

APPLICATION OF URETHANE FOAM TO WOOD PRODUCTS INDUSTRY

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INTRODUCTION

Urethane foam technology is now new. Serious application within the wood products industry started five years ago. The greatest advance in this work has been made in the last two years.

The approach to the subject is an attempt to answer these questions: What is urethane foam? How is it applied? How can it benefit the wood products industry? How much does it cost to apply?

Within this framework there is considerable latitude. There are a number of processes for foam preparation, such as prepolymer, semi-prepolymer and one-shot, dispensed by frothing, spraying or pouring-in-place equipment. My remarks are confined to a two-component system for spray-in-place application. We use Gusmer Corp. spray equipment and a foam system from P. P. G. Industries. Attention is centered on the use of this equipment and material in the field, on dry kilns, and other buildings or equipment within the wood products industry. A full description of the steps involved in a field application are given in Appendix I.

In describing a urethane system I have simplified the chemistry, physical chemistry and complexity of the components therein. Only highlighting components which have some interest or bearing on the application on hand. This information is given in Appendix II.

Three factors are worthy of note when foam is considered in buildings or equipment associated with the wood industry: Corrosion protection; strengthening effect; thermal insulation. These subjects are dealt with at some length, particularly, thermal insulation.

In the application of any new material economics are always of interest. Realistic cost factors drawn from our experience in the field are provided. Inevitably comparisons will be made with other materials or methods of construction. In the text a few comparisons are suggested. The hope is to stimulate people to see the material in its true perspective, to encourage them to inquire of its application to process equipment, buildings or situations we may not have considered.

The correct application of foam to structures can be summarized as requiring four main elements: A good foam system; correct conditions for application; efficient spraying equipment; intelligent labor. Phrased another way; research can develop the best foam system for the task; surface and atmospheric conditions can be just right; the latest spray equipment can be available; yet the finished work is still only as good as the operator's knowledge and technique.

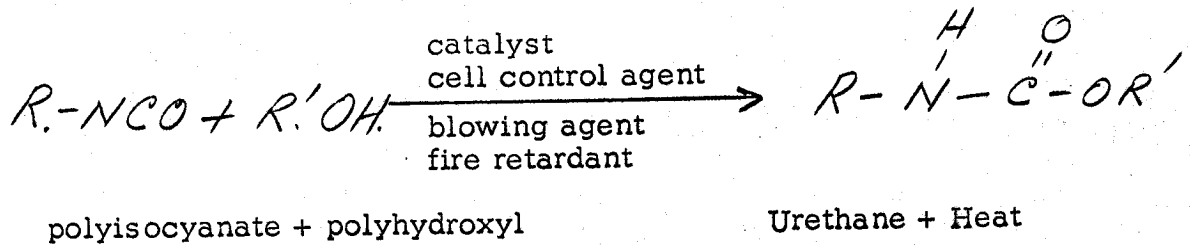
Operator training and technique is very important. It constitutes a large part of the "know-how" in this work. Our learning curve has moved slowly and been rather expensive, but progress has been made. We now tackle most problems with a great deal more assurance than even one year ago.

What is Urethane Foam?

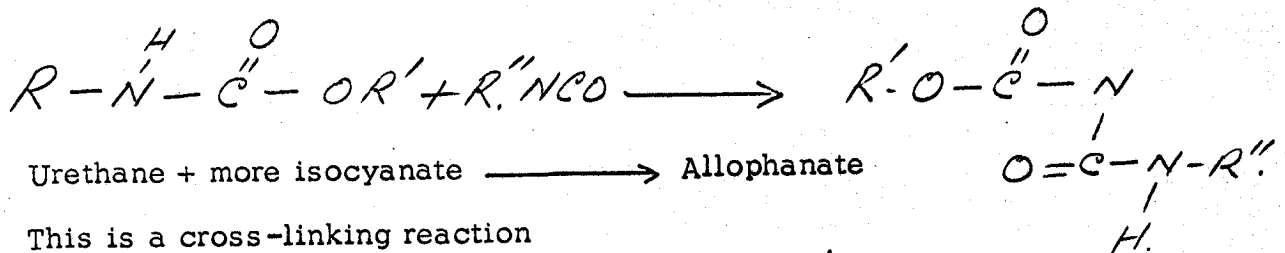
Rigid urethane foams are the reaction products of a polyisocyanate and a polyhydroxyl material. They are classified as a thermosetting resin. Because of their cellular nature, however, they do show some plasticity at higher temperatures. Some of the reactions which take place are given in Figure 1.

Figure 1

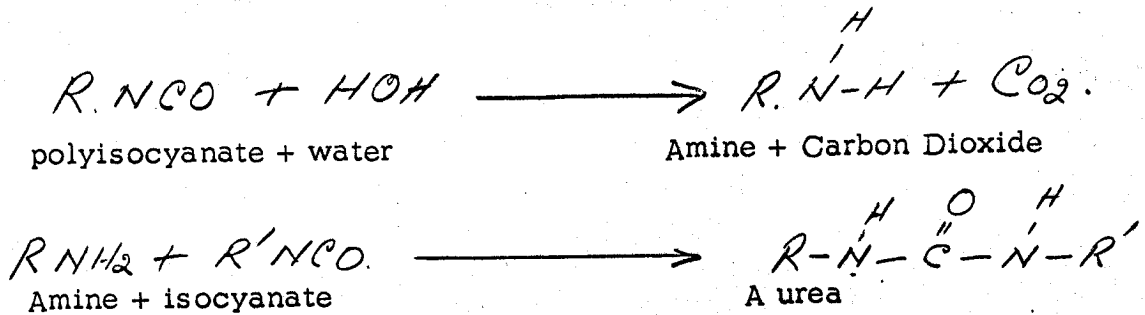
(1) Urethane Reaction



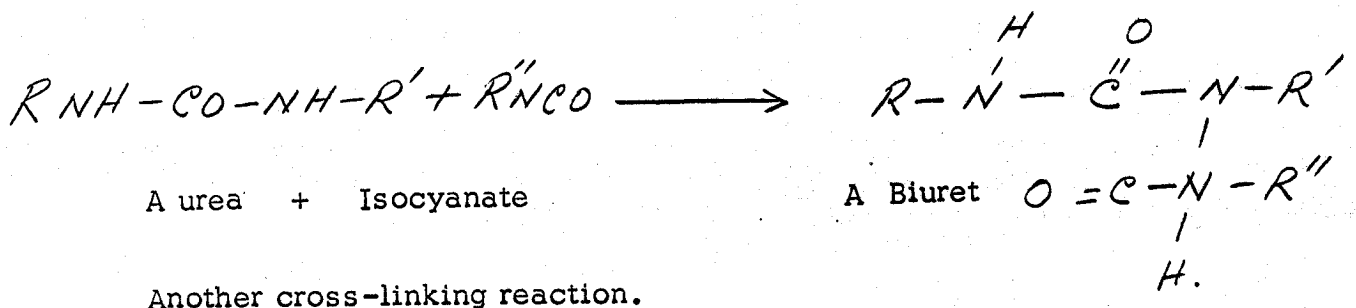
(2) Allophanate Formation



(3) Urea Reaction



(4) Biuret Formation



The reaction is carried out in the presence of catalysts, a surface active agent and a blowing agent. The polyhydroxyl compound and the polyisocyanate react exothermically to form the polymer structure of the foam. The blowing agent expands the polymeric structure while it is being formed. The catalyst helps control the speed of the reaction. The surface active agent (surfactant) aids in controlling the cell structure. It encourages the production of foams with fine, uniform, cell structure.

In the manufacture of rigid urethane foams expanded with inert blowing agents such as the fluorocarbons, only equation (1) is of importance. The moisture content of all ingredients should be very low so that equation (3) is only of minor significance. The importance of moisture-free conditions will be emphasized many times. Equation (3) is one reason why.

A brief description of the chemical components in a urethane foam system are included as Appendix II.

How is it Applied?

There are three techniques commonly used to apply a protective layer or fill a cavity with urethane foam. (1) Pour-in-place; (2) frothing; (3) spraying or spray-in-place.

Pour-in-place techniques are used for the preparation of insulated panels, e. g., prefabricated kiln or dryer panels are best made by this methods.

Frothing is the production of foam in a pre-expanded form. The addition of another more volatile blowing agent causes this to occur. It is used in vertical pour application where the surface-to-volume is high.

This report deals only with a two-component spray-applied rigid foam. The spray equipment consists of liquid transfer pumps conveying the separate components to a balanced high-pressure control center. Thence through electrically heated hose at 3, 000-4, 000 spi. to the spray gun. All of the equipment, together with two drums of material are mounted on a steel frame for truck transportation. It is mobile, allowing quick and easy application in the field. Application techniques have now been developed which allow most structures, however complex, to be coated. The coating may be applied to the internal or external surface as desired or dictated by the conditions.

