THERMAL INSULATIONS IN THE PETROCHEMICAL INDUSTRY

STP 581

AMERICAN SOCIETY FOR TESTING AND MATERIALS

THERMAL INSULATIONS IN THE PETROCHEMICAL INDUSTRY

A symposium sponsored by
ASTM Committee C-16 on Thermal
and Cryogenic Insulating Materials in
cooperation with the American Institute
of Chemical Engineers, 12 March 1974,
Tulsa, Okla.

Reprinted from the August 1974 issue of
Chemical Engineering Progress (Vol. 70, No. 8)

ASTM SPECIAL TECHNICAL PUBLICATION 581
F. S. Govan, symposium chairman
J. S. Kummins, symposium cochairman

List price $3.25
04-581000-10

AMERICAN SOCIETY FOR TESTING AND MATERIALS
1916 Race Street, Philadelphia, Pa. 19103

Library of Congress Catalog Card number: 75-2515

NOTE

Printed in Gibbsboro, New Jersey
March 1975

Foreword

The Symposium on Thermal Insulations in the Petrochemical Industry was held on 12 March 1974 in Tulsa, Okla. It was sponsored by the American Society for Testing and Materials' (ASTM) Committee C-16 on Thermal and Cryogenic Insulating Materials in cooperation with the American Institute of Chemical Engineers (AIChE) and was presented during a meeting of AIChE. F.A. Govan, York Research Corp., presided as the symposium chairman, and J.S. Kummins, Dow Corning Corp., served as the cochairman.

Related ASTM Publications

Heat Transmission Measurements in Thermal Insulations, STP 544 (1974), $30.75, 04-54400-10

Supplement to the Bibliography and Abstracts on Thermostat Metals, STP 288C (1974), $4.25, 04-288030-40

Manual on the Use of Thermocouples in Temperature Measurement, STP 470A (1974), $17.50, 04-470010-40

Contents

Introduction

All of a sudden politicians, architects, and building owners have made a new discovery – thermal insulation saves fuel! Even the petrochemical industry, a major user of insulation for process control and industrial safety have been lax in the proper use and application of these materials. In fact, it has been a basic axiom of almost all owners that when the project is "overbudget" – eliminate the insulation. Thus, the professional engineer who has been involved in thermal insulation evaluation by means of such technical societies as ASTM Committee C-16 and ASHRAE TC4.4 has now become an important asset.

We are thus very pleased with this opportunity to present five technical papers which should help the petrochemical industry properly consider thermal insulation. Today the proper use of insulation is no longer a matter of economics and safety but rather a need for conservation of raw feed-stocks. It is all well and good to argue about the economics of thermal insulation, but if there are no feed-stocks to produce the thousands of products made from petroleum then all arguments are academic.

We hope in this short symposium to demonstrate a wide range of applications and procedures which will help the industry *make* money but also indicate how the petrochemical industry can lead the way for our Government and its bureaucratic and meandering attempts to help us become energy independent. We need more technical committees like a hole in the head. The time for action is now!

F. A. Govan
President, York Research Corp., Stamford, Conn., chairman, ASTM Committee C-16, and symposium chairman.

STP581-EB/Mar. 1975

Insulation Practices:

Criteria for Installing Insulation Systems In Petrochemical Plants

A complete thermal insulation system performs more than one function, and its economic evaluation must include all the services the installation is to supply.

W. C. Turner, Consultant, South Charleston, W. Va.

If they are to properly fulfill all their functions, insulaation systems must be designed with considerable care. Such care includes discriminating engineering judgment in evaluating tests on materials that are to be used in the system. To illustrate: an engineer might know that the ultimate strength of a particular steel, by test, is 98,000 lb./sq. in. In the design of structural members he would probably use a value of 20,000 to 22,000 lb./sq. in. to allow a safety factor for the unknowns—corrosion, fatigue, etc.

In a like manner, engineers who design insulation systems must use the results of laboratory tests only as a basis of establishing realistic design values. Properly designed industrial insulation systems, in most instances, perform more than one function. Therefore, true economic evaluation should include all the functions the system will serve. If insulation systems are poorly designed and the materials for it are not selected with care, it becomes difficult to accomplish the objectives listed below, and increases the chances of explosion, fires, and human burns.

The most common plant operating functions, and therefore reasons for using insulation systems, are:

1. Conservation of energy, which may be in the form of heat energy, or energy required to produce refrigeration. Direct conservation can be converted to dollar savings.
2. Control of process temperatures in columns, reactors, etc., a necessity in the manufacture of product.
3. Control of condensation of water vapor on vessels, cold equipment, and pipe, essential to protect insulation efficiency and to prevent excessive rusting or corrosion of pipe and equipment.
4. Protection of pipe and vessels from external accidental fire.
5. Control of surface temperatures, important in the protection of personnel from burns and in holding surfaces below ignition point of products being manufactured.
6. Protection and conservation of product, during manufacturing, but also in transportation and storage.

Some of the most common problems which an improperly designed insulation system might cause are:

1. Too high a surface temperature, which might cause ignition of spilled product, or personnel burns.
2. Too low a surface temperature on refrigerated pipe and vessels, thus causing constant water drip and rusting or corrosion.
3. Lowering of ignition point of product into which it might come in contact, or cause spontaneous combustion.
4. Act as an absorbent to trap large quantities of combustibles.
5. Be, in itself, a combustible and act as a fire distribution system.
6. Rusting or corrosion of the substrate to which it is applied.
7. Self-detonate in the presence of liquid oxygen.
8. React with various gases and cause self-ignition.

Insulation and all accessory materials must be selected with utmost care. The purpose of this article is to provide a simplified guide to the requirements to be considered, and to the corresponding related characteristics of insulation and/or accessories which should be determined for correct selection of materials. Some of the more critical points will be discussed.

How heat moves through insulation

Why do service requirements affect the performance of insulation? To answer this, it is essential to understand how heat is transferred from the hot side to the cold side of insulation. The term "thermal conductivity" as used to measure heat transferred from one surface of insulation to the other is basically a misnomer.

Heat is transferred through insulation by four mechanisms: 1) by conductance of the solids in a long circuitous path, 2) by conductance of the air (or gas) filling the spaces, 3) by radiation from one solid (and through) to the next, across the spaces, and 4) by convection currents in each space.

As a result, test methods to accurately determine heat transfer from one surface to another are difficult to attain. If the method does not somewhat approximate service conditions, the apparent conductivity obtained by the test may not be close to the actual heat transfer of tested material in practice. Three questions should be posed regarding results of any conductivity test: preparation of sample, change of conductivity in respect to change in mean temperature, and temperature difference between hot side and cold side.

In sample preparation it is standard practice to dry out all insulation to a bone dry condition before testing. This is a state never experienced in practice when the insulation material is absorbent or adsorbent—even when used at high temperatures. Thus, some safety factor should be allowed in thermal calculations. All materials change conductivity as mean temperatures change.

It follows that when an insulation manufacturer provides the conductivity at one mean temperature he has probably selected the one mean temperature at which his material has the lowest thermal conductivity.

Temperature difference between hot and cold sides makes a great difference in measured conductivity results for any given mean temperature. Thermal conductivity measurement of any lightweight and/or translucent insulation, at 70 to 75°F. mean temperature, with 10°F. difference across specimen (ASTM C-518), may be indicative of heat transfer in very moderate temperatures. However, transfer rate obtained under these conditions is practically worthless for calculating heat transfer in industrial applications.

Moisture in insulation can cause great changes in thermal conductivity. Insulation in a dry state at 100°F. mean temperature might have a thermal conductivity of 0.31 B.t.u., in./sq. ft., hr., °F. The same insulation, water soaked, will have a conductivity of approximately 5.5 B.t.u., in./sq. ft., hr., °F. At freezing temperatures, an insulation having a thermal conductivity of 0.25 at °F. mean temperature will have a conductivity of 15.0 at the same mean temperature if it becomes filled with ice. For these reasons, published conductivity values should not be accepted and used blindly in heat transfer calculations without due consideration of service requirements and the system used to install and its effectiveness in keeping the insulation dry.

Temperature effect on installation needs

When insulation systems become inefficient, fail completely, do not maintain safe surface temperatures, cause fires, or cause corrosion to substrates it is the result of incomplete evaluation of requirements and selection of materials and systems which do not satisfy the needs of the installation. All that is possible here is to provide a simplified guide for checking requirements, the related properties of insulation and accessories, and some explanation of most important considerations.

Service and ambient temperatures are generally the first consideration in selection of insulation materials, accessories, and systems. Types of insulation and systems required can be divided into four main temperature ranges: elevated, hot, moderate, and low.

Elevated range (500 to 1,200°F.). This requires insulations suitable for the maximum temperatures to which it is subjected, with minimum amount of shrinkage or temperature distortion. The systems must be designed to provide for circumferential and linear expansion of the substrates without causing cracking or openings between insulation pieces. It is recommended that insulation expansion joints be provided and double-layer construction be considered. All protective jackets or coatings must be installed to allow for expansion without opening of joints or splitting. Jackets and coating with high surface emittance will reduce the possibility of excessively high outer surface temperatures.

High range (212 to 500°F.). This requires insulation suitable for temperatures to which it is subjected. Expansion of pipe and vessels is less than at higher level; thus in most instances, single layer construction is suitable. At the lower end of this temperature range, reflective surfaces of aluminum outer jacketing will not cause excessively high outer surface temperatures.

Moderate range (average ambient air to 212°F.). The insulation should be water-repellent and/or nonabsorbent. Weather-barriers must be water-tight. This is because substrate temperature is insufficient to vaporize any leaked water.

Low range (below ambient). This includes refrigerated spaces and the insulation of low temperature pipe and equipment.

1. Low-temperature space installations: In these, the vapor migration through the walls must be such that walls stay relatively dry. For recommendations it is suggested that "ASTM Standard Recommended Practice for Selection of Vapor Barriers for Thermal Insulation" be consulted.

2. Low-temperature pipe and equipment: The major problem in this case is prevention of moisture entry. In such installations, all moisture that enters the system migrates to the substrate low temperature. It continues to build up until the insulation is completely saturated with liquid water or ice.

Two basic solutions are recommended. The first is to provide an outside vapor-barrier which provides a vapor-resistance in the magnitude of a vapor migration rate less than 0.0005 grains, in./hr., sq. ft., in. of Hg. Such vapor-barriers are most frequently constructed of welded aluminum or stainless steel. In very cold cryogenic service (below −180°C.), it is further suggested that these be purged with cold dry nitrogen, or be evacuated of air.

The second method is to use vapor-resistant insulation which has a vapor migration less than 0.0005 grains, in./hr., sq. ft., in. Hg. This insulation must have all the joints of the outer layer sealed with vapor-resistant sealants. Such applications, with tightly fitted sealed joints, should give approximately 20 years of service before conductivity increases to the point that replacement is necessary. Because of these factors it is much more important that the insulation have a very low rate of vapor transmission than an initial low thermal conductivity.

In all applications of low-temperature insulation on pipe and vessels it is absolutely necessary that the insulation system be so constructed that the thermal contraction of the pipe or equipment does not damage the insulation or its vapor-barrier. An example of low temperature insulation, on piping in an ammonia plant, is shown in Figure 1.

A fact frequently overlooked by design engineers is that many cold gas and liquid systems require thawing-out. Such systems are thawed-out generally by purging the pipe or vessels with hot nitrogen at 150°C. to 200°C. Where this is standard practice the insulation and all accessories which might be in contact with the substrate must be able to withstand this high temperature. In addition, the system must be designed to allow for expansion as well as contraction.

