.018	.019	.027	.023	.032	.032	.045
Foam mfr.	.106-.264	.106-.264	.022	.022	.022	.022	.022	.022	.022	.022

Selling Price

1.8 pcf to large end-users $.085 - .10 bd ft

1.8 pcf to Dow's super distributors .075

Note: Since The Dow Chemical Company is the only producer of extruded polystyrene foam, information concerning process conditions and costs is limited.

Styrofoam production per unit is very high because the units are operated 360 days per year, 24 hours per day, and they can turn out approximately 600 pounds per hour.

TABLE

Costs and Prices of Polyethylene Foam

Formulation Material	Percentage by Weight	Price: Present	Price: 3-5 yr Future	Cost per lb. foam ($/lb.): Present	Cost per lb. foam ($/lb.): 3-5 yr Future
Polyethylene resin (low density)	85	.275	.25	.234	.212
Blowing agent	13	1.00	1.00	.130	.130
Additives	2	.25	.25	.005	.005
	100			.369	.347

Foam Manufacturing Process Losses — Information not available; we assume 5%

Costs per Unit of Foam Produced

	$/lb		$/per board foot at density of 1.5 pcf		2.0 pcf		2.5 pcf		3.0 pcf	
	Present	Future	Present	Future	Present	Future	Present	Future	Present	Future
Materials	.389	.366	.049	.046	.065	.061	.081	.076	.097	.092
Foam Mfr.	.35-.70	.35-.70	.088	.088	.088	.088	.088	.088	.088	.088
	.739-1.09	.716-1.07	.137	.134	.153	.149	.169	.164	.185	.180

Selling Price $/Bd.Ft. ± 2 pcf

TABLE

Rigid Urethane Foam, Slab Line Investment

Prepolymer System

	Large Company Operation		Small Company Operation
	Purchased Prepolymer	Manufactured Prepolymer	Purchased Prepolymer
I. Equipment & Installation			
Storage facilities	30,000	30,000	15,000
Prepolymer facilities	- - -	95,000	- - -
Foam line	60,000	60,000	30,000
Storage & handling equip.	10,000	10,000	5,000
Fabrication line	38,000	38,000	25,000
Laboratory	5,000	5,000	5,000
II. Nonmanufacturing Equipment			
Erected building (10,000 sq. ft.)	140,000	140,000	- - -
Other	40,000	40,000	- - -
Rented floor area (10,000 sq.ft.)	- - -	- - -	5,000
	180,000	180,000	5,000
III. Working Capital			
Raw material (30-day supply @ 38.4¢/lb)	- - -	35,200	- - -
Purchased prepolymer (@ 65¢/lb)	59,800	- - -	59,800
IV. Total Investment (I,II,III)	382,800	453,200	144,800

Note: The information presented in this table is based on plants capable of 600,000 lb/yr of foam production (2 pcf or 3.6 MM bd.ft). It is noted that the raw materials required are greater than foam produced because of losses.

TABLE

Profit and Loss - Urethane Rigid Foam - Continuous Slab Line

	Large Company Operation		Small Company Operation
	Purchased Prepolymer	Manufactured Prepolymer	Purchased Prepolymer
Poundage Sales	(600,000)	(600,000)	(600,000)
Board Foot Sales (MM lb)	(3.6)	(3.6)	(3.6)
Gross Sales[1]	(648,000)	(648,000)	(648,000)
Less freight, etc.(2% of sales)	13,000	13,000	13,000
Net Sales	(635,000)	(635,000)	(635,000)
Raw materials[2]	500,000	299,520	
22% absolute loss allowed (purch. prepoly.)			
23% absolute loss allowed (mfg. prepoly.)			
Operating labor[3]	31,000	35,000	31,000
Plant adm overhead, util. (175% of labor)	54,200	61,200	54,200
Maintenance (4%/yr on equip. invest.)	5,700	9,500	3,200
Taxes-insurance(2.5%/yr of total invest. excluding working capital)	8,100	10,500	2,100
Depreciation			
-10%/yr on equipment	14,300	23,800	8,000
- 5%/yr on building, etc.	9,000	9,000	- - -
- rent expense	- - -	- - -	5,000
Total Cost of Goods Sold	622,800	488,520	604,000
Gross Profit (or Loss)	(12,200)	(146,480)	(31,000)
Less GASR&D	64,800	64,800	64,800
Net Profit Before Taxes	(- - -)	(81,680)	(- - -)
Less 52% Federal Taxes	(- - -)	42,400	(- - -)
Net Profit After Taxes		(39,280)	(- - -)
Total Capital Investment		453,200	
Return on Investment (%/yr)		(8.7%)	

Notes: 1. Sales of 600,000 lb or 3.6 MM board feet (prime foam) 2.0 pcf at 18¢/bd.ft.

2. Raw materials required to produce above quantities, taking account of losses is:
   Purchased prepolymer - 770,000 lbs @ $.650/lb.
   Manufactured prepolymer - 780,000 lbs @ $.384/lb.

3. Labor
   Purchased prepolymer - 6 men @ $2/hr, 1 shift, 250 dy/yr, 1 spvr. @ $7,000/yr.
   Manufactured prepolymer - 7 men.

128 p.