A detailed explanation of the steps involved in the application of sprayed-in-place foam is included as Appendix I. It covers such aspects as surface preparation, correct conditions for foaming and the application of a vapor barrier.

The more interesting points concerning the principal components of a foam system have been briefly covered. Some components are high-lighted more than others, e. g., the fluorocarbon blowing agent. This was stressed because of its influence on thermal insulation.

The chemistry of these foam systems is complex. It increases in complexity almost daily as new ingredients, blending techniques or applications are found. Books are written on individual components. For those whose interest has been stimulated by these opening remarks, or the details in Appendix II, there is no shortage of technical literature.

Normally, one purchases a foam system and all the complex organic and physical chemistry comes free. Use it as directed and the liquids combine, like magic, to produce foam.

There are many kinds of foam. In our desire to find the right foam for the stringent conditions prevailing in some of our equipment, we combined forces with P. P. G. Industries. Through them, the organic and physical chemistry was already available. The education needed concerned the conditions encountered in a dry kiln, humidifier, bake oven, etc. Could a foam be developed which would withstand a high temperature, high humidity, wood acid environment? The batchwise nature of these units subjects the foam to sudden and repeated

expansion and contraction. Could it be made to adhere to a variety of substrates under such conditions and not deteriorate?

I am happy to report that many of these problems have now been overcome.

Corrosion Protection

This derives from the urethane resin created by the chemical components shown in Figure 1. It is very 'inert' to many materials. In fact, rigid urethane is not readily dissolved, softened or destroyed. A typical expanded urethane system would resist or be rated as in Table 1.

This table is a selection from a long list of materials tested against rigid urethane foams. Materials are included which might conceivably be around a sawmill. Even if splashed on the walls of a dry kiln or spilled on a foamed roof, there are few oils, solvents or other solutions which will do it much harm. The temperature levels of 75°F. and 125°F. used in the rating test were not very high. Normally, attack or deterioration increases with temperature. The regular production of foams rated stable at 250°F. has highlighted this gap in our knowledge. Recent tests at 200° - 225° using a variety of the materials shown, prove the foams to have good resistance even at these higher temperatures.

A dry kiln environment is considered corrosive. The contributing factors are heat, humidity and the acidic or other breakdown products of wood. If we define corrosive, as the gradual decay or wasting away of a material. A kiln has as many 'types' of corrosion as materials of construction, e.g., normal metallic corrosion; decay or rotting of wood structures; spalling or etching of cementitious materials.

The protective mechanism of urethane is the same in all cases. It blankets any substrate with an inert layer. Only a thin skin is required to achieve protection. This shuts out contact with the hot, humid, acidic environment. In a dry kiln, a pH 3.5-4.0 is common. Acidity in the form of formic or acetic acid is about 1.0 to 1.5%. Other elements encountered in low concentration are gum or wood resin, terpenes, essential oils and fragrant esters admixed with water vapor. Of this group, water vapor presents the most serious problem. The acidity or other materials do not attack or deteriorate the foam. Wood resin can often be found deposited on the foam after a few months of operation. This is a useful protective coating for the foam. But it can present problems when a new vapor barrier or sealing coat is applied. (See comments on re-coatability in Appendix I.)

Heat, moisture and nutrients in the wood are necessary for fungi to grow. The polymer itself is inert to mildew or fungi. The foam transmits neither heat, moisture, nutrients nor spores. Wood beneath such a layer should not wet or dry rot.

Repeated wetting and drying and acid action account for the spalling of block or concrete and the crumbling of mortars. By avoiding this, deterioration is controlled. Foam readily fills the voids of such materials, providing excellent adhesion of a protective layer.

External building materials corrode or decay by similar mechanisms. Heat, moisture, atmospheric gases and the sun cause the damage. On an outside surface urethane functions the same way; it blankets, keeping the surface dry and out of contact with the atmosphere.

Urethanes are not attacked by atmospheric gases, such as oxygen, ozone or exhaust fumes at temperatures encountered in everyday service. They can withstand driven rain or dust and ice and snow. They absorb the actinic rays of the sun. Therefore, on outside coatings, the vapor barrier, or sealing coat, should reflect or protect from the ultra-violet. This prevents the deterioration of the foam by sunlight. In sunlight, foam 'yellows', or ages. The surface layer becomes friable and powders away, as the thermosetting resin reacts to the ultra-violet. Good coatings prevent this effect.

Table 1

<u>Active Material</u>	<u>Urethane Resin</u>	
	30-day test period	
	<u>Rating</u> 75° F.	<u>Rating</u> 125° F.
Motor Oil	E	E
Gasoline	G	G
Turpentine	E	G
Linseed Oil	G	G
Benzene	E	G
Toluene	E	G
Alcohol	G	G
Carbon Tetrachloride	E	E
Acetone	P	P
Water	E	G
Brine (10%)	E	G
Sulphuric Acid (Conc)	N	N
Sulphuric Acid (10%)	G	G
Nitric Acid (Conc)	N	N
Nitric Acid (10%)	N	N
Hydrochloric Acid (Conc)	N	N
Hydrochloric Acid (10%)	G	G
Ammonium Hydroxide	G	G
Sodium Hydroxide (Conc)	E	E
Sodium Hydroxide (10%)	E	G

RATING:

E - Excellent - material unaffected
G - Good - only slight discoloration took place
F - Fair - Moderate effect on plastic
P - Poor - Considerable change in the material
N - Not recommended - Severe attack on plastic

Lastly, urethane resins do not nourish insects or rodents. Thus, expanded plastic systems from this family of resins normally have long working lifetimes without deterioration.

Strengthening Effect

Density affects mechanical properties. Cellular structure is related to mechanical properties according to the anisotropy of the cells. The height to width ratio of the cells, their shape and the way they are packed all affect the strength. The difference a small percentage of silicone cell control agent makes is appreciated at this point.

A properly prepared foam, with the correct cell structure, has a high strength to weight ratio. This, coupled with the ability of the resin framework to adhere tenaciously to most surfaces accounts for the increased strength. It produces the greatest benefit in a composite or laminated structure. Here, bonding to both faces markedly increases the strength of the composite system.

It can be used as a 'rigidizing' agent which will bond-in-place to metal skins, provide continuous skin support eliminating the usual rib and internal strengthening members. Additional strength is added but the weight of the structure is only increased slightly. This allows lighter support members to be used. Corrugations, vee crimp, etc., may be a thing of the past in the membrane or skin for future buildings. Simpler building designs can be used if urethane foam is added as an insulating/strengthening agent. A layer of foam will carry foot traffic so it can be used on both sides of any roof or structure. The main limitation is temperature. Above 250°F. strength starts to fall off quite rapidly as shown in Figure 2.

We have foamed 0.024" thick corrugated aluminum roofs with considerable success. We are now working on a flat sheet design which is easier to foam. In wooden roof design the three layered T & G has given way to a single deck. A layer of 2" x 6" or 3" x 6" has proved satisfactory. When correctly foamed, this has adequate strength for snow loads, inspection of vents or the foot traffic necessary to apply a built-up roof. Our latest venture on roofs involves the use of plywood support members. Correctly foamed on both sides, this plywood 'insert' can produce a very sound roof structure.

These thoughts can also be applied to the side and end walls of kilns or any other building. No longer are multi-layer walls necessary. If adequate structural support is available in the form of wooden pilasters or steel beams; why not a simple wall membrane and foam to complete the building?

In flat roofed kilns, we have successfully used a composite foamed panel design for snow loads of 100 pounds per square foot and over. These laminates consisted of 0.024" thick aluminum skins bonded by 1 3/4" foam. They were produced by a pour-in-place technique at Portland. We are currently working on a simpler design for flat roofs. This will have the high strength features desired, but allow spray-in-place foam to be used.

In other large buildings around a sawmill which house planers, saws or grading lines, simple quonset, peaked roof or barn type structures can be used. A coating of foam on the sheet metal or wood skin can provide the building strength to resist snow and wind loadings. Buildings coated in this manner will be cool in summer and easy to heat in the winter. A layer of foam also helps with the acoustics in any building.

Thermal Insulation

The thermal conductivity of a foam system is the effect of several factors contributing to the over-all properties of the insulating structure: Conduction through the resin solids; conduction through the gas; radiation and convection. A urethane foam is like a honeycomb. The framework is composed of a large number of fine-walled, closed cells. These cells trap the low conductivity blowing agent. With spray foam the closed cell content is over 95% insuring excellent retention of the fluorocarbon.