How heat loss or gain is determined

The maximum heat loss or gain to be tolerated in a piping system is the heat transfer per sq. ft. of insulated surface multiplied by the area, plus all losses or gains by

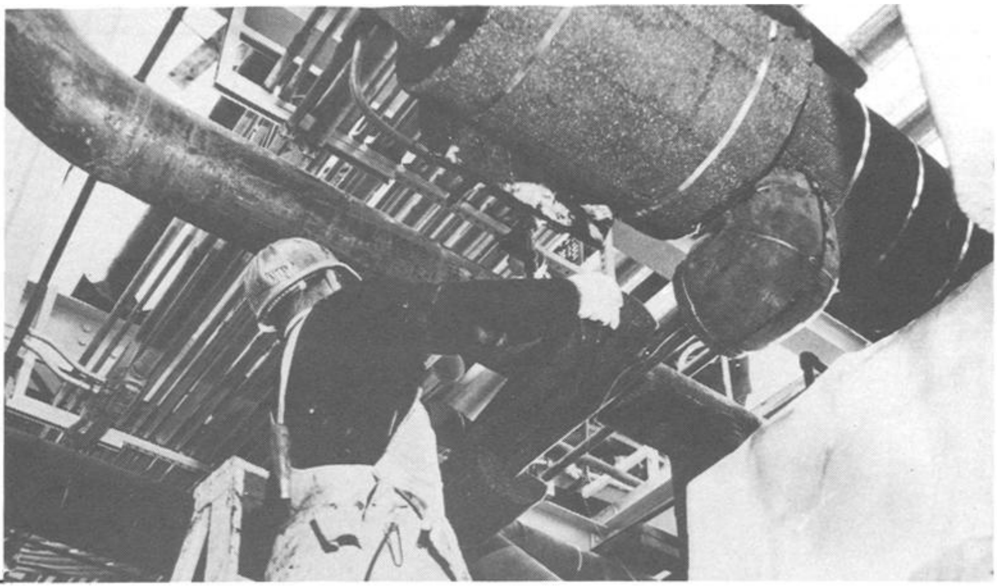


Photo courtesy Pittsburgh Corning Corp.

Figure 1. A cellular glass insulation, Foamglas, being applied to piping at Collier Carbon and Chemical's ammonia/urea plant in Kenai, Alaska.

thermal short circuits such as supports and bare exposed surfaces.

The amount of the maximum heat loss might be dictated by one or more of the following installation requirements: conservation of energy, conservation of product, obtaining of the most efficient operating cost, control of process temperatures, and protection from accidental fire by limiting the heat input to substrate metal.

The characteristic of insulation which controls heat transfer is this: heat transfer equals temperature differential divided by total thermal resistance. Temperature differential is fixed by system conditions. Thermal resistance equals insulation thickness divided by thermal conductivity of the insulation (under service conditions) plus surface thermal resistance. The surface thermal resistance is a variable which depends upon emittance of surface, size, shape, location, and velocity of air across surface.

Control of the outer surface temperature frequently is the criterion for insulation design. Industrial reasons for control of surface temperature are most frequently one or more of the following:

1. On hot piping and equipment, the outer surface should be below the temperature which causes personnel burns.
2. On hot piping and equipment, outer surface should be below temperature which would ignite spills or blow-offs of products.
3. On cold piping and equipment, surface temperature should be sufficiently high to retard the condensation of water from ambient air.

Surface temperature is a function of the following relationship, for insulation on hot pipe or equipment: the difference between the jacket or coating temperature and the ambient temperature, divided by the jacket or coating surface resistance is equal to the difference between substrate metal temperature and jacket or coating temperature, divided by the thermal resistance of the insulation.

The ambient temperature, temperature of substrate metal, and the resistance of thermal insulation are known values in the problem under consideration. The variable is insulation surface temperature, which is determined by surface thermal resistance. The lower this thermal resistance, the higher the surface temperature.

One of the major functions determining thermal resistance of the surface is radiation emittance. For this reason, when surface temperature is to be controlled, the surface emittance of outer jacket or coating must be considered. On hot installations (all other conditions remaining the same) bare aluminum with $E = 0.05$ can cause the surface temperature of jacket to be as much as 90°F. higher than coatings or jackets having high emittance surface.

On low temperatures, the same relationship is true, with the signs of the temperatures given above reversed. However, in this case the insulation of ambient air conditions and thermal resistance of the insulation is the variable. A low surface emittance of 0.05 as compared to emittance of 0.9 will require two and one-half to three times greater thickness of insulation to obtain surface temperature above dew point. Basically, this means when insulation is used to prevent condensation from air, a low emittance barrier such as bare aluminum should not be used and the color selected should not be less than medium tints of color.

When it is necessary to reduce solar radiation to a surface, the material facing the sun should have high reflectance to the visible heat rays (0.36 to 0.74 microns in length). It is natural to first think that aluminum would be a proper material to reduce the radiation effect. Unfortunately, all aluminum becomes oxidized when exposed to air. Reflectance of oxidized aluminum in solar heat range is 0.1 to 0.3 microns. Much better solar reflectance can be obtained by high-gloss white paint.

Some processes require stable temperatures even when heat input to vessel or pipe varies. Where insulation is used to dampen out temperature fluctuations, the desired characteristics are high density, high specific heat and low conductivity. This time rate of heat transfer is designated thermal diffusivity. Another area where these same characteristics are important is where insulation is used for fire protection.

Conversely, when rapid temperature change is desired, the materials should have low density, low specific heat and high conductivity.

It might be pointed out that the use of very lightweight insulations on unrefrigerated vapor and gas lines and vessels to reduce effect of outside ambient temperature change or solar radiation effects is almost useless.

When it is necessary to heat-trace piping or equipment to maintain temperature of the pipe or equipment, two methods of installing tracing are used. One is air conduction heating, the other is to heat-bond the tracer to the substrate surface.

In air conduction tracer heating, the tracer heats the air in the annular space, which in turn heats the substrate surface. In the case of heat cement-bonded tracers, the substrate surface is heated directly by conduction. In this case, the substrate temperature is higher than the annular air space. Thus for the same design pipe operating temperature, the annulus of bonded tracing is much lower than air convection tracing. For same thickness of insulation, the savings in energy loss can be as much as 30%, by the use of heat transfer cement. However, all these savings, and satisfactory operation of the system, depend upon insulation which stays dry.

Two classes of physical requirements

The physical requirements of an insulation system may be divided into two parts, external forces and internal forces.

Some of the external forces to which the insulation is subjected are: being walked upon; being bumped; wind loading (pressure on one side, partial vacuum on other); compression loads at external supports; bridging loads, such as when used to bridge gaps, or form the containment for steam or electric tracing; and the structural strengths required for its own construction and support of weather-barriers or jackets.

Internal forces are in most instances the most critical. These are: stresses caused by expansion and contraction of the substrate; compression forces by the expansion of cylindrical surfaces to which it is secured; vibration of pipe or equipment; abrasion caused by expansion and contraction movement; and twisting and bending caused by change of dimensions in substrate metals.

There is no way to relate these requirements directly to physical characteristics of insulation materials. Each must be properly evaluated and provided for in the design of the insulation system. The insulation system must be such that the supporting mechanisms, securements, expansion joints or cushions, sealants, adhesives, cements, weather-barrier or outer coverings, all function together to form an efficient, serviceable method of controlling heat transfer. The design is further complicated by the fact that the characteristics of materials change as they are heated or cooled.

The characteristics of insulation and accessory materials which should be known for proper structural design of systems are as follows:

1. *Rigid insulations:* breaking load, coefficient of expansion, compressive strength, deflection before breaking, density, dimensional stability, flexibility, hardness, impact strength, incidence of cracking, linear expansion or shrinkage, modulus of rupture, resistance to abrasion, resistance to dropping (or impact), resistance to vibration, rigidity, shrinkage (linear and volumetric), shear strength, tensile strength, thermal shock resistance, and warpage.
2. *Blanket and non-rigid insulations:* All applicable in the list above, plus compressible in respect to load and % recovery.
3. *Cements, spray-on insulations:* a. all applicable in list of rigid insulations, plus adhesion (both wet and dry); b. shrinkage (wet to dry); and c. expansion from initial application to cured state.

Petrochemicals create special problems

In the petrochemical industry it is always possible that product or product fumes might come in contact with materials of the insulation system. Also, it is practically impossible to keep moisture out of insulation systems, thus the insulation materials themselves may cause chemical problems. Some of the basic problems in this regard are:

1. Will the insulation or any of its accessory materials react with products with which it might come in contact?
2. Is there a possibility that the insulation may be contaminated with toxic chemicals?
3. Will it be subjected to nuclear radiation?
4. Will the insulation by itself, or if it is contaminated, cause rusting or corrosion of the pipe or vessels?
5. Will wet or moist insulation cause galvanic action?
6. Will the insulation be ruined by acids, caustics or solvents?

Characteristics of insulation material to be considered are: absorptivity, alkalinity, capillarity, chemical composition, hygroscopicity, resistance to acids, resistance to caustics, resistance to solvents, and soluble chloride content.

Thermal insulation systems, with a primary function to conserve or control energy, can also serve as fire protection of pipe or equipment, reduce the possibility of personnel burns, and reduce the possibility of ignition of chemicals in contact with hot surfaces. However, improperly selected materials and systems can increase hazards. For some reason this is frequently overlooked, thus this part of the discussion is directed basically to the hazards in use of insulation, and to the most common hazards to be avoided.

Good construction practices should be observed to prevent injuries. In addition, when insulations which give off hazardous dust, dangerous particles or solvents are installed, the applicators and other persons in the area should be supplied with proper safety devices such as masks. Any potential ignition sources should be eliminated.

Fire hazards in service

Reactive chemicals in contact with both organic and inorganic material may change their self-ignition point. To illustrate: ethylene oxide has an ignition point of 571°C. In contact with calcium silicate, the ignition point is 298°C. The hazard is that 298°C. is below process temperature, thus any leak can result in immediate burning.

Liquid oxygen will self-detonate by mechanical shock when in contact with most organic and some inorganic materials. For this reason, all materials used in such service must be given a shock test before being approved for such service. No organic insulation should be used in cryogenic services where the temperature may be lower than −180°C. which is the temperature at which oxygen will condense out of air.

Many common flammable liquids such as oil, butanol, diethanolamine, and hexanol will react and start fires when they leak into inorganic absorbent insulations. A critical mass sometimes causes this internal heat. An additional factor which should be considered with all absorbent insulations is that the insulation has the ability to store large quantities of combustible liquids should a leak occur. Any small fire or spark near the system then has large quantities of fuel available to feed the fire.

Combustible insulations, as in the case of fuel soaked insulations, will spread fire and contribute fuel to the fire. Use of such insulations in fire hazard areas should be avoided. But, if used, all its outside surface should be protected with sprinkler systems.

In the past few years a very dangerous practice of using combustible insulations has developed. This is due to the erroneous thinking that if combustible insulations are covered with metal jackets, they are fire-safe. Unfortunately, the metal jackets only increase the hazard. Any external fire rapidly heats the jacket to above the ignition temperature of the combustible material, and ignition occurs inside the jacket. As the fire burns between the jacket and substrate surface, the jacketing system becomes a distribution system for the fire because the water from sprinkler systems or hose streams cannot reach the fire to extinguish it.

Properties of insulation related to fire hazards are: absorptivity, capillarity, melting temperature (hot drip of burning or hot material), hygroscopicity, and combustibility or flammability.

Common usage has made combustibility or flammability similar in meaning. The definition could be: A material is combustible or flammable if, when subjected to fire or heat, it will ignite, burn, support combustion, and release flammable and toxic vapors. By this definition, materials that are basically non-combustible as well as those basically combustible must be included. For example, non-combustible materials might contain contaminants that are combustible. In either case, all the combustible properties must be considered.

The combustibility of materials evaluation should include the following four categories of properties:

1. *Ignition:* as evidenced by glow, flame or explosion.
   a. flash point temperature.
   b. flame point temperature.
   c. self-ignition temperature.
   d. detonation by mechanical shock.
2. *Burning:* to become altered by fire or heat.
   a. burning rate, depending upon position
      (1) vertical, up
      (2) vertical, down
      (3) horizontal, underside
      (4) horizontal, topside
      (5) horizontal, enveloped
   b. burning rate, depending on heat or temperature
      (1) temperature of ambient air or gas
      (2) heat flux to surface
   c. burning rate, depending on surrounding air or gas
      (1) air or gas surrounding
      (2) movement of air or gas
3. *Combustion:* change of state due to burning.
   a. release of heat, rate in respect to time
   b. consumption of material, rate in respect to mass and time
   c. generation of temperature
      (1) flame temperature
   d. change from solid to liquids or gases
   e. heat energy available (energy per mass)
   f. smoldering
   g. residues
4. *Release of vapors or gas*
   a. rate of release of combustible gas or vapor
   b. toxicity of released vapors or gas
   c. density of released gases of vapors

Because of the number of factors involved, no combustible material can be tested as to degree of flammability (or combustibility) by one or two simple tests. The practice of rating insulations by small laboratory tests and tests which are not applicable to the materials is deceptive and dishonest.