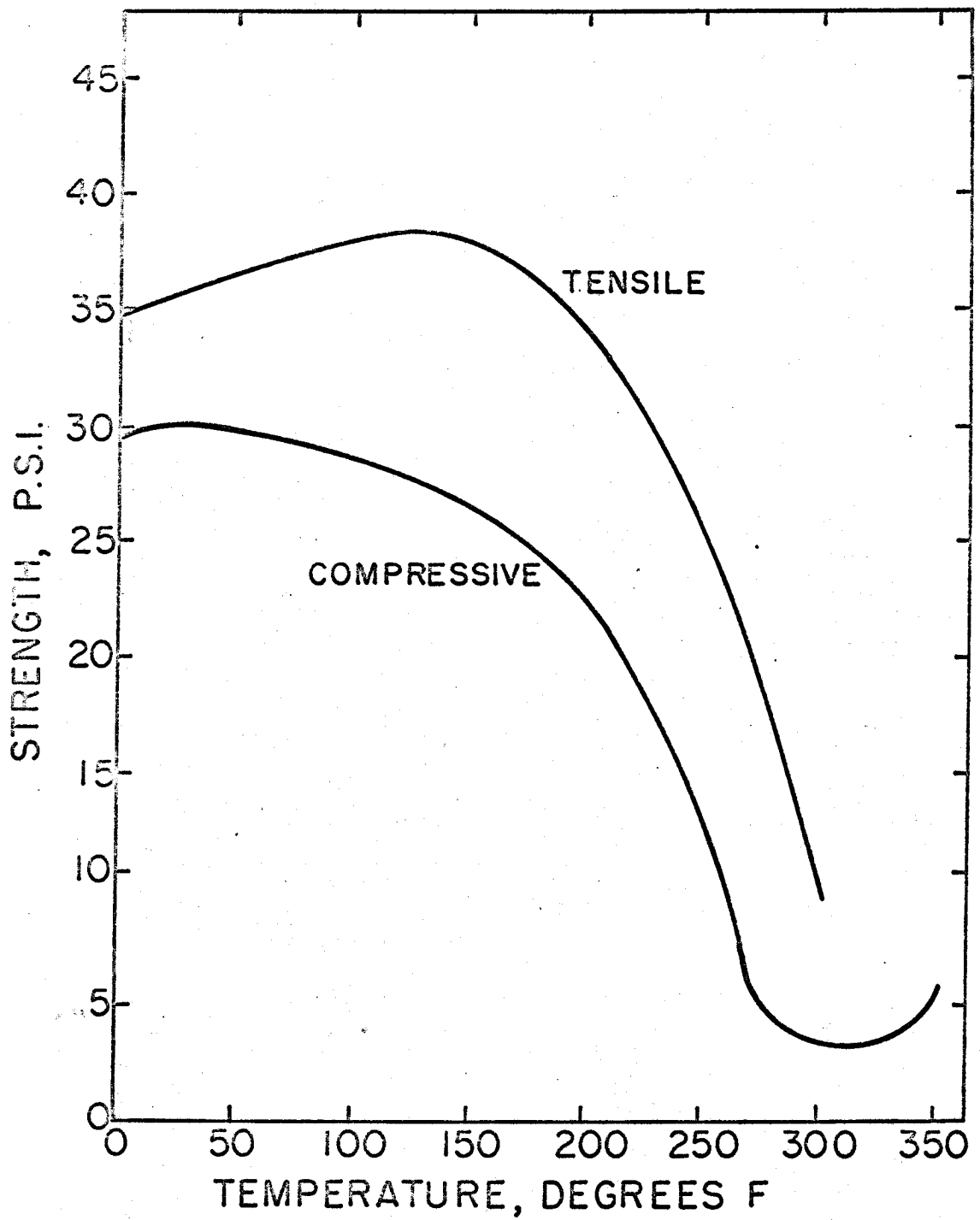


Figure 2. Approx effect of temp. on 2 lbs cu. ft. rigid foam fluorocarbon blown

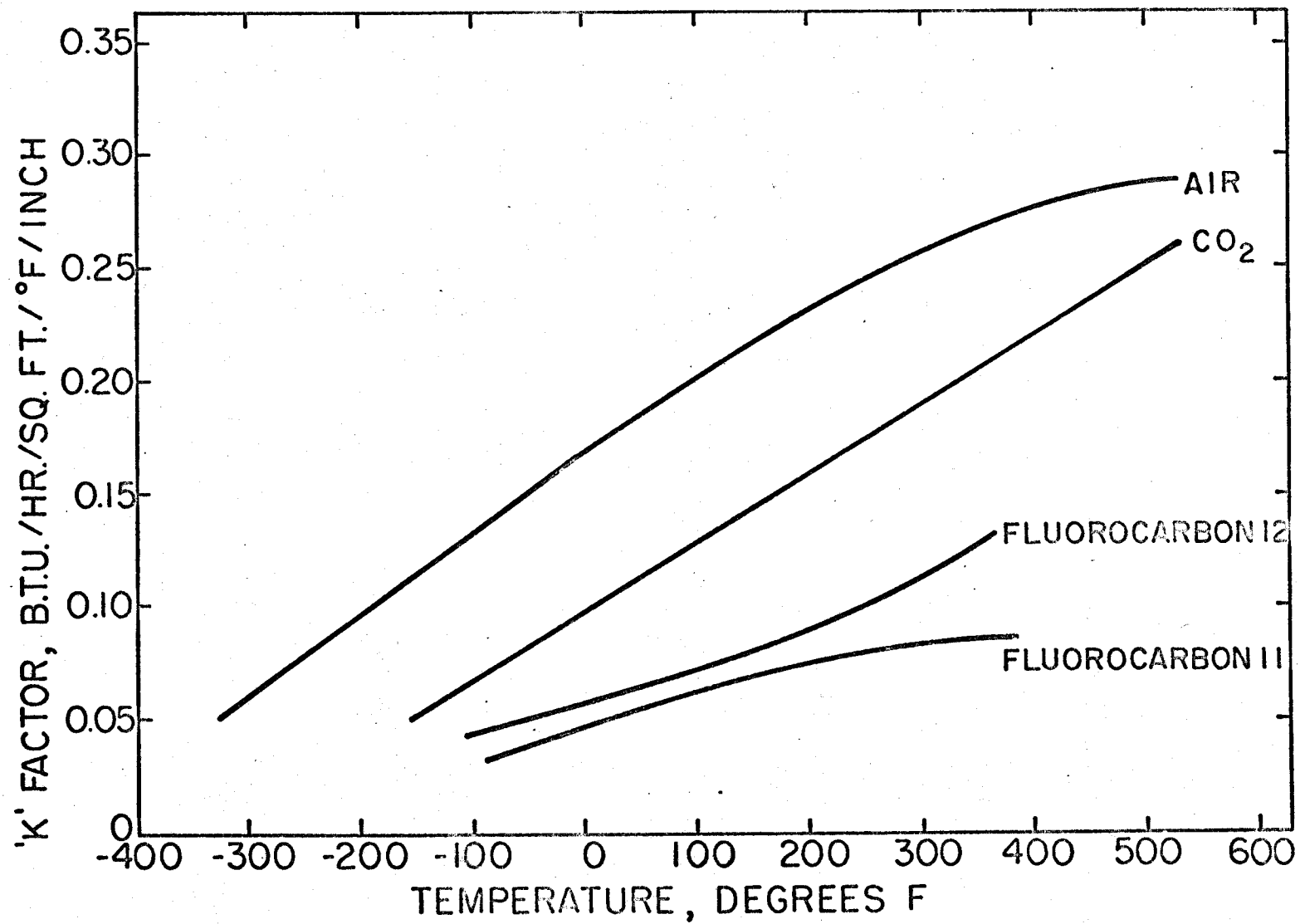


Figure 3. Thermal conductivity of gases at various temperatures

Other insulators such as cork, rock wool, glass wool, vermiculite, etc. depend also on voids filled by gas. Generally, these voids are filled by air and the air gaps are interconnecting.

A comparison of the thermal conductivity of some void filling gases at room temperature highlights the fluorocarbon in foam.

Gas	K factors BTU/Hr. Sq.Ft./°F. in. at 68°F.
C Cl ₂ F ₂ (Type 12)	0.064
C Cl ₃ F (Type 11)	0.057
CO ₂	0.117
Air	0.180
Hydrogas (Moist air)	0.25-0.5
Water	4.25

The change in thermal conductivity of the gases over a wide range of temperature is given in Figure 3.

The interconnecting voids in most insulators allows air to diffuse through the structure. Moisture laden air or 'hydrogas' is an even better conductor. Voids filled with humid air will thus show a greater increase in thermal conductivity than for dry air shown in Figure 3. The closed cell system of foam reduces this tendency.

In all foam systems there is a tendency for the blowing agent to diffuse through the cell walls and equilibrate with the air. At equilibrium the conductivity of the foam will be the result of the diffusion process, altering the gas content of the cell according to the partial pressures of the gases.

Fluorocarbons diffuse through a urethane film slowly.