Special needs for coatings and barriers

Surface finishes are used over insulation installed indoors. In most instances they provide some mechanical protection and color to provide pleasing appearance.

Vapor-barriers are used to retard moisture vapor from entering insulations on substrates operating below ambient temperatures. They may be required indoors or outdoors. The need for vapor-barriers depends upon the vapor resistance of the insulation and the vapor pressure difference between surrounding temperature and humidity conditions and the temperature of the substrate. If substrate surface is below freezing, the requirements of the vapor-barrier multiply, because conduction of ice is three times that of liquid water.

Vapor-barriers on insulation of relatively high vapor transmission should have extremely low vapor transmission if long service life is desired. This is because vapor differences can be very large. For an example, an insulated surface wet after a summer rain is often heated to 150°F. When this happens, the vapor pressure on the surface will be approximately 7.57 in. Hg., or 535 lb./sq. ft. If operating temperature of substrate is 30°F., the water vapor pressure is 0.164 in. Hg., or 11.6 lb./sq. ft.

The water vapor pressure difference under these conditions is 7.46 in. Hg., or 525 lb./sq. ft. When these differences exist, a vapor-barrier must have extremely low vapor transmission and be absolutely free of pinholes, to be effective.

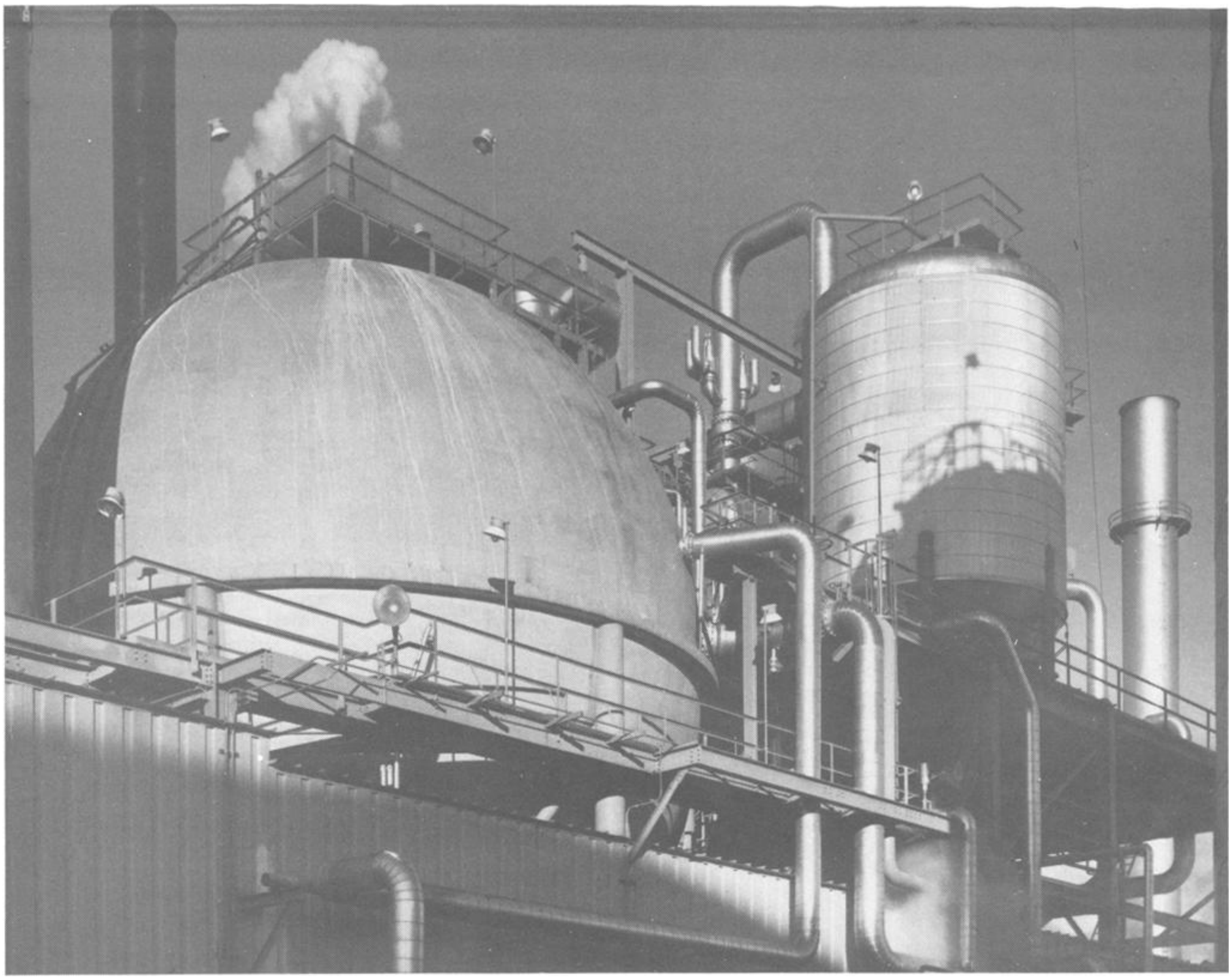
Like published thermal conductivity values which, by necessity, are obtained by laboratory test methods, the published values of vapor transmission must be evaluated as to what might be expected in service. First, it should be pointed out that vapor migration rates determined by wet-cup method generally give vapor transmission rates approximately five times that of the same material tested by dry cup method. Most advertising gives results based on dry cup method. It is also interesting to note that on vapor-barrier coatings applied over the irregular surfaces of insulation, compared with laboratory samples of the same material, will often have 15 to 20 times greater vapor transmission when both are new and tested in identical manner.

Weather-barriers are the outer coverings over insulation to protect it from all external abuse and weather. They may be water-resisting felts, metal jackets, or mastics (most frequently reinforced with fabric.)

The surface finishes, vapor-barriers, and weather-barriers must satisfy all the requirements previously stated for insulation. However, these materials must all be installed so as to allow for expansion and contraction which is transmitted from substrate through the insulation to the outer surface. It thus becomes evident that corrugated metals should never be used in horizontal position. Even if sealants are used in the overlap, movement will break the seal and the corrugations will funnel water into the insulation. Special care should be given to all external materials in respect to their fire hazard, as they are the surface that is exposed. #

W. C. Turner, III, received his electrical engineering degree from Washington Univ. College. He is a consulting engineer in thermal insulation and a registered professional engineer in the states of Missouri and West Virginia. He is co-author of "Thermal Insulation" and has written a chapter on thermal insulation in "The Encyclopedia of Chemical Process Equipment."

STP581-EB/Mar. 1975



Sphere coated with Vi-Cryl (CP-10), a chemical resistant weatherproofing coating, and tower, deep corrugated aluminum sheets. Also various accessory products—pre-fabricated firrint covers, strapping, and wing seals.

Insulation Practices:

Protection of Thermal Insulation

Insulation protection can be provided by metal jacketing, mastic coatings, or a combination of both, depending on the application, service, and economics.

J. B. Marks and **K. D. Holton**
Childers Products Co., Inc., Cleveland, Ohio

It has been proven that it actually costs less to properly insulate process vessels, pipes, valves, and flanges, and thereby conserve energy, than not to insulate and supply sufficient additional heating or cooling capacity to cover the loss or gain of heat. Thermal insulation is, therefore, a long-term investment. In the present energy crisis it becomes even more; it becomes a definite necessity and an obligation.

In any application, thermal insulation requires protection of some type, be it against rain, snow, sleet, wind, ultraviolet solar radiation, mechanical damage, vapor passage, fire, chemical ravages, or any combination of these. Protection can be provided in the form of metal jacketing, mastic coatings, or a combination of both, depending upon the application, service, and economic requirements.

In view of the overall cost of a new facility, and the initial cost of the insulation system as a percentage of that overall cost compared with the increased operating costs due to inefficient insulation protection, it is common sense to provide only the best protection for that long-term investment, consistent with the appropriate design and economic requirements. This article will outline just that type of protection—that is, the best available for the particular application consistent with the appropriate design requirements.

Metal jacket system characteristics

Prior to the use of metal jacketing systems, refinery and similar pipelines, vessels and tanks were covered with asphaltic roofing papers. This system offered virtually no weather, mechanical, or fire protection. The use of 55 lb. roofing felt held with tie wire did not offer much improvement. Metal jacketing met the requirements of a more efficient, more protective and more esthetic insulation covering.

Aluminum was the first metal to be used as jacketing material. In alloys 3003, 5005, and 5010, and tempers H14 through H19, it is still the most widely used product for general purpose industrial installations, but is not recommended for use in areas requiring chemical resistance under alkaline conditions.

Its advantages are low initial cost and easy workability. Its disadvantages are low chemical resistance in pH range 7-11, low mechanical strength, and low fire resistivity, no load factor at 800°F.—melts at 1,200°F.

Clad aluminum, (Alclad) the result of a mechanical process wherein an aluminum alloy core is coated prior to rolling with an aluminum alloy anodic to the core for its electrolytic protection against corrosion, is a product with slightly better surface chemical resistance than unclad aluminum.

Aluminum which has been chemically cleaned, primed with a corrosion inhibitor and then mill-coated with a polyester or acrylic resin offers greater use, flexibility, and somewhat more protection at a higher cost.

Its advantages are: coating can be selected to suit the environment, offering improved corrosion resistance; its moderate cost, and easy workability. Disadvantages are that the coating can be abraded relatively easily, and polymer degradation may result in failure.

Organosol-coated, electro-galvanized steel (Childer's trade name—Steel Jac) is manufactured from 0.010 in., or heavier, Type 1010, cold-rolled steel. The steel is then chemically-treated, coated on both surfaces with a vinyl acrylic primer and finally top-coated with a vinyl-organosol which is then fused to the metal.

Its advantages include excellent mechanical properties, attractive vinyl finish, chemical resistance, and abrasion resistance. Its disadvantages: it is somewhat more costly than aluminum, and the organic coating, though it will not support combustion, will char at incendiary conditions.

Stainless Steel (T304 and T316) is meeting with wide acceptance resulting in large scale usage. Advantages include high mechanical strength, high fire retardance (melts at 2,600°F.), excellent corrosion resistance, and excellent weather resistance. Disadvantages are high initial cost and susceptibility to stress corrosion cracking in the presence of chloride ions.

Moisture barriers frequently needed

Soluble salts present in most industrial insulations function as a weak electrolyte when the insulation becomes moist. The metal pipe and the metal jacketing function as opposite poles, thus a low-voltage, galvanic cell is formed, detrimental to both poles.

To prevent this attack at the metal/insulation interface, the incorporation of an integrally laminated moisture barrier is highly recommended. Childers Products Co. supplies two types of moisture barrier, each laminated to 100% of the metal surface on the underside of the jacketing: One is "Poly Kraft" moisture barrier, consisting of one layer of 50 lb. virgin kraft paper coated on one side with one mil polyethylene film. The other is a 30-90-30 moisture barrier consisting of a uniform film of pure high-melting, oxidized asphalt, laminated between two sheets of 100% virgin kraft paper.

Two other types of protective jackets are: "GAF®T/NA 100 Jacketing" a tough, flexible, flame-, weather-, and chemical-resistant laminate of Tedlar®, Neoprene®, and asbestos. Where a vapor barrier is required, the addition of one mil film of Saran (polyvinylidene chloride) to the laminate drops the vapor permeability of the system to 0.05 perms, without sacrificing any of the aforementioned properties.

Polyvinyl chloride (PVC) jacketing is another tough, flexible system used mainly for its superior chemical resistance and flame retardance. Its limited service temperature range and lack of dimensional stability detract from its other properties.

Mastic systems useful on irregular surfaces

The choice of the material used to protect the insulation may be governed by the size, shape, and location of the insulated surface to be protected. Materials which cling to the surface by adhesion facilitate the installation of a protective covering to large, irregular surfaces offering no ready means of securement.

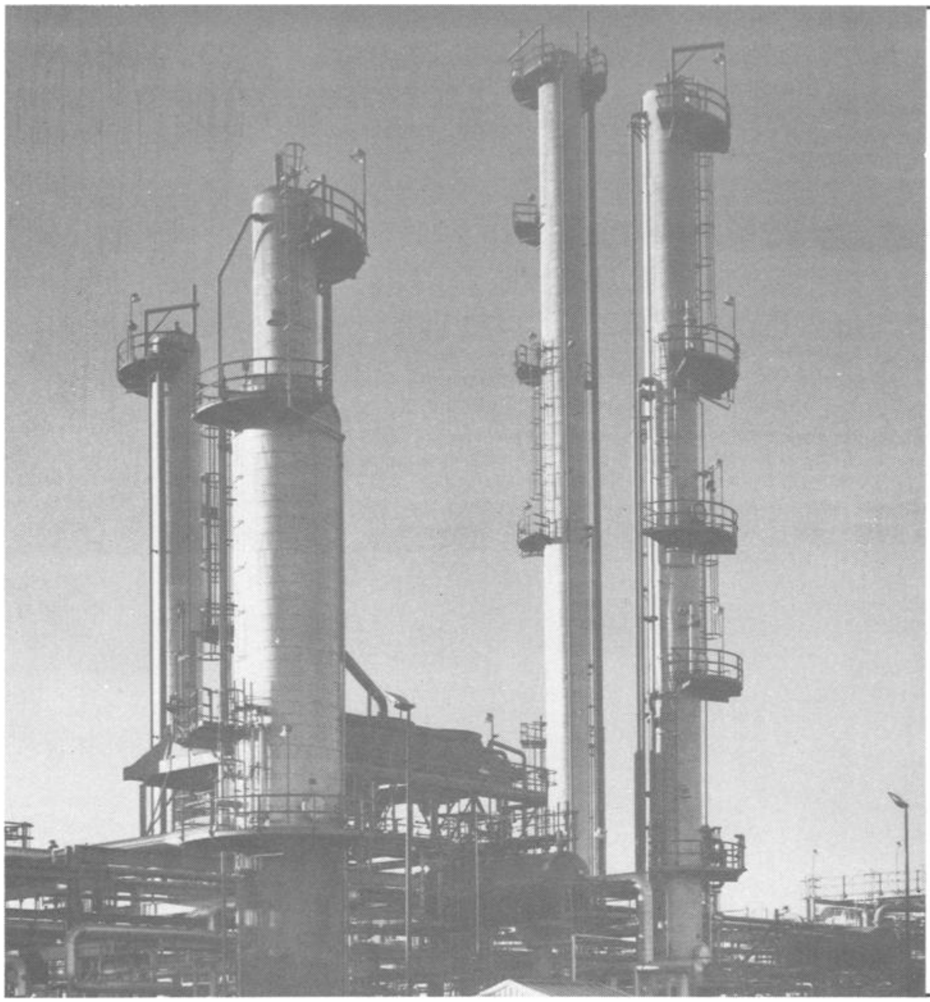
Mastics may be applied by spray, brush, or trowel to large, flat surfaces which will not easily accommodate metal jacketing. They may be used in conjunction with metal jacketing in situations such as flashing between two adjacent surfaces, or around irregular shapes such as fittings, valves, etc., because they lend themselves to easy application in these areas.

A weather barrier coating is applied to the outer surface of thermal insulation primarily to protect it from the ravages of weathering. It is designed to prevent water (rain, snow, sleet, spillage, wash water, etc.) from entering the insulation system. There are, however, many additional benefits. The tough flexible films provided by vinyl acrylic breather coatings (a breather coating is one through which vapors under pressure will pass), also afford protection from mechanical damage, chemical attack, and fire.

Mechanical damage can result from external forces in the form of shear, abrasion, impact or compression, which may occur when a sharp object is dropped, when the surface is walked on, or even from extreme weather conditions. Damage may also result from internal forces due to thermal expansion and contraction, differential movement, or vibration.

An appropriate weather barrier can protect the insulation from chemical attack of acids, alkalis, solvents, and salts, either airborne or from intermittent spillage, as well as from the effects of oxidation, infrared and ultraviolet radiation.

Weather barrier coatings can even be properly formulated and compounded so as to have a minimal contributory effect on the stress-corrosion cracking of austenitic stainless steel resulting from the presence of halogen ions.



Catalytic cracker and alkalation unit at an oil refinery. All piping, vessels, tanks, and towers protected with 3/16-in. corrugated and deep-corrugated aluminum sheets.

"Vicryl," a Childers' product, is used both outdoors in hot, cold, and dual temperature service. It is a breather coating, thus it should be used in cold and dual temperature installations only in conjunction with a vapor-barrier coating, or where the insulation itself is a vapor barrier. In hot service, a breather coating allows the escape of a minimal amount of water vapor resulting from heat applied to the moisture entrapped in the insulation, while still preventing the passage of liquid to the insulation.

Glass cloth and other fabric membranes are generally used as reinforcements for weather barrier coatings. In situations subject to severe abuse, chicken wire and other metal-mesh membranes may be used.

In cold and/or dual temperature service, the equipment operates below ambient room temperature at least part of the time. Water vapor in the air seeks to move from the area of high vapor pressure (room temperature) to the area of lower pressure (the low-temperature equipment). As the vapor passes through the insulation, the closer it comes to the low-temperature equipment, and the colder it becomes. At some point the water vapor reaches its dew-point temperature and condenses to the liquid phase. Closer to the cold surface, if the temperature is low enough, the liquid phase may solidify into ice.

Because the thermal conductivity of water is considerably greater than that of air, and that of ice is even greater, the value of the insulation is substantially reduced by the presence of moisture in any form. In dual temperature service, alternate freezing and thawing of the moisture in the insulation may actually destroy the insulation.

All these problems can be eliminated, or at least minimized, by the proper application of a vapor barrier coating to the warm side (outside) of the insulation. Vapor barrier coatings are formulated to afford maximum protection from mechanical damage, chemical attack and fire, at the same time preventing the passage of vapor to the insulation. These products, whether brushed, palmed, or sprayed, are normally applied with a fabric reinforcing membrane. However, in some applications the use of membranes only at butt overlaps may be satisfactory. In addition to being used as coatings, they may also be used as joint-sealers and adhesives in special applications.

Adhesives, coatings, and sealers must be considered

Lagging is the process of insulating piping and cylindrical or rectangular duct work and equipment and then covering the insulating material with canvas, brattice cloth, asbestos cloth, or a similar fabric.

Lagging adhesives and sizings are generally white, emulsion resin-based systems which adhere the lagging cloth to the insulation and to itself at the lap joint. They also serve to seal the fabric and secure it tightly to the surface.

Combination systems which function both as adhesives and protective coatings are also available. They provide somewhat greater protection from mechanical damage, vapor penetration, and chemical attack than the previously noted lagging adhesives, and this precludes the necessity of applying another material as a protective coating. The water-based system offers the versatility of a tenacious, permanent adhesive coupled with a tough, highly resistant, yet flexible and attractive coating.

Decorative coating and color-coding products are heavy protective coatings that are used over masonry blocks, canvas, glass cloth, etc. bridging the unevenness of the rough surfaces and giving a smooth, tough, flexible, fire resistive finish.

These coatings may be applied directly to such materials as polystyrene foam, polyurethane foam, cellular glass and fibrous glass. They serve as effective sealer coats over many types of asphalt. Their availability in a full spectrum of colors gives an added advantage of virtually eliminating the need for painting and continued maintenance.

Sealers in insulation work function primarily as water and vapor seals. In many applications, however, they may also function as adhesives and expansion joints with metal, masonry, cellular glass, etc. The requirements for this type of product include low shrinkage, excellent adhesion, and permanent flexibility. Many are virtually 100% non-volatile, and they form a skin by oxidation, remaining permanently soft and flexible under the skin. Others contain polymers dissolved or dispersed in varying amounts of volatile solvents; these exhibit somewhat greater shrinkage and dry by evaporation of the solvent rather than by oxidation.

What a complete system requires

Today there are many governmental and private industry influences specifying, among other things, supplier and user compliance with OSHA, USDA, GSA, and Mil Spec requirements. These specifications include consideration of the following conditions or questions:

Solvent or water based system? Care must be taken that the system will not attack the substrate to which it is applied. It must dry in the time required and under the conditions to which it will be exposed.

Toxicity. What is the threshold limit value of each ingredient, and what steps must be taken to prevent exceeding that level?

What is the flammability of the system (in the wet state), and will it create an undesirable hazard?

What is the flame-retardance of the dry film, and will it meet all the necessary requirements?

Is the material UL (Underwriters Laboratories) listed? What are its Tunnel Test ratings (ASTM E-84)? Flame spread? Fuel-contributed? Smoke-developed?

What is its resistance to various mechanical factors, including expansion and contraction, vibration, shear, abrasion, impact, and compression?

Thermal factors: application temperature limits, freeze thaw stability, and service temperature requirements.

Chemical resistance factors: acid resistance, alkali resistance, and solvent resistance

Method of application: trowel, brush, or spray.

Sample recommendations for eleven different kinds of applications are given in the following.

Petrochemicals operation. 0.016–0.019 in. aluminum; 0.019–0.024 in. deep corrugated aluminum on vertical vessels and 0.024 in. smooth aluminum on horizontal vessels. Type 304 stainless steel is to be used in areas where the atmosphere contains corrosive vapors of a highly acid or highly alkaline nature. All metal jacketing is to have a moisture barrier. "Vicryl" is to be used to give protection to any irregular shape or surface where the application of a metal jacketing system is impractical.

Detergent alkylate unit. Steel Jac with moisture barrier, or Type 304 stainless steel with moisture barrier, is recommended due to aluminum's intolerance for caustics. (Vicryl to be used where necessary.)

Power house. 0.016 in. acrylic-coated aluminum is suggested for improved appearance. Polykraft moisture barrier is recommended. The acrylic coating facilitates washing down the surface.

Food processing. Type 304 stainless steel was once the only recommendation made. However, today more and more aluminum jacketing is being used. T/NA 100 applications are also being used extensively, as are USDA-approved mastic systems.

Urea plant. Steel Jac with moisture barrier, or Type 304 stainless steel with 30-90-30 moisture barrier, is recommended due to the wide range of extremely corrosive acidic and basic process chemicals present (e.g., nitric acid, ammonium nitrate).

Chlor-alkali plants. Steel Jac with Polykraft moisture barrier is recommended due to the high degree of soluble chlorides existing. (Stainless steel is weak under these conditions, and aluminum fails in caustic areas.)

Off-site steam lines. Since only weather protection is necessary, aluminum jacketing with Polykraft moisture barrier, or an application of Vicryl, is all that is required.

Nuclear containment vessels. Type 304 stainless steel used in conjunction with chloride-free, nuclear grade mastics.

Roofing applications over sprayed urethane. A weather-resistant, moisture-resistant, ultraviolet barrier is required to protect the urethane insulation.

SNG/LNG (synthetic natural and liquefied natural gas.) As with all cold piping installations, the application of a vapor barrier coating over the insulation will prevent the passage of moisture vapor from the warm (outside) surface to the cold surface, thereby preserving the integrity and utility of the insulation. Aluminum jacketing will do the job in thicknesses from 0.016 to 0.040 in., depending upon the specific requirements.

Paper mills. Where formerly Type 316 stainless steel was the only recommendation, it has been found that Steel Jac and Vicryl work well under conditions of intermittent spillage in areas of white, black and green liquor make-up and storage. #

J. B. Marks is a technical director of the Coatings, Adhesives and Sealants Div. of Childers Products Co. Marks attended Brooklyn College, Upsala College and Seaton Hall Univ. He has been with the Coatings, Adhesives and Sealants Div. of Childers since 1956.