Carbon dioxide diffuses	"	"	"	"	750 times faster.
Air	"	"	"	"	1,000 " "
Hydrogas	"	"	"	"	100,000 " "

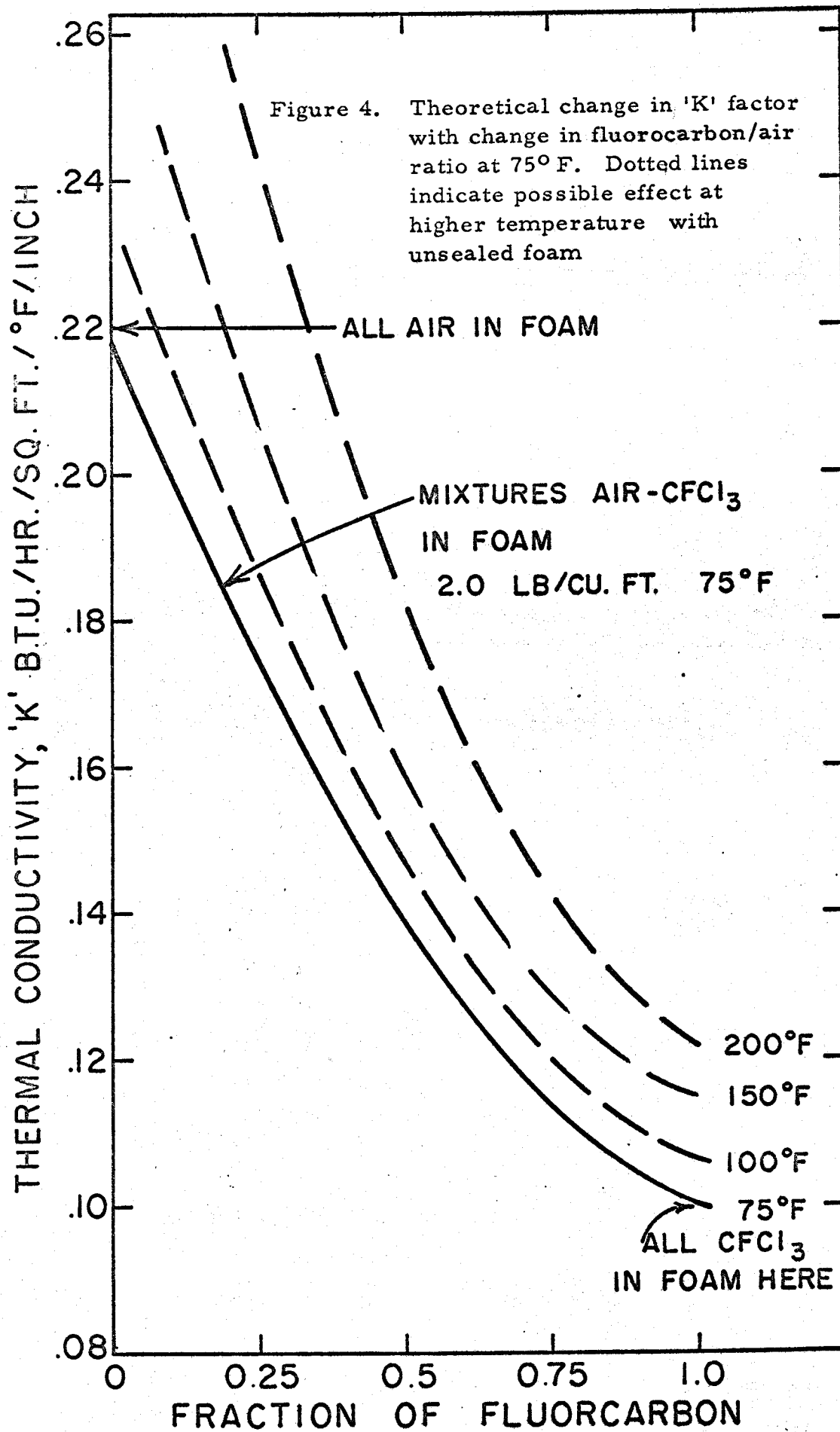
Figure 4 shows the change in conductivity at room temperature as air displaces fluorocarbon. Gases diffuse more rapidly through a solid as temperature rises. Time and humidity also influence the increase in conductivity. A summary of these effects allowing a working "k" factor to be determined, is shown in Figure 5. A "k" factor of 0.16 BTU/Hr. Sq. Ft./°F. inch at 75°F. is used in calculations. It allows the thickness of foam necessary for various tasks to be calculated. The thickness recommended for heated or refrigerated buildings is given in Figure 6.

The most important factor in the cellular foam, from a conductivity standpoint, is the gas. We wish to retain it within the closed cellular network. Hence the emphasis on vapor barrier or sealing coats. They all attempt to reduce the drift in "k" factor by decreasing the permeability of the foam surface. This reduces air/fluorocarbon interchange and penetration by moist gases.

Density affects the thermal conductivity of foams, as shown in Figure 7. A minimum occurs in the density range 2 to 3 pounds per cubic foot. We attempt to achieve a 2 Lbs./Ft.³ spray foam by the proper balance of blowing agent and cell control agent in the system.

Resin solids have a "k" value of 0.5-2.0. High density foams increase the contribution of the solid to the total conductivity. This is the influence seen in Figure 7 above 3 Lbs./Ft.³ density.

Of interest to most people is the comparison between foam and other building or insulating materials. Using the "k" factor, or resistance (R) of the materials to heat flow, Table 2 can readily be produced. This only highlights the excellent insulation properties of foam. A comparison of this nature, to be accurate, must take into consideration: Installed cost of various materials; expected life span; amount and frequency of maintenance.



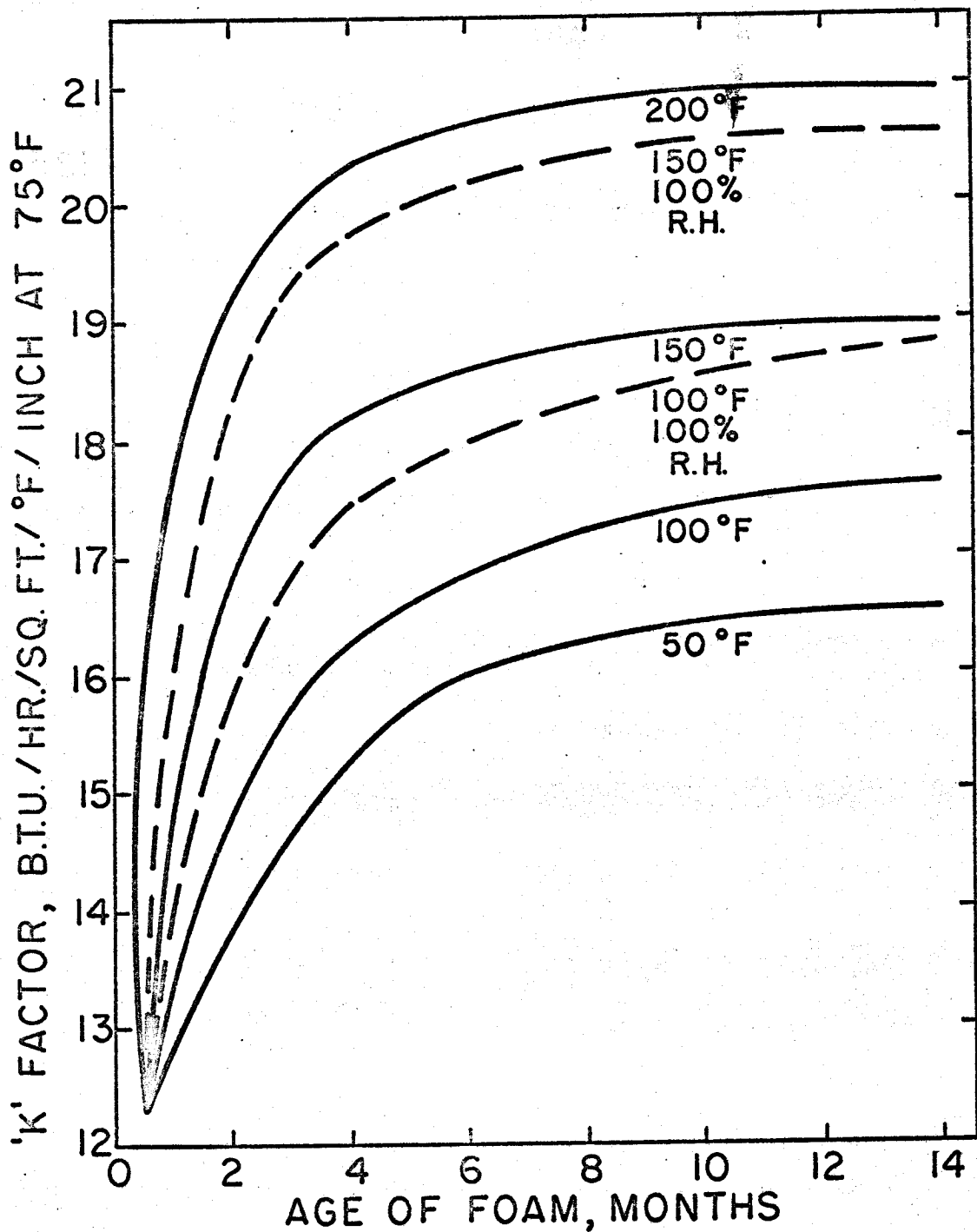


Figure 5. Typical effect of time, temperature, humidity on 'K' factor of 2.0 lb/cu. ft. spray foam, fluorocarbon blown, no vapour barrier

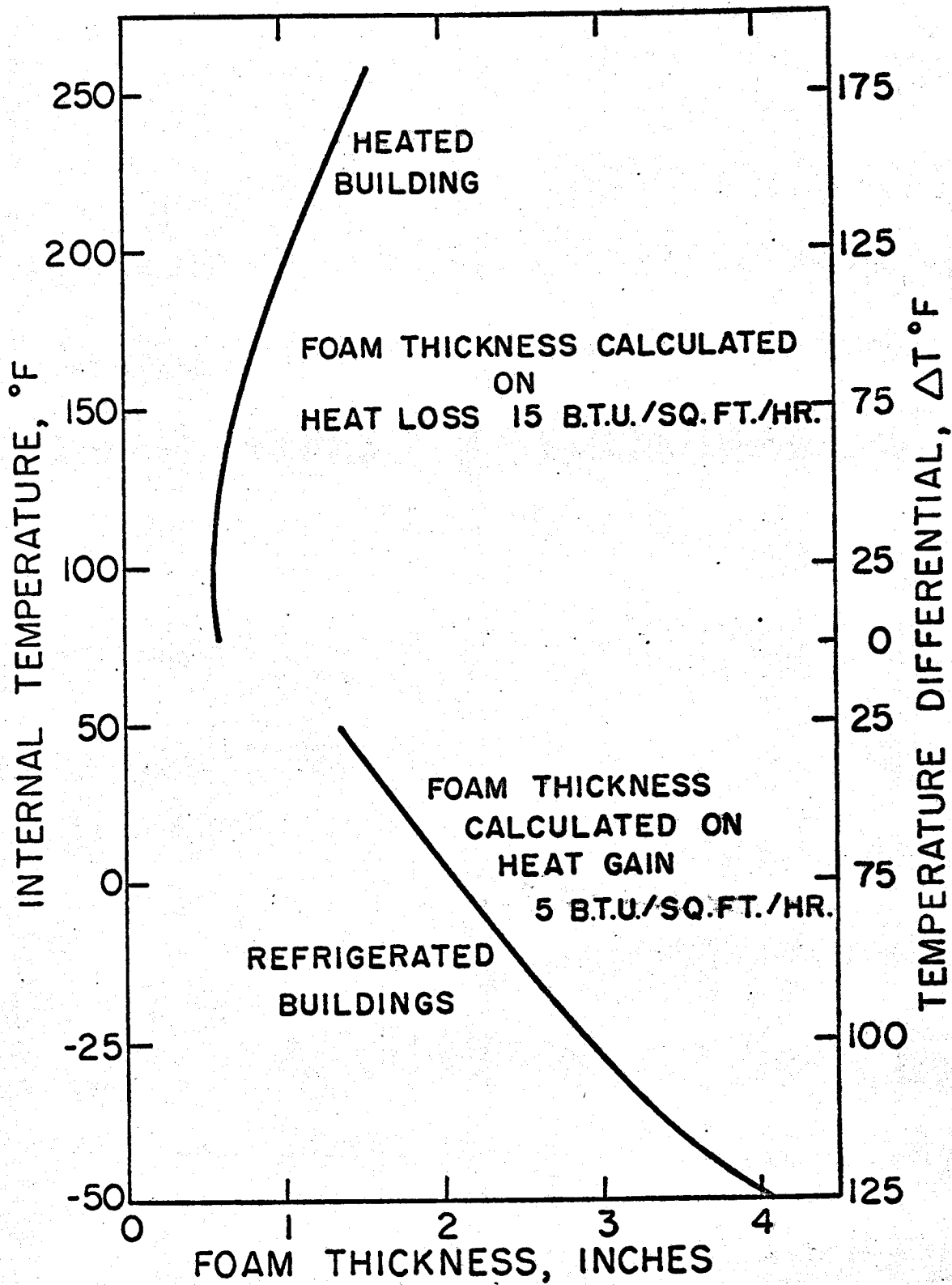


Figure 6. Estimation of foam thickness for heated and refrigerated buildings ambient conditions 75° F. 50% R.H.

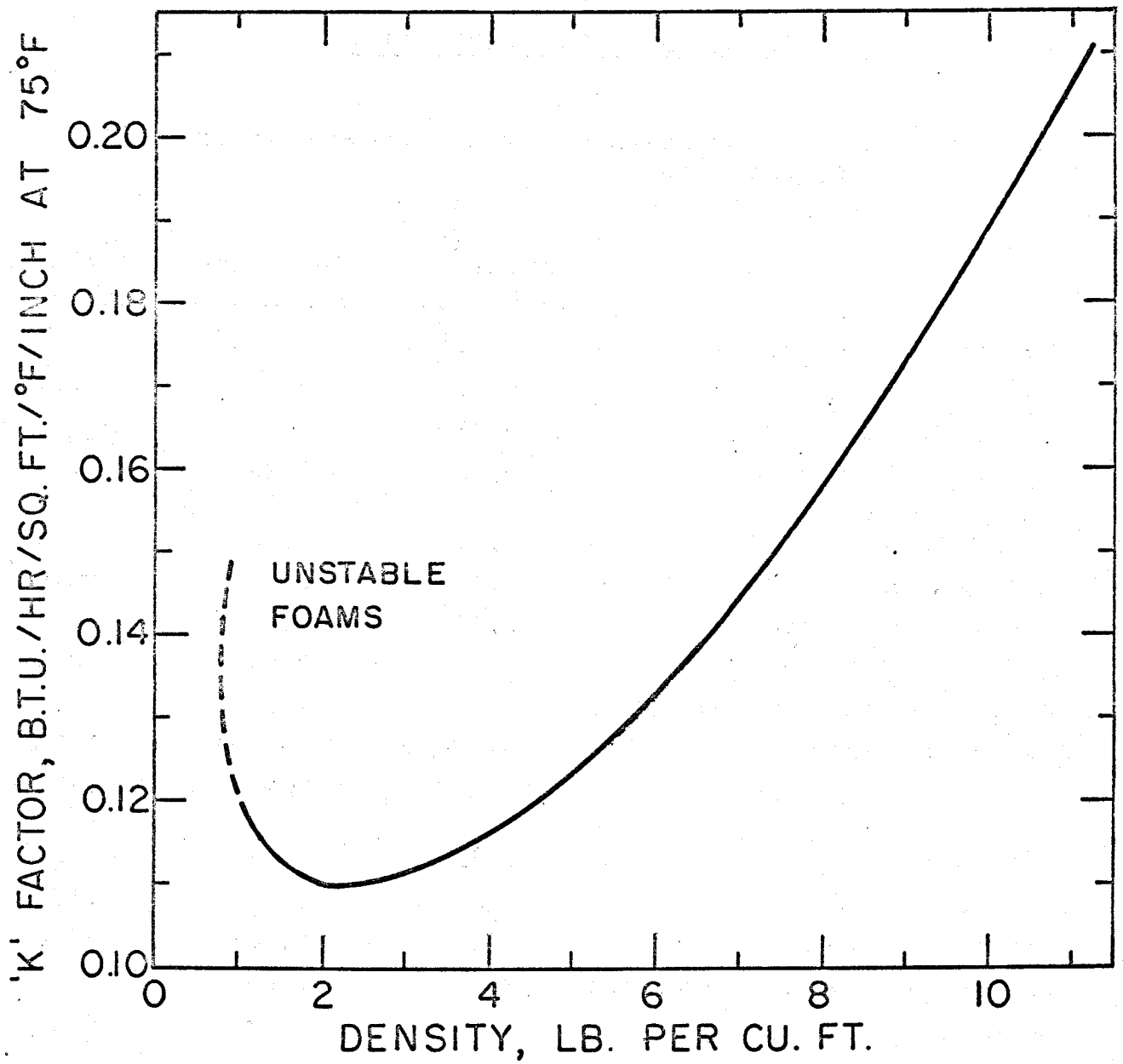


Figure 7. Effect of density on thermal conductivity of rigid urethane foam fluorocarbon blown

Table 2

INSULATION COMPARISON CHART

Non-urethane insulation thicknesses required at a mean temperature of 80° F. vs. 1" of high-temperature foam.