K. D. Holton is general sales manager for Childers Products Co. He is a graduate of Lafayette College with a degree in chemistry. He has been active in the thermal insulation industry since 1955.

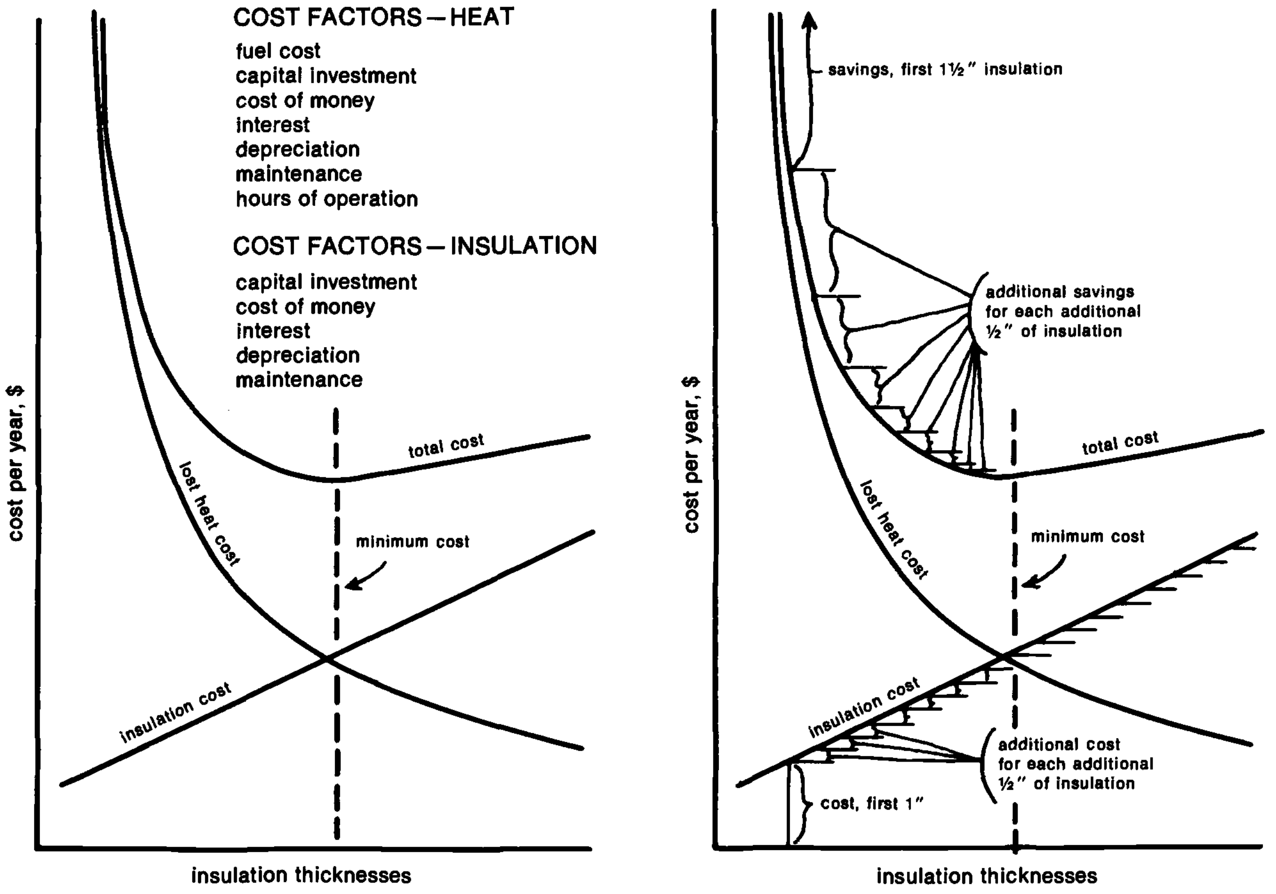


Figure 1. Determination of economic thickness of insulation.

Insulation Practices:

Economic Thickness Of Thermal Insulation

At one time, calculating the economic thickness of pipe insulation was a rather tedious affair. Computers have greatly simplified this work.

J. M. Barnhart
Thermal Insulation Manufacturer's Assn., Mt. Kisco, N.Y.

Since the properties of various types of insulation at various temperatures are known, the correct thickness of the chosen material can be easily calculated when the primary reason for applying it is protection, or maintaining close process temperatures, or preventing condensation. The calculation of the optimum thickness based upon economic thickness is not so easy, however, because an unwieldy number of variables must be handled—among them: the cost of heat energy, the cost of insulation, the cost of capital at various periods of amortization, and the conductivities of various insulations at different temperatures. The more insulation, the greater the original insulation cost, yet the lower the operational cost through the expected life of the facility, and the lower the cost of the equipment needed to supply the heat.

The selection of optimum or economic thickness has been a challenge to engineers for many years. Basic laws and mathematical equations governing heat loss and insulation were published in 1853 by Peclet. In 1926,

L. B. McMillan published the basic equation for the selection of optimum or economic thickness.

Economic thickness is defined as the minimum annual value of the sum of the cost of heat loss and the cost of insulation; or, in more general terms, as the thickness of a given insulation that will save the greatest cost of energy while paying for itself within an assigned period of time.

Even with a sound formula, the need for a separate calculation for each piece of equipment or run of pipe calls for time consuming effort. Many large companies, working from the McMillan equations, have developed their own shortcuts in setting up tables of economic insulation thickness that apply to their own temperature ranges, types of equipment, and financial programs. But there was no generally useful reduction of available information to tabular form to cover most conditions likely to be encountered in American industry until the original version of a manual covering various temperature differences was published in June, 1960, by the Thermal Insulation Manufacturer's Assn.

York Research Corp., under the direction of Francis A. Govan, P.E., president, and J. W. Grabiner, project leader, was invited by the Thermal Insulation Manufacturer's Assn. to revise and authenticate their manual for specifying the economic thickness for pipe and flat surfaces at elevated temperatures.

Among the areas investigated by York Research were:

Heat costs: fuel, capital investment for energy, maintenance, cost of money, and depreciation.

Insulation costs: capital investment for the installed insulation, cost of money, and depreciation.

Included in this new manual are:

1. Steam plant depreciation period curves (N_h = 10, 15, 20, 30, 40 yr.).
2. Capital investment lines for steam plant construction (10, 20, 30, 40, and 50 $ per 1,000 lb. steam hr.)
3. *B* factor, the insulation cost factor, for calcium silicate, fibrous glass, mineral wool, and cellular glass.
4. Sample calculations for economic thickness.
5. Basic insulation thickness tables.

The determination of economic thickness of insulation would be relatively simple if the monetary value of heat energy did not vary over so wide a range, and for so many reasons. One type of fuel costs more than another, and the same fuel varies in cost according to time and place. Heat is transmitted by manufacturing process reactions, by steam, by chemical fluid, by hot gas, and in other ways. Each factor influences the cost of heat energy. Where heat in piping systems and vessels is produced by process reactions rather than by fuel, the cost of heat energy is obviously lower. The amount of heat lost and its cost are affected by pipe size, operating and ambient temperatures, conductivity of materials, insulation thickness, and shape of the containers.

The higher the cost of heat energy, the more insulation is warranted to conserve it. Therefore, there may be a different economic thickness of insulation for each increment of heat cost. Similarly, the total cost varies with the type of insulation application, labor cost, type of facility, efficiency of labor, conditions at the location, depreciation, and maintenance.

Insulation surface temperature not always important

Only if safety and comfort of working personnel are involved will the temperature of the surface of the insulation be a significant matter. Surface temperatures alone offer absolutely no reliable indication of heat loss and, therefore, should not be specified or used exclusively in selecting insulation thickness. Since the major purpose of insulation is to save valuable heat, the proper thickness to achieve this objective should be based on economics.

Besides safety of personnel, which makes surface temperature rather than economic thickness the basis of minimum specification, other conditions may take precedence over economic thickness requirements. Examples include: 1) where it is necessary to maintain product temperatures at a given level for a process requirement; 2) where limited amounts of heat are available, and therefore extra insulation is specified so that the required heat is available at the discharge end of a pipe; 3) where time heat lag is a major factor, and 4) where fire exposure dictates the insulation type and thickness. Such special situations call for careful allocation of costs.

In this study, the equations are so derived that economic insulation thickness can be determined under a wide variety of cost conditions, both present and those of the foreseeable future.

In the simplest terms, the basic problem is this: at low values of thickness, the amortized annual cost of insulation is low (curves labelled "insulation cost" in the graphs of Figure 1), but the annual cost of heat energy (curves labelled "total cost") is high. Greater thickness sends the cost of insulation up, but reduces the loss of heat energy and its cost. At some value of insulation thickness, the sum of the cost of insulation and the cost of lost heat will be a minimum, as indicated by the curves so labelled. This value is obtained at any point by adding the values of the other two curves at that point. Beyond the minimum, the lost heat cost curve rises, because the increased cost of insulation is no longer offset by the reduced cost of lost heat.

Values for the production cost of heat used for determining the economic thickness should be based upon an estimate at the mid-life of the plant. Mid-life cost is the estimated cost of energy when an installation reaches half of its economic life, as shown in Figure 2. This procedure would prevent under insulating the system with future fuel cost increases.

Observe, in Figure 1 on the insulation cost curve, that once beyond the cost of the first 1-1/2 in. of insulation, which includes labor, the additional cost of each increment tends to be uniform, reflecting primarily the added cost of material. On the lost heat cost curve, the amount of savings in total cost decreases for each increment of insulation.

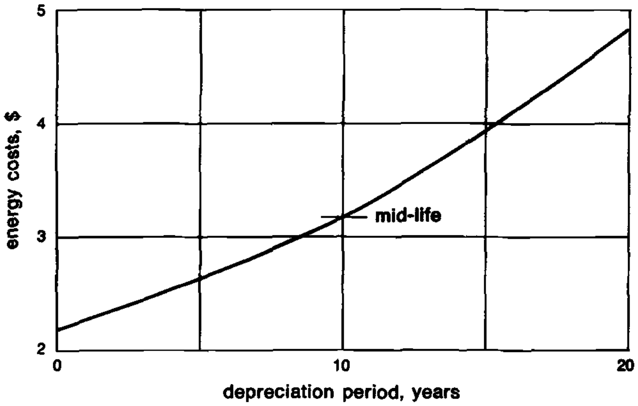


Figure 2. The concept of mid-life.