<u>Material</u>	<u>Conductivity "k"</u>	<u>Resistance "R"</u>	<u>Thickness Inches</u>
High-temperature Urethane	0.16	6.25	1
Cork	0.22	4.6	1.35
Mineral Wool (2 Lbs./Ft. ³)	0.25	4.00	1.5
Glass Wool or Fiberglass	0.27	3.70	1.75
Structural Wood Fiber (20 Lbs./Ft. ³)	0.38	2.63	2.4
Perlite (expanded)	0.38	2.63	2.4
Vermiculite (expanded)	0.48	2.08	3.0
Fiberboard 25/32"		2.06	3.0
Concrete (expanded shale aggregate)	0.90	1.11	5.5
Wood (across the grain)	0.65-0.1.15	0.15-0.87	4.0-7.25
Wood (parallel to grain)	1.6 -2.9	0.625-0.335	10.0-18.5
1" nominal lumber (accepted Industry Standard)	1.02	0.98	6.4
Asbestos "T" Deck	4.0	0.25	25.0
Common Building Brick	4.9	0.205	30.0
Concrete (sand and gravel aggregate)	12.0	0.08	78.0

"k" = thermal conductivity in BTU/Hr. Sq.Ft./°F. inch thickness

"R" = resistivity or resistance to heat transmission $R = \frac{1}{K}$

We have foamed a number of existing dry kilns produced from a variety of materials. Under Corrosion Protection I mentioned how we expect to reduce maintenance and annual upkeep. We have speculated on occasions on how long we can extend the useful life of these building materials. In a dry kiln, we have indications that foam can: Reduce start-up times; hold the kiln at temperature for long periods without heat demand; lead to better over-all temperature and humidity control in a building.

By mentioning the protection, strengthening and insulating effects I have attempted to show the possibility for foam in over-all building considerations.

Based on insulation value, Table 2 shows 1" foam equivalent to 6.5" lumber. This is about equal to a three-layer T&G wood roof. We have been comparing the installed cost of this type of roof, its projected lifespan and annual maintenance with 1" foam on a roof. Here the wood deck can be lighter; the foam adds the strength. Insulation value is better and protection of the wood allows at least a 10-15 year life to be projected. In this case, the long-term economics appear to favor the foamed roof.

Another example considered was a prefabricated kiln. Cost of preparing aluminum panels, complete with fiberglass insert, their erection, and lifespan was compared to a foamed aluminum skinned building. The installed or first cost shows the foam building is cheaper. Further information on the maintenance or upkeep of the foam structure and its durability over a 15-20 year period are required to complete a study of this type.

These are two examples of how urethane foam can assist kiln economics. The return on capital expenditure is often of short duration; especially in old kiln structures. It does not only apply to kilns. The same approach can be used on humidifiers, bake ovens or dryers.

Storage tanks for hot water or condensate; retorts and tanks for wood impregnation fluids; tanks and pipelines for chemicals which solidify in the cold or need to be kept at elevated temperatures, all have been foamed successfully.

Storage buildings is another area receiving attention. Freedom from sweating roofs can be guaranteed with a layer of foam. Working buildings which should be warm in winter and cool in summer are not above consideration. The comfort in these buildings when foamed is appreciated and shows as increased productivity.

The Cost of Applying Urethane Foam

To arrive at the installed cost of a layer of foam, the simplest procedure is to cover the operations involved. These are described in Appendix I as: Surface preparation, involving descaling or degreasing, priming and reinforcing; care of foam components and spray equipment; foam application; application of sealing coat.

(1) Surface Preparation

If it involves the removal of layers of paint or coating from old structures, the best process is sandblasting. Different grades of sand allow the surface finish to be tailored to the needs of the job. Priming is often unnecessary after sandblasting, especially if foaming is not delayed. Cost of this preparation is approximately 10-15¢/Sq. Ft., depending on the nature of the work. This cost includes labor, material and equipment. Less elaborate, but more expensive treatments are air scraping or wire brushing.

Films of oil, grease or moisture can be removed most easily by a good non-toxic solvent. A gallon of good solvent costs \$1.00-\$1.50 and can clean 200-300 sq. ft.

A prime coat, applied to promote adhesion is good practice. Primers vary with the substrate. Compatibility with the foam is also important. A gallon costs approximately \$2.50-\$3.50 and covers about 300 sq. ft.

If reinforcing is required, it can be supplied as mesh, staples, clips, or welded studs. Mesh reinforcing costs approximately 2¢/sq. ft., staples can be 1/2¢/sq. ft., while stud welding might run to to 3-4¢/sq. ft.

(2) Care of Foam Materials and Spray Equipment

Neither components of the foam system should be allowed prolonged contact with the moisture in the atmosphere. To prevent this, the drums are blanketed with dry nitrogen. A special nitrogen supply with dew point around -30°F. to -40°F. is used. The cost is 12 1/2¢/ft.³

Pumps transfer the components from drums to the spray gun via electrically heated hose. A non-hygroscopic lubricant is supplied continuously to the pump shafts. These cost approximately \$4.50/gal.

The spray gun nozzle needs to be flushed with solvent on occasion to avoid build-up of resin solids. On less frequent occasions the heated pressure hose needs to be flushed clean. New tips or needles are required for the spray gun and a felt washer needs replacing occasionally.

All these items are classified as accessories in the cost analysis.

(3) Foam Application

One pound of liquid system should theoretically produce 4.65 bd. ft. of 2.0 lbs./ft.³ density foam. (See calculations Appendix I.)

The theoretical return is never obtained due to overspray or fallout losses, poor temperatures, etc. It can vary anywhere from 4.5 bd. ft./lb. to 3.3 bd. ft./lb., depending on the conditions--a loss of from 3.0% - 30%. At a raw material cost of 50¢/lb. the foam cost can vary from 11 - 15¢/bd. ft.

In estimating a kiln, we assume a loss of 15% - 20%, giving 3.8 bd. ft./lb. of system, or a foam cost of 13¢/bd. ft. On outside work, or where large uninterrupted areas are involved, a 10% loss is realistic. Foam prices are then 11 - 12¢/bd. ft.

(4) Application of Sealer

Coating materials suitable for this work range in price from \$2.50 - \$6.50/gal. The coverage expected is 75-80 sq.ft./gal. Foam surfaces having coarse 'orange-peel' texture may reduce this to 60 sq.ft./gal. A cost per coat of sealer ranges from 5 - 10¢/sq. ft.

A two-coat application is recommended, particularly in dry kilns and humidifiers. Outside roof applications have had some success with asphalt based materials or latex emulsions. On external surfaces, ultra-violet is the main problem. The presence of a reflective pigment in these coatings is a help.

(5) Other Factors Considered in Cost Estimates

a. Site visits are required to inspect the state of old buildings, complexity and congested nature taken into consideration.

b. Drawings and design work to outline new ideas.

c. Depreciation of spray equipment and vehicle. Our complete rig cost \$10,000.00.

d. Insurance of equipment and vehicle.

e. Accident insurance of operators.

Table 3
Approximate Application Costs
for
Rigid Sprayed-in-place Urethane Foam
Coating 1" Thick

<u>Old Structure</u>	<u>¢/Sq.Ft.</u>	<u>New Structure</u>	<u>¢ Sq. Ft.</u>
<u>Surface Preparation</u>		<u>Surface Preparation</u>	
Sand blast, brush or scrape 10.0 (8.0-12.5)		Degrease and/or prime and rein- 4.0 force as necessary.	
Prime surface as 4.0 necessary	14.0		4.0
<u>Foam Application</u>		<u>Foam Application</u>	
Foam raw materials (11.0-15.0) 13.0		Foam raw materials (11.0-15.0) 13.0	
Two sealer coats 14.0 (6.0-10.0)		Two sealer coats 14.0 (6.0-10.0)	
Accessories for 1.0 spray gun (Solvents, N ₂ , etc.)	28.0	Accessories for 1.0 spray gun	28.0
<u>Principal Labor Costs</u>		<u>Principal Labor Costs</u>	
Travel & Subsistence		Travel & Subsistence	
150-500 Miles 7.5 (5.0-10.0)		150-500 Miles 7.5 (5.0-10.0)	
2-3 operators to prepare surface, prime, reinforce foam and seal 15.0 (12.5-17.5)	22.5	2-3 operators to degrease, prime, foam and seal 12.5 (10.0-15.0)	20.0
	<u>64.5</u>		<u>52.0</u>
Profit 12%	7.75		6.25
	<u>72.25</u>		<u>58.25</u>
<u>Overall Price Range</u>		<u>Overall Price Range</u>	
60.0¢/Sq.Ft. - 89.6¢/Sq.Ft.		48.1¢/Sq.Ft. - 72.8¢/Sq.Ft.	
Average Fixed Costs	40%	Average Fixed Costs	56%
" Variable Costs	60%	" Variable Costs	44%