Step 1—Determine B

TABLE 1

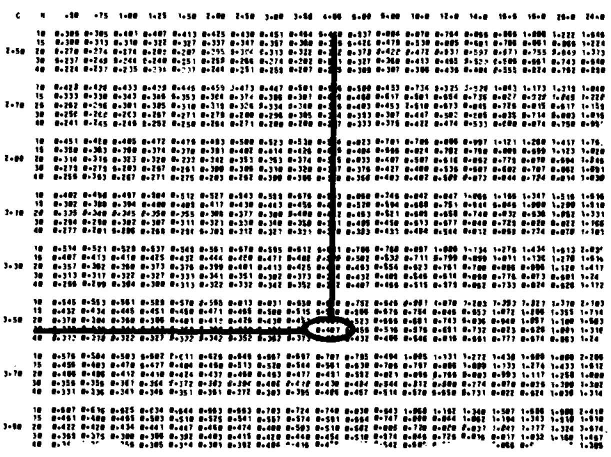
Values of Insulation Cost Factor, B_p, for Pipes

Calcium silicate, cellular glass, mineral wool

C = Cost of insulating a 2½" pipe with 1½" of insulation

N_n = Depreciation period of insulation, years

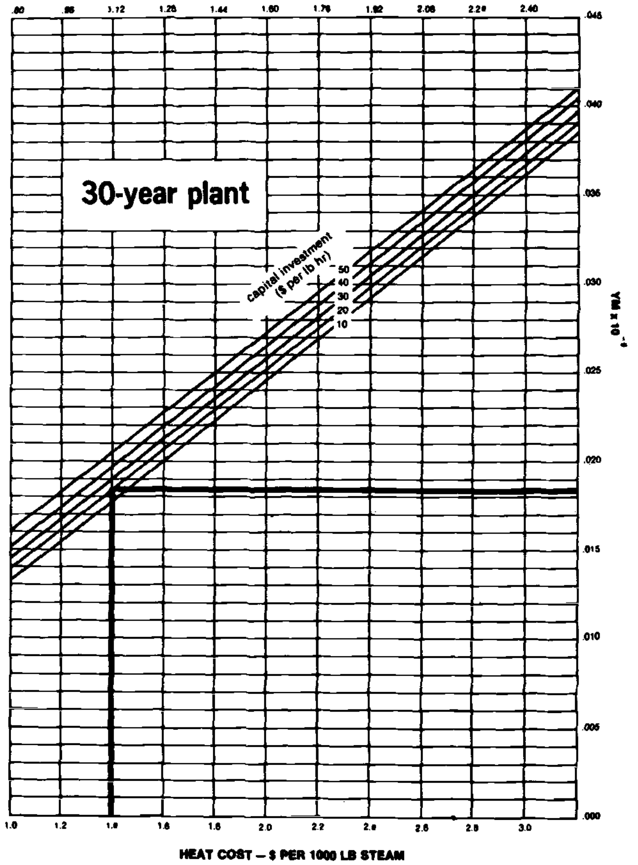
Pipe Size



Step 2—Determine D

HEAT COST — $ PER MILLION BTU

FIGURE 7

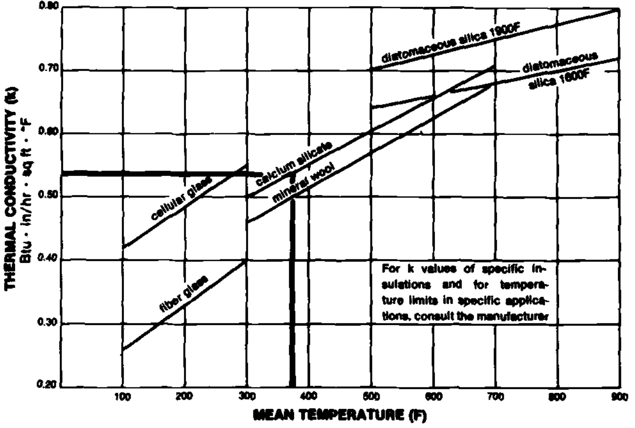


$$D = \frac{YM \times 10^{-6}}{B} = \frac{.018}{.407} = .044 \text{ (use .040)}$$

Step 3—Determine k

INSULATION CONDUCTIVITIES (k FACTORS)

FIGURE 9



For k values of specific insulations and for temperature limits in specific applications, consult the manufacturer

Step 4—Determine economic thickness

D = .040 K = .50

**** EX

PIPE SIZE	TEMPERATURE DIFFEPENCE DEGREES CENTIGPADE																											
	50	75	100	125	150	175	200	225	250	275	300	325	350	375	400	425	450	475	500	525	550	575	600	625	650	675	700	725
.50	.5	1.0	1.0	1.0	1.5	1.5	1.5	2.0	2.0	2.0	2.0	2.0	2.5	2.5	2.5	2.5	3.0	3.0	3.0	3.0	3.0	3.5	3.5	3.5	3.5	3.5	3.5	4.0
.75	.5	1.0	1.0	1.5	1.5	1.5	2.0	2.0	2.0	2.5	2.5	2.5	2.5	3.0	3.0	3.0	3.0	3.0	3.5	3.5	3.5	3.5	3.5	4.0	4.0	4.0	4.0	4.0
1.00	1.0	1.0	1.5	1.5	1.5	2.0	2.0	2.0	2.5	2.5	2.5	3.0	3.0	3.0	3.0	3.5	3.5	3.5	3.5	4.0	4.0	4.0	4.0	4.0	4.5	4.5	4.5	4.5
1.25	1.0	1.0	1.5	1.5	2.0	2.0	2.5	2.5	2.5	3.0	3.0	3.0	3.5	3.5	3.5	3.5	4.0	4.0	4.0	4.0	4.5	4.5	4.5	4.5	5.0	5.0	5.0	5.0
1.50	1.0	1.5	1.5	2.0	2.0	2.5	2.5	2.5	3.0	3.0	3.0	3.5	3.5	3.5	4.0	4.0	4.0	4.0	4.5	4.5	4.5	5.0	5.0	5.0	5.0	5.0	5.5	5.5
2.00	1.0	1.5	2.0	2.0	2.5	2.5	3.0	3.0	3.0	3.5	3.5	3.5	4.0	4.0	4.0	4.5	4.5	4.5	5.0	5.0	5.0	5.5	5.5	5.5	5.5	6.0	6.0	6.0
2.50	1.5	1.5	2.0	2.5	2.5	3.0	3.0	3.5	3.5	3.5	4.0	4.0	4.5	4.5	4.5	5.0	5.0	5.0	5.5	5.5	5.5	6.0	6.0	6.0	6.0	6.5	6.5	6.5
3.00	1.5	2.0	2.5	2.5	3.0	3.0	3.5	3.5	4.0	4.0	4.5	4.5	4.5	5.0	5.0	5.5	5.5	5.5	6.0	6.0	6.0	6.5	6.5	6.5	7.0	7.0	7.0	7.0
3.50	1.5	2.0	2.5	3.0	3.0	3.5	3.5	4.0	4.0	4.5	4.5	5.0	5.0	5.5	5.5	5.5	6.0	6.0	6.0	6.5	6.5	6.5	7.0	7.0	7.0	7.5	7.5	7.5
4.00	~~1.5~~	~~2.0~~	~~2.5~~	~~3.0~~	~~3.5~~	~~3.5~~	~~4.0~~	~~4.0~~	~~4.5~~	~~4.5~~	~~5.0~~	5.0	5.5	5.5	6.0	6.0	6.0	6.5	6.5	6.5	7.0	7.0	7.5	7.5	7.5	8.0	8.0	8.0
6.00	2.0	2.5	3.0	3.5	4.0	4.5	4.5	5.0	5.5	5.5	6.0	6.0	6.5	6.5	7.0	7.0	7.5	7.5	8.0	8.0	8.5	8.5	9.0	9.0	9.0	9.5	9.5	9.5
8.00	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.0	6.5	7.0	7.0	7.5	7.5	8.0	8.0	8.5	8.5	9.0	9.0	9.5	9.5	10.0	10.0	10.5	10.5	11.0	11.0
10.00	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.0	7.5	8.0	8.0	8.5	9.0	9.0	9.5	9.5	10.0	10.5	10.5	11.0	11.0	11.5	11.5	12.0	12.0	12.0
12.00	3.0	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.0	8.5	9.0	9.5	9.5	10.0	10.0	10.5	11.0	11.0	11.5	11.5	12.0	12.0	****	****	****	****
14.00	3.5	4.0	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.0	8.5	9.0	9.5	9.5	10.0	10.5	10.5	11.0	11.5	11.5	12.0	12.0	****	****	****	****	****	****
16.00	3.5	4.5	5.0	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.0	9.5	10.0	10.5	10.5	11.0	11.5	12.0	12.0	****	****	****	****	****	****	****	****	****
18.00	3.5	4.5	5.5	6.0	6.5	7.5	8.0	8.5	9.0	9.5	10.0	10.0	10.5	11.0	11.5	12.0	12.0	****	****	****	****	****	****	****	****	****	****	****
20.00	4.0	5.0	5.5	6.5	7.0	7.5	8.5	9.0	9.5	10.0	10.5	10.5	11.0	11.5	12.0	****	****	****	****	****	****	****	****	****	****	****	****	****
24.00	4.5	5.5	6.5	7.0	8.0	8.5	9.0	9.5	10.0	11.0	11.5	12.0	12.0	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****
30.00	5.0	6.0	7.0	8.0	9.0	9.5	10.0	11.0	11.5	12.0	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****
36.00	5.5	6.5	8.0	8.5	9.5	10.5	11.0	12.0	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****
FLAT	1.0	1.5	1.5	2.0	2.0	2.0	2.5	2.5	2.5	3.0	3.0	3.0	3.0	3.5	3.5	3.5	3.5	4.0	4.0	4.0	4.0	4.0	4.5	4.5	4.5	4.5	4.5	5.0
	90	135	180	225	270	315	360	405	450	495	540	585	630	675	720	765	810	855	900	945	990	1035	1080	1125	1170	1215	1260	1305
	TEMPERATURE DIFFERENCE DEGREES FAHRENHEIT																											

Figure 3. How to determine economic thickness of insulation. The procedure from the ECON I Manual.

Commercial installation—1,000 ft of 1½" pipe

Insulation Thickness (in)	Heat Loss (Btu/hr)	Cost of Lost Heat ($/yr)	Insulation Cost ($/yr)	Total Cost ($/yr)
0	230,320	6,930	0	6,930
1	31,770	960	240	1,200
1½	25,480	770	310	1,080
2	20,290	610	430	1,040
3	17,090	510	580	1,090
4	15,050	450	740	1,190

Economic thickness: 2"
Depreciation period: 20 yr
Operating temperature: 250F
Ambient temperature: 80F
Present cost of heat:
$2.20/million Btu
Cost of heat at mid-life:
$3.25/million Btu

Ten years ago, under the economic conditions of the times, the economic thickness would have been 1". The amount of energy conserved per year (2" of insulation compared with 1") is 101 million Btu. The annual cost reduction is $160.

Process industry installation—1,000 ft of 6" pipe

Insulation Thickness (in)	Heat Loss (Btu/hr)	Cost of Lost Heat ($/yr)	Insulation Cost ($/yr)	Total Cost ($/yr)
0	7,333,160	164,330	0	164,330
2	391,860	8,780	940	9,720
3½	264,620	5,930	1,510	7,440
4½	227,390	5,100	1,860	6,960
6½	184,310	4,130	2,560	6,690
8½	159,180	3,570	3,250	6,820

Economic thickness: 6½"
Depreciation period: 15 yr
Operating temperature: 750F
Ambient temperature: 80F
Present cost of heat:
$1.75/million Btu
Cost of heat at mid-life:
$2.35/million Btu

Ten years ago, the economic thickness would have been 2". The amount of energy conserved per year (6½" of insulation compared with 2") is 1.82 billion Btu. The annual cost reduction is $3,030.

Utility installation—1,000 ft of 12" pipe

Insulation Thickness (in)	Heat Loss (Btu/hr)	Cost of Lost Heat ($/yr)	Insulation Cost ($/yr)	Total Cost ($/yr)
0	13,794,490	323,390	0	323,390
4	397,800	9,330	1,940	11,270
4½	366,350	8,590	2,150	10,740
6½	284,750	6,680	2,990	9,670
8½	239,410	5,610	3,830	9,440
10½	210,020	4,920	4,660	9,580

Economic thickness: 8½"
Depreciation period: 30 yr
Operating temperature: 750F
Ambient temperature: 80F
Present cost of heat:
$1.75/M lb steam
Cost of heat at mid-life:
$3.15/M lb steam

Ten years ago, the economic thickness would have been 4". The amount of energy conserved per year (8½" of insulation compared with 4") is 1.39 billion Btu. The annual cost reduction is $1,830.

Figure 4. How insulation saves—three examples, from the ECON II Manual.

It is shown in the new manual (*1*) that for cylindrical surfaces:

$$D_p \Delta t\, k \frac{(r_2 - R_s k)}{\left(r_2 \ln \frac{r_2}{r_1} + R_s k\right)^2} - 1 = 0 \qquad (1)$$

where: D_p = total cost factor for pipes.

$$= \frac{(\text{hr.}) \times (\text{linear ft.}) \times (\text{in.})}{(\text{million B.t.u.})}$$

Δt = temperature difference.

k = thermal conductivity.

$$= \frac{(\text{B.t.u.}) \times (\text{in.})}{(\text{hr.}) \times (\text{sq. ft.}) \times (^\circ\text{F})}$$

R_s = outside surface resistance.

$$= \frac{(^\circ\text{F}) \times (\text{hr.}) \times (\text{sq. ft.})}{(\text{B.t.u.})}$$

r_1 = inside radius of pipe insulation, in inches.

r_2 = outside radius of pipe insulation, in inches.