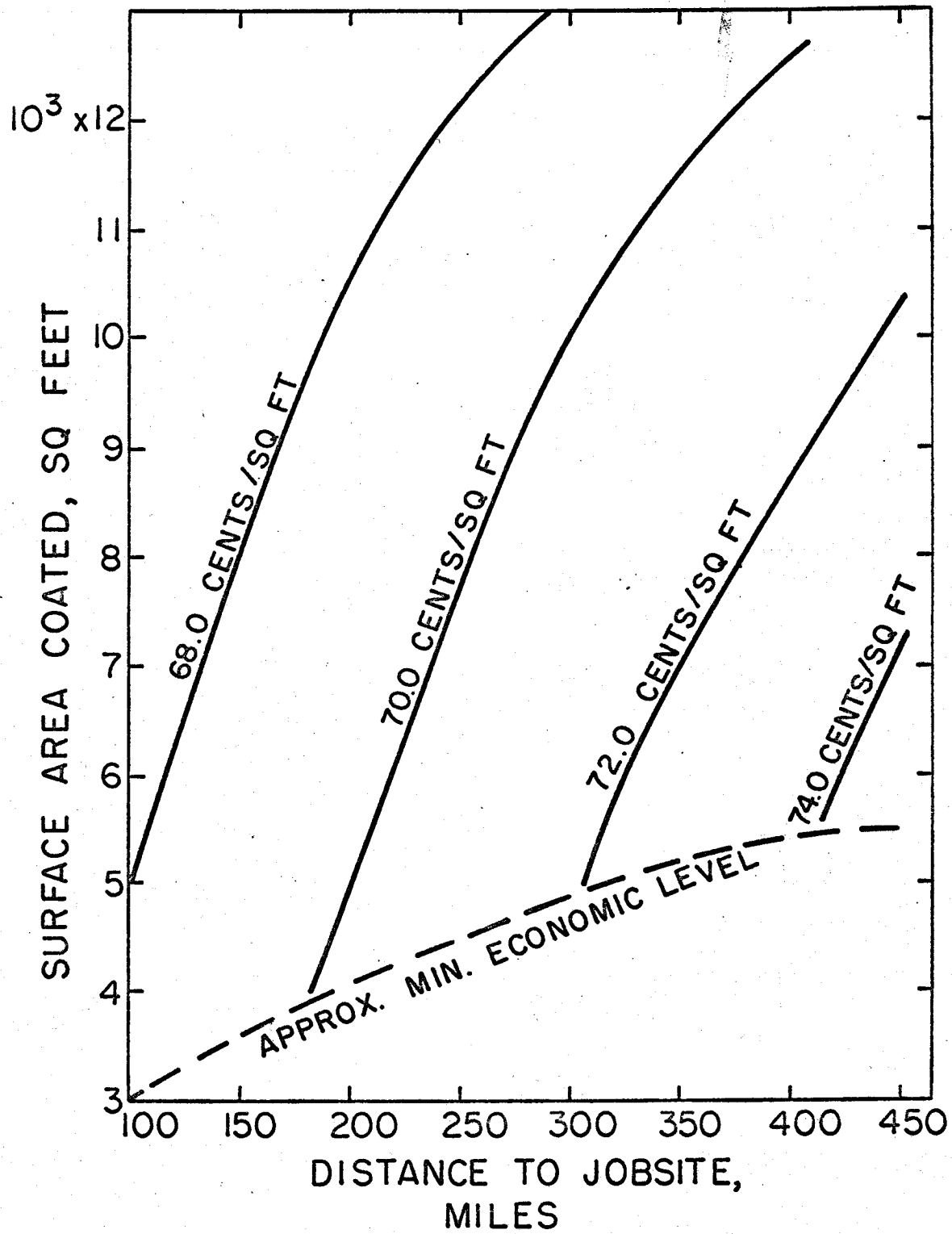


Figure 8. Simplified applied cost chart for variations in distance & sealed.

- f. Freight allowed on all raw materials.
- g. Distance to jobsite and workers involved.
- h. The area to be coated at one time.

All of these cost factors are taken into consideration in Table 3. This is typical of the costs involved in the treatment of an old or a new kiln.

We assume 5,000 square feet is about the minimum internal surface area that can be coated economically at 500 miles. Or a total cost of approximately \$4,000.00 should be involved to justify a site visit. As the area to be coated increases or the travel involved decreases, the price and the acceptance level alters. Figure 8 shows this relationship where 66' single-track kilns are used to compute the surface area coated. Variable costs have a greater influence on the price for an old structure as shown by Table 3.

On outside coating work, the cost to apply and seal 1" of foam ranges from 35¢/sq. ft. to 55¢/sq. ft. Surface preparation and area involved are the two main variables.

On a roof, particularly a flat roof, 35 - 40¢/sq. ft. is a useful working figure. On storage tanks, etc., where scaffolding is required, but surface preparation is minimal or unnecessary, a 1" sealed coating can be applied for 50 - 55¢/sq. ft.

These facts and figures show that guidelines or estimates can be given for the cost of coating various structures with foam. In most instances, however, the details specific to each building must be studied before realistic prices can be stated.

APPENDIX I

Steps in the Foaming Process

I. SURFACE PREPARATION

A. Old Structures

1. Removal of old coatings from substrate. The substrates vary between wood, block, tile, concrete, steel or aluminum. If the expense involved in removal by sand blasting, air scrapers, solvents, etc. is too great, 'cover-up' techniques can be employed.

Sand blasting runs 10 - 15¢/sq. ft., depending on the complexity of the work.

2. Foam does not adhere well to surfaces coated with dust. This can be old paint, cement dust, saw-dust or fly ash. Blowing the surface clean with dry, oil-free air is a help.
3. Once cleaned, it is good practice to prime or treat the surface in some manner. This coating should not be thick or heavy. Adhesion promotion is the main aim.

This treatment is not always essential. Each circumstance dictates the requirements.

4. On 'difficult' surfaces, such as an awkward overhead area, an overhang, or a part of a combined structure subject to differences in expansion and contraction, it is sometimes useful to reinforce. This again assists adhesion or provides an anchor. It can be in the form of reinforcing mesh, staples, clips, studs or any fastener or support grid which gives the foam a better chance to remain in place. A metallic or non-metallic mesh is suitable for the task. They cost approximately 2¢/sq. ft.

B. New Structures

1. Removal of grease films from steel, aluminum or poured concrete. Finger marks on steel or aluminum are sufficient to cause poor adhesion. Non-toxic, non-hazardous solvents which do not just move the grease film around cost at least \$1.00 per gallon. A gallon can be expected to clean 200-300 sq. ft.
2. A light prime coat of material compatible with the foam, e.g., a urethane, vinyl, alkyd, acrylic, or epoxy wash primer provides a well prepared surface. These materials cost \$2.50 - \$3.50/gal. and cover approximately 300 sq. ft./gal.
3. On occasions, some form of reinforcing is useful even with 'new' clean structures. Overhead work or where a heavy layer (1 1/2" and greater) is used an expansion is somewhat restricted can call for a secondary support system.

With either type of structure, moisture is unwelcome. Hence, the request for heat and dry surfaces. With an existing unit, we usually ask that at least 24 hours at operating temperatures elapse between the last charge and the start of foam application. Wood roofs, block or concrete walls have a chance to dry out.

In new structures, green or air dried lumber, fresh block or concrete walls, often soaked during erection can take longer than 24 hours to dry out. It is unwise to rush this phase because it 'looks' or 'feels' dry. We realize your kiln or equipment is down and losing money, but undue haste is not recommended.

Surface preparation is one of the keys to success in this work. Rush it, or turn a blind eye to essential points and you can pay for it the rest of the coating's operating life.

The above treatments are all applicable for field work on old or new internal structures. Preparation, and the correct conditions for foaming external surfaces is also controlled by the weather. Because of generally cooler conditions, a faster reacting foam is used. Warm, clean and dry surfaces, however, are again best.

Where foam work is done at the factory, other surface treatments, such as Bonderizing, Phosphatizing Anodizing as well as sandblasting, can be used as appropriate. The same type of wash primers, as mentioned above, are applied if needed.

2. FOAM APPLICATION

A. Preparation and Care of Materials

Spray-in-place urethane foam is normally produced by a two-component system, (resin and isocyanate). Care should be taken not to expose either component to water or air. Moisture in the atmosphere is sufficient to cause a reaction. Dry nitrogen is used as a blanketing agent on the drums of material. A non-hygroscopic lubricant, such as tricresyl phosphate (T. C. P.) is used on pump shafts.

The resin, as previously mentioned, contains the fluorocarbon or blowing agent, catalyst and additives. It should be kept below 75°F. to prevent loss of blowing agent. Prolonged exposure of the drums to the sun is unwise. However, it is a help to place the drums of raw material in a warm building, e.g., a dry kiln, prior to use. This reduces the viscosity of the components which assists pumping and metering. The necessary balanced flow to the spray gun is more readily obtained. Pumping and metering units for airless spray are designed for high pressures of 3,000-4,000 psi.

Usually, each component is pumped through electrically heated pressure hose. The temperature of the liquids at the spray nozzle is, therefore, accurately controlled at a desired 90°F. to 110°F. The substrate temperature is not so easy to obtain and/or maintain, at this temperature. The ability to maintain a high

This is exclusive of overspray or other losses.