It is also shown that for flat surfaces:

$$\frac{D_s \Delta t\, k}{(1 + R_s k)^2} - 1 = 0 \qquad (2)$$

where: D_s = total cost factors for flat surfaces.

$$= \frac{(\text{hr.}) \times (\text{sq. ft.}) \times (\text{in.})}{(\text{million B.t.u.})}$$

Before the advent of the computers, calculations to determine the economic thickness of pipe insulation were very tedious. Now, that has been changed.

The use of the manual in determining economic thickness, as discussed below, utilizes a composite, Figure 3, of the tables and charts which have been computed and plotted from the developed equations. *Figure and table numbers shown in Figure 3 and referred to in this discussion are from the manual itself.* (To eliminate confusion, references to these figures and tables are italicized.) The steps in proper order provide an easy way to arrive at the economic thickness of insulation.

The method requires the user to establish his costs (by whatever accounting methods his company practices) before applying it. The system functions by having all costs resolved into one cost factor, D, which is used as a function in the heat transfer equation.

For a given installation, the cost of insulation and the cost of heat for the system can be determined very closely before the insulation design is started. This relationship is resolved in the D factor for each size of pipe and flat surfaces. This D factor remains fixed until either the cost of heat or cost of insulation changes. Thus, many plant managers, having set down their cost factors on their own forms, and knowing their depreciation periods and the conductivity of their specified insulation, can go directly to the proper table for the optimum thickness, without working out the earlier steps for each stretch of pipe or piece of equipment. Indeed, they may find that they require only one or two portions of the tables, those applicable to their own individual conditions.

There are four basic steps in the use of this manual. Normal rules of interpolation are observed.

Step 1: Determine B, the insulation cost factor. Use *Tables 1-4* (only *Table 1* from the manual is illustrated in Figure 3), under the given value of C (cost of 1-1/2 in. of calcium silicate insulation on 2-1/2-in. pipe) and the column for the given depreciation period. Read over to the given pipe size column. The number shown is the value of B. If the given value of C is not tabulated, interpolate. For differences equal to or greater than half, use the higher value. For differences less than half, use the smaller value.

Step 2: Determine D, the cost of heat factor. Select the proper graph (*Figures 4* through *8* in the manual) for the given plant depreciation period, N_h. Enter the graph at the value of the total production cost of steam, S, in \$ per 1,000 lb. of steam or \$ per million B.t.u., and read to the proper planned capital investment, F (do not include mid-life; the $YM \times 10^{-6}$ curve automatically adjusts for mid-life).

The value of S should include the thermal efficiency of the fuel. It is recommended that a 40% efficiency be used. Read the vertical scale for the proper value of $YM \times 10^{-6}$. Divide $YM \times 10^{-6}$ value by B, determined in Step 1 to obtain the D factor.

If the operating time is not the full 8,760 hr. assumed in the standard formulas, the proper D factor is derived in the following way. Determine the value of $YM \times 10^{-6}$ as directed above. This value must be modified for the hours of operation as follows. $YM \times 10^{-6}$ (modified) = $YM \times 10^{-6}$ (graph value) × (hr. of operation)/8,760. Divide the modified value by B from Step 1 for the proper value of D.

Step 3: Determine k, the conductivity of the insulation. Find the new mean temperature, t_m, as follows:

$$t_m = (t_o + t_{\text{amb}})/2$$

where: t_o = operating temperature.
t_{amb} = ambient temperature.

Using the graph (*Figure 9* is the example illustrated), enter the graph at the mean temperature, t_m, as determined. At the intersection of this line with the curve of the insulation in question, read the value of k on the left axis. Adjust this value, if necessary, to the closest twentieth by interpolation.

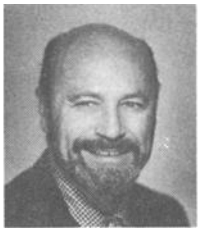
Step 4: Determine Δt, the temperature differential between operating temperature and ambient temperature. Note carefully whether the Centigrade or the Fahrenheit scale is to be used. The economic thickness of insulation may now be determined.

Use *Tables 5 and 6* (portions of which are illustrated), finding first the section for correct thermal conductivity determined in *Step 3* and then the section for the D value determined in *Step 2.* Enter the table at the correct pipe size or flat surface of interest, and go horizontally to the column with the Δt value determined in *Step 4.* If the value of Δt determined in *Step 4* is not tabulated, interpolate. For differences equal to half or greater, use the larger value; for less than half, the smaller. The value shown is the economic thickness.

Figure 4 shows examples of how insulation saves. It is from a second manual, ECON II, which was developed as a marketing tool to provide helpful hints. #

Literature cited

1. "ECON-I—How to Determine Economic Thickness of Thermal Insulation," Thermal Insulation Manufacturer's Assn.



J. M. Barnhart graduated from Rensselaer Polytechnic Institute with a bachelor's degree in mechanical engineering. He is executive director of the Thermal Insulation Manufacturers Assn., Inc.

STP581-EB/Mar. 1975

Insulation Practices:

Foam Insulation for Tanks and Vessels

In one instance where polyurethane foam was used to insulate five storage tanks, the saving on heating fuel alone paid for the insulation in 18 months.

C. S. Foster, The Upjohn Co., Torrance, Calif.

A spray type of polyurethane foam insulating material has been found, in two commercial scale test cases, to be a completely satisfactory method of minimizing energy costs, by cutting down on energy waste.

In one instance, it kept heat in, maintaining the temperature of Bunker C fuel oil at the required 120 to 200°F. in storage tanks. In the other case, the insulation kept heat out, maintaining the temperature of liquefied natural gas (LNG) at the proper levels (below −260°F.) during storage and transportation.

Insulation available for heated bulk storage tanks prior to sprayed urethane foam was costly in materials and labor. Blocks or blankets of material had to be cut by hand and fitted into place, and some kind of mechanical bonding of insulant to the tank was required. Finally, the insulation had to be covered with either a sprayed or troweled coating. Perhaps the most expensive element of installation was the scaffolding erected around the tank. Total installed cost of this type of insulation was a prohibitive $3.50 to $4.50/sq. ft.

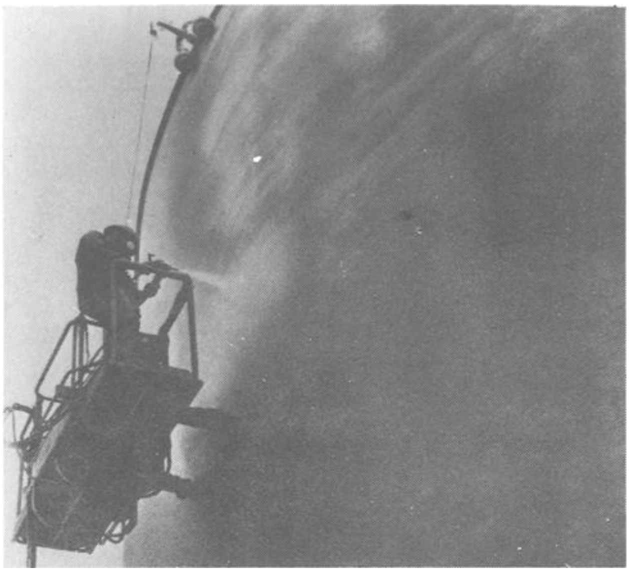


Figure 1. Mechanized, revolving scaffolds permit fast application of spray urethane foam insulation on refinery storage tanks.

Sprayed urethane can be applied to these tanks at total installed costs of $1.00 to $1.50/sq. ft. and insulates better than previously used materials. At temperatures of 120 to 200°F., urethane is the most efficient available insulation. Insulation efficiency is measured by the K-factor, which is the number of B.t.u. of heat transmitted through the insulation, per hour, per square foot, per Fahrenheit degree of temperature difference, per inch. The lower the K-factor, the more efficient the insulation. Urethane has a K-factor of only 0.13 at 100°F. and 0.21 at 200°F. Table 1 lists K-factors of various insulating materials.

A case in point

In 1971, the CPR Div. of The Upjohn Co. was called in to insulate five tanks, each 40 ft. high and 125 ft. in diameter, in a trial by one of the largest U.S. oil companies. The tanks were being heated by steam coils to 180–190°F. The insulation problems were solved, and savings were attained of 70¢/sq. ft. in costs of heating fuel. This meant that the insulation paid for itself in 18 months. Calculated savings were based on a 200°F. tank temperature, 60°F. ambient, $1.00/sq. ft. installed cost of insulation and $1.00/million B.t.u. to heat the tank at 75% efficiency.

Table 1. Efficiencies of insulating materials.

Insulating Material	K-Factors[c] −250°F	−30°F	+100°F	+200°F
Urethane Foam[a]	0.04	0.13	0.13	0.21
Styrene Foam[b]	0.04	0.17	0.25	b
Glass Fiber	0.08	0.19	0.25	0.30
Cork	0.13	0.23	0.30	0.35
Asbestos Fiber	0.23	0.33	0.38	0.42
Glass Foam	0.18	0.33	0.42	0.47

---

[a] CPR urethane foam, nominal density 2 lb./cu. ft.
[b] Styrene foam is not suited for service at 200°F.
[c] B.t.u./hr./sq. ft./°F./in.

The tank surface was washed with detergent solution, then 1 in. of urethane foam was applied to the thoroughly dried surface and two coats of butyl rubber compound were sprayed over the foam to protect it. The tank remained in service at 180°F. throughout the application procedure.

An acrylic paint already on the tanks caused blisters to form under the foam, 6 in. to 4 ft. in diameter. This problem was quickly detected and solved by a light brush blast to break up the paint surface. Lack of foam adhesion also occurred with some epoxy paints.

Zinc-based or red lead primers are best for preparing surfaces for urethane foam spraying at less than 200°F. Tensile adhesion of 2 lb./cu. ft. foam to steel is 41 to 47 lb. Primers reduce tensile adhesion by only 5 to 6 lb.

Instead of scaffolding, a single, 20 ft.-wide, aluminum stage was suspended by two steel cables from the center of the tank top. Electric or compressed air-powered hoists on each side of the stage raised and lowered the stage. A small frame with rubber wheels rolled around the circumference of the tank top to carry the stage around the tank, Figure 1.

During foam application, the stage was lowered from top to bottom and a 20 ft. wide strip was sprayed on. Then the stage was raised to the top again, moved to the next adjacent strip and the operation was repeated. By using five to six aluminum stages, each placed 6 ft. below the one above, several men can ride down the face of the tank slowly enough to allow the foam to cure from the spraying before the men following apply the butyl rubber coats.

Protective coatings for urethane foam guard against ultra-violet degradation in sunlight, weathering, and mechanical abrasion. Many good elastomeric coatings are now available with good elongation, adhesion, covering power and chemical and solvent resistance. Coating materials include butyl rubbers, urethane elastomers, vinyl resins, and Hypalon, which is based on chlorosulfonated polyethylene.

Electric power plants as well as refineries also have heated fuel storage tanks. Most utilities have installed three to ten tanks at each power plant in the past two to three years in anticipation of shortages and needs to switch to alternate fuels. These tanks are generally heated at 120 to 190°F.

Cryogenic insulation

At the other end of the temperature spectrum, superior insulation is needed for transport and storage of LNG and other gas liquids. Most natural gas is almost pure methane, which boils at −260°F. The K-factor for sprayed urethane foam is 0.04 at cryogenic temperatures, while that of glass fiber is 0.08, which shows the superiority of urethane.

Table 2. Properties of liquid gases.