The foam components cost approximately 50¢/lb. When estimating, I make allowances for waste: in the drum; balancing the system and setting the spray gun; overspray and fallout; poor volumetric return due to low temperatures.

Overspray and fallout can be particularly prevalent in the congested areas of a dry kiln. We assume one (1) lb. of system actually produces 3.80 bd. ft. of foam on a surface. An over-all loss of approximately 18.0%. The raw material cost is, therefore, 13¢/bd. ft. of foam.

For most applications, outputs of 2-10 lbs./min. have been used. In a dry kiln, a large unobstructed wall area might allow the use of an 8 lb./min. nozzle or tip on the spray gun. In the enclosed and congested fan deck or vent area, a 2-3 lb./min. spray is about the maximum. Usually, the final thickness is built up from 1/4" to 1/2" layers produced per pass.

On outside work such as roofs and storage tanks, the higher rates of application normally apply. One restriction is wind velocities greater than 10-15 m. p. h. This may result in excessive heat loss and overspray. Caution should be used in attempting to foam under windy conditions. Rain and high humidity also rule out foam application. Outside work is, therefore, seasonal in some localities.

3. VAPOR BARRIER OR SEALING COAT

Vapor barriers are required with urethane foams exposed to temperatures below 32° F. Some form of sealing coat is recommended for higher temperature operation. Mastics, foils and films have all been used successfully as water vapor barriers with rigid urethane foam. Typical among those tried are: Tedlar, aluminum foil type; Paper, aluminum foil type; Tedlar, neoprene asbestos; Hypalon, based coatings.

Bitumastic based materials and other elastomeric based coatings are also being tried. Latex emulsion type sealers have been used with some success on external applications.

This list shows that many materials can be considered as a vapor barrier/sealing coat. The sealing coat should be inspected every 2-3 years. This is particularly true of dry kiln operating above 200° F. It also applies to an outside roof or tank coating subject to the ravages of sun, wind and rain. A single coat application at this stage may be all that is necessary to maintain a sound, protective and insulating system.

At this re-coating stage, many of the original materials show up in a bad light. A cheap material, used because first cost was all important, may have flaked, crazed, or dried out. Removal of this old coating from foam can be expensive. You cannot scrape, or sandblast foam as readily as wood, block, concrete or steelwork.

Consideration should be given to the 're-coatability' of the foam surface at the outset, especially if a long, useful life is desired from the foam.

Coating material costs normally range from \$3.50-\$6.50/gal. At 35%-40% solids, a 20 mil wet film produces a 7 mil dry film and 75-80 sq. ft./gal. coverage. Raw material cost is 5-10¢/coat.

In most instances a 2-coat system is recommended to give adequate protection at high temperatures and high humidities. The combination aluminum foil coatings generally cost a little more. Some are applied to the foam while it is still at the tacky stage, others use an adhesive between foil and foam.

The proper preparation of a structure and the correct application of a foam emphasize the importance, on our part, of skilled operators. There is also the question of cooperation on any jobsite. Many of the conditions necessary for good foam application are not easily obtained. We require management, interested in their investment, to help achieve the best conditions possible.

After a foam treatment, we rely on a thoughtful management to bring to our attention any inconsistencies which may occur. This is important at start-up and in the first few months of operation. Foam has excellent adhesion to itself, so repairs or further sealing are a simple matter. After a few years of operation, it is wise to inspect the entire sealed system. It will ensure that a sound protective and insulating layer is maintained.

With this two-way approach to the application of foam, under these testing conditions, I believe foam can become a useful tool to the wood products industry.

APPENDIX II

Components of a Foam System

A. Polyhydroxyls or Polyols

At one time, castor oil and its derivatives were used. Attention switched to polyesters as they provided a high percentage of closed cells and high-strength combined with good resistance at elevated temperatures. Lower cost polyether polyols are now displacing the polyesters.

They should have a high functionality, or ready reaction with isocyanates. Low to intermediate viscosity to ease handling and pumping is useful. A balanced chain length to provide a strong cellular system. Short chain molecules increases the cross-link density of the foam. They add to the rigidity of the resin and too much cross-linking produces friable foams.

The choice of the polyol is usually a compromise between the physical properties desired in the foam, the ease of handling, and the cost.

B. Polyisocyanates

Polymeric or undistilled isocyanates are dark in color. They have a higher viscosity than pure isocyanates but a lower isocyanate content.

The polyisocyanates offer attractive possibilities for improving the economies of the foam preparation. They cost less than pure isocyanates. They have significantly improved handling characteristics. The very low vapor pressure reduces the vapor hazard during handling. More comfortable and less complicated handling procedures can be used. They are stable in storage and do not freeze until - 10°F. and below.

With complex isocyanates, fire retardant components and materials to improve resistance to ultra-violet rays can readily be incorporated. They are also useful in preparing foams with high heat distortion resistance. The foam properties which benefit most from their use are related to the permanence of the foam; thermal, and dimensional stability and flame resistance.

C. Blowing Agents

Early foams were blown or expanded with carbon dioxide liberated as a result of the isocyanate-water reaction (equation 3, Fig. 1).

Modern foams for normal insulation purposes are expanded by fluorocarbon blowing agents. These materials have a very low thermal conductivity. The relationship of two fluorocarbons to air and carbon dioxide, which can fill the cell voids, is shown in Figure 3.

The important properties of the most commonly used blowing agent are listed in Table 4. The low cost of the fluorocarbons, their low b. pt. and low thermal conductivity in the gaseous state, are the main reasons for their widespread use.

Table 4. Important Properties of the Blowing Agent Fluorocarbon $C_2Cl_2F_6$.

Toxicity	Has a low value. Not a serious health hazard.
Flammability	Does not burn.
Thermal Conductivity	Is low at room temperature. Does not increase rapidly with temperature.
Volume Expansion	Very high. Some 250 times its equivalent liquid at room temperature.
Diffusivity	It is low--meaning the heavy gas does not diffuse through the cell walls very rapidly.
Latent Heat	This is high. It helps absorb the exothermic heat of reaction. It makes foaming conditions less critical and provides better control over finished product.
Viscosity	It is very low. Polyols and isocyanates are very thick. This material helps reduce their viscosity which aids pumping, metering and mixing.
Solvent Power or Reactivity	Has to be low or it would act on the urethane resin system. They do not produce cross-linking. Are inert and retained in the polymeric structure of foam.
Stability to Water	Very stable in water. Does not readily react with water vapor to produce corrosive by-products.

The low cost of the halocarbons, their low boiling points and low thermal conductivity in the gaseous state are the main reasons for their widespread use.

D. Catalysts

The reaction between a polyol and isocyanate will take place without a catalyst, but it is too slow. Without a catalyst, a foam may expand but it may not cure adequately to give good physical properties.

Suffice it to say there are a number of classes of catalysts and a wide range of materials available in each. A knowledge of their chemistry is now well advanced. It is a fairly simple matter to select a suitable catalyst, to trigger the reaction of any mixture of polyol and isocyanate, at a known rate, to produce the desired end product.

F. Surface Active Agents

Many foam systems contain as little as 0.25% surfactant based on the total weight of ingredients. They are a minor but very important ingredient. In modern, rigid foam systems, the surfactant is usually a silicone derivative.

They have been termed, foam stabilizers, cell control additives, regulators, or agents. As the name implies, they have a marked effect on surface activity. The silicones used are powerful surface tension depressants. They reduce the energy required to form new surfaces and thus promote bubble formation. They also equalize tension on the surface of the bubble, imparting resilience to the film and resistance to collapse when distorted during rising of the foam.

The practical effect is uniform, fine cell-structured foam, with a high closed cell content. Such foams have better all round physical properties.

F. Flame Retardants

Urethane foam is an organic material blown into cellular form. It does not decompose below 375-400° F., but it will burn or char to simple carbon if the temperature is raised high enough. Its widespread use in homes, trailers, storage buildings, etc. as an insulating media has led to an extensive investigation of its ability to spread flames, feed a fire, etc.

This was never high even with the early urethanes. Modern foam systems contain additives to help further suppress the ability to ignite, spread flame or continue burning in the presence of a flame. The most common elements associated with heat and fire resisting foams are chlorine, bromine, antimony, and phosphorous. Compounds containing one or more of these elements are added to the polyol or isocyanate in liquid or solid form. Another approach is to build into the resin or isocyanate one or other of such elements.

The end result is foams with various ASTM flame test ratings. The degree of flame resistance varies widely. Some foams are merely slow-burning, others burn only in contact with flame. Still others have low flame spread ratings.

The self-extinguishing qualities are obtained at a slight premium in cost or with a sacrifice in properties or processing ease.

The P. P. G. foam systems we use have a very low ASTM and Underwriters Laboratory flammability rating.