Gas	Boiling Point, °F.	Heat of Vaporization (B.t.u./lb.)
Ammonia	− 28	589
Methane	−260	219
Oxygen	−297	92
Nitrogen	−320	85

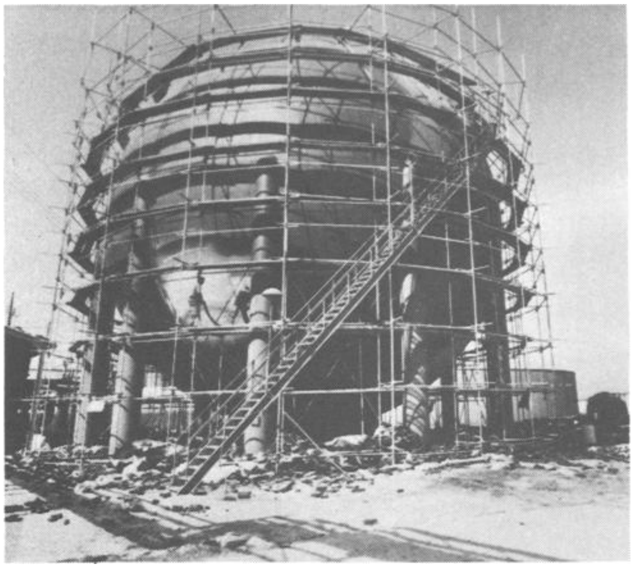


Figure 2. A large ammonia storage sphere at Coastal Chemical Co. in Pascagoula, Miss. receives a 3-in. coat of urethane insulation, which will maintain the contents at −25°F.

The cryogenic insulation keeps heat out of and prevents the boiling away of liquefied gases. The relatively low heat of vaporization of methane—about 220 B.t.u./lb.—means that it's difficult to keep this gas in liquid form. Only a little heat is needed to convert a pound of liquid methane to gas at its boiling point. By comparison, heats of vaporization of liquid nitrogen, oxygen and ammonia are 85, 92 and 589 B.t.u./lb., respectively. Table 2 lists the properties of several liquid gases.

When protective coatings are applied to cryogenic urethane foam insulation, care should be taken that it has lowest possible permeability to moisture. Cold liquid gas temperatures can condense moisture in insulation, decreasing its efficiency. Even though urethane foam has 90% closed cells, uncoated foam tends to absorb and transmit moisture. The problem is especially bad with glass fiber. From time to time, glass fiber insulation must be taken out of service, the accumulated ice thawed and the insulation drained of water.

Urethane insulation is also best for anhydrous ammonia, which is fertilizer in liquid form. It can be used on mobile tanks and storage tanks. Near the −28°F boiling point of liquid ammonia, urethane still has the lowest K-factor of any commercially available insulation. Figure 2 shows an ammonia storage sphere receiving a coat of urethane insulation. #

C. E. Foster is technical sales representative for the CPR Div. of the Upjohn Co. He is a past-president of the Southwest Insulation Contractors Assn. He joined the Upjohn Co. in 1970.

STP581-EB/Mar. 1975

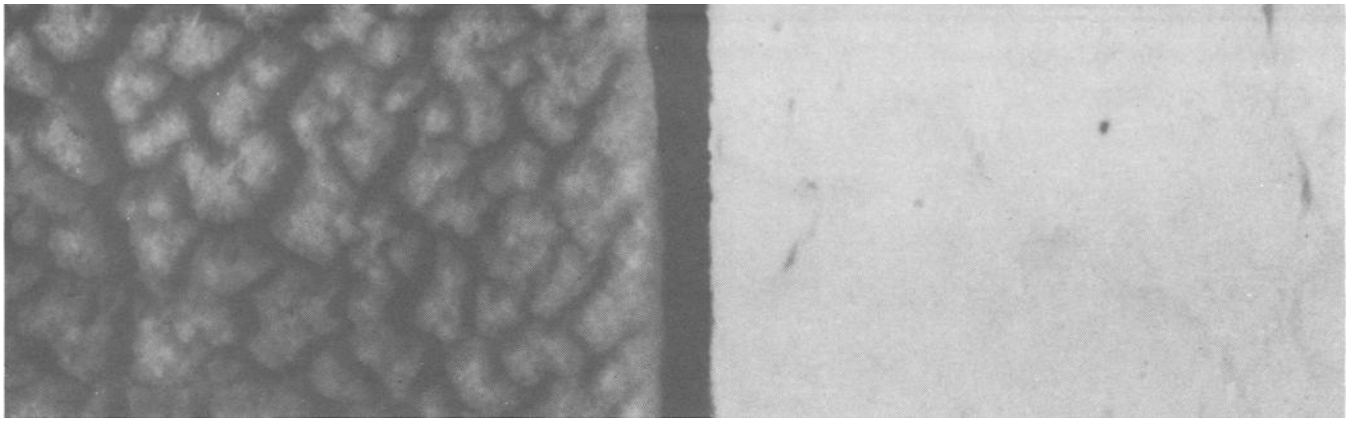


Figure 1. Polyurethane foam unprotected (left) and coated (right), after 1,000 hours in a Weatherometer.

Insulation Practices:

Protective Coatings for Foam Insulation

Although polyurethane has excellent insulating properties, its weather resistance is poor. A proper protective coating is essential.

J. C. Smith and **J. S. Kummins**, Dow Corning Corp., Midland, Mich.

Fuel shortages, and the resulting increase in the cost of energy, has spurred the use of more efficient insulation systems for residential and commercial buildings, as well as for industrial applications. As can be seen from Table 1, the R value of polyurethane foam has almost a two-fold advantage over polystyrene foam and glass fiber, making it the best insulation material available today.

On the other hand, the weather resistance of polyurethane is very poor; it is highly susceptible to degradation from ultraviolet radiation and will erode at a rate of 1/4 in./yr. This means that an inch of foam would be completely gone in only four years. And well before this moisture will enter the foam when the skin degrades, causing loss of insulating properties. Because of the lack of durability, the urethane foam must be protected by a coating.

The poor weathering of unprotected polyurethane foam in contrast to coated foam is shown in Figure 1. The sample has had 1,000 hr. of exposure in an Atlas filtered Weatherometer, which is equivalent to over three years of actual outdoor weathering.

Sprayed-in-place polyurethane foam with a high performance elastomeric protective coating, the subject of this article, can be applied quickly and economically. After the tank walls are properly prepared and cleaned, the foam is sprayed from a dual-component spray gun from 55 gal. drums. The two liquid streams are blended at the gun tip and start to foam and cure almost as soon as they hit the substrate. In less than one minute, the foam insulation is cured in place with tenacious adhesion. Application rates of up to 10,000 sq. ft./day are easily obtainable with a small crew.

Smooth surface improves performance

Because the foam tends to follow the texture of the substrate and most tanks have a fairly smooth surface, it is easy to get a smooth foam surface. This is important for two reasons. First, rougher foams present a larger than anticipated surface area, and hence need more protective coating. Second, the chance of pinholes occurring is far greater with a rough texture foam.

As an example of foam textures, note that Figure 2 shows a smooth foam which is described as "orange peel" while the foam in Figure 3 has a rougher surface described as "popcorn." This latter surface will increase coating usage by 30–50% and have a greater tendency to pinhole due to difficult coverage on the extremely rough surface.

The surface texture obtained depends upon a number of application variables such as substrate texture, type of foam system, applicator skill, wind velocity, and surface temperature.

Table 1. Insulation values (based on 1-in. thickness at 70°F.).

Insulation Material	K Factor	R Value
Polyurethane Foam	0.13	7.16
Vinyl Foam	0.18	5.55
Glass Fiber	0.27	3.85
Styrene Foam	0.28	3.67
Mineral Wool	0.30	3.33
Foam Glass	0.38	2.63

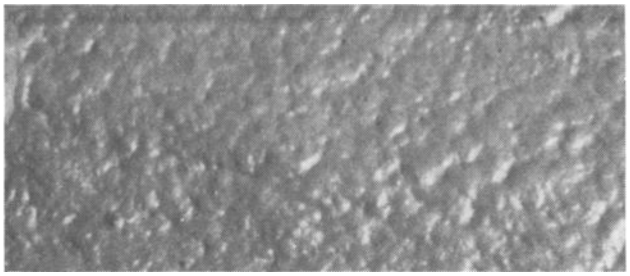


Figure 2.
Acceptable foam surface: "orange peel."

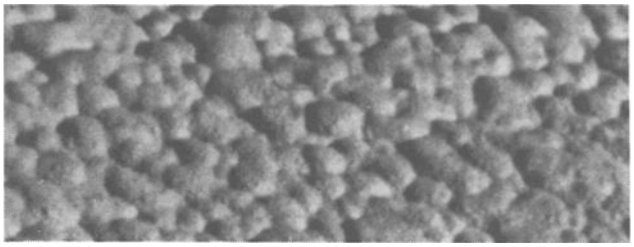


Figure 3. Non-acceptable foam surface: "popcorn." Surface will result in an increase in coating used and a tendency to pinhole.

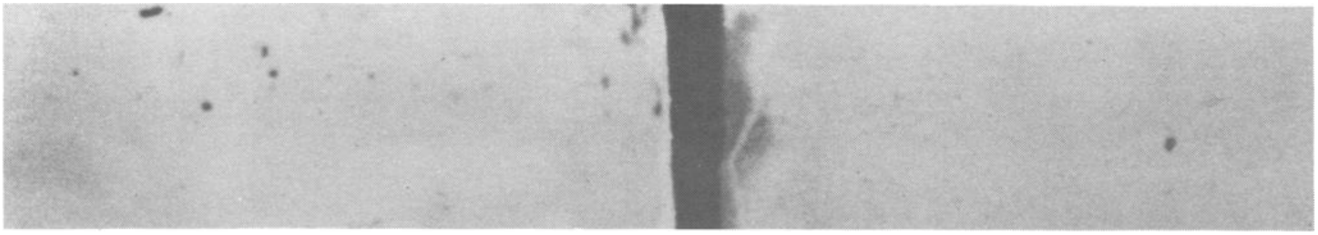


Figure 4. Polyurethane foam with recommended thickness of coating. Two coats (left) protect foam better than one coat (right) during Weatherometer exposure.

Once the foam is in place, the protective coating is applied from either single or dual-component spray guns, depending on the type of material used. With certain coatings, a primer is required to get the necessary adhesion to the foam, but the majority of coatings can be applied unprimed. Coatings will vary as to number of coats and thickness required. However, the most important consideration is to use two separate applications or coats, preferably using two different colors.

The two-coat application usually eliminates pinholes, because the probability of two pinholes lining up between two coats is very slight. The two colors simply allow better judgment of coverage rates to better control film thickness. As an example of this problem, Figure 4 shows a piece of foam with the recommended thickness on each side; however, one side was applied as a single heavy coat while the other used two light coats. After a few hundred hours in a weatherometer, the pinholing becomes quite evident with the one-coat sample.

Before foam and coating are applied, however, the material choice must be made. This depends on many factors, such as maintenance, service environment, type of substrate, service temperature, humidity conditions, geographical location, cost, safety requirements, hail or impact resistance, and aesthetics.

Coatings will have different life expectancies. If the foam installation is such that routine, periodic maintenance is difficult and/or expensive, then a high-life expectancy coating should be chosen. For a number of reasons, a coating's life expectancy may be reduced when applied over a polyurethane foam surface, therefore data on weathering over a polyurethane foam surface will be needed. It is also important to remember the effect of the coating on performance of the insulation system. The use of the most durable coating that is economically feasible cannot be too highly stressed.

Material first cost alone not important

Cost per gallon should not be used to determine the economics of the coating system. Rather, cost in place and maintenance costs should be considered to give a total cost picture.

Safety considerations in terms of the uncured coating include flash point and toxicity. This information should be obtained from the coatings manufacturer. Fire classification data can be obtained from the material suppliers or from the testing agency. Factory Mutual and Underwriters Laboratories have tested various foam and coating systems.

If the system is to be used in an area with high probability of hail, data should be known on the ability of a system to withstand a certain size hailstone. The National Bureau of Standards has developed a test which deals with this property. A higher density foam (3-5 lb./cu. ft.) and a thicker than normal coating may have to be used to increase hail resistance.

If a high degree of foot traffic is expected on a regular basis, a walk-way system should be used. The coating manufacturer can help out with specific recommendations.

Texture and color can be varied with some systems if aesthetics are important. Ceramic coated mineral aggregate, sprayed into the coating before cure, is one method used to achieve this.

An example of one decision especially important in tank insulation is the choice between using a vapor barrier material or a breathable membrane. The breathable membrane allows water vapor to pass, but completely stops any liquid water. The vapor barrier allows neither water vapor nor liquid water through the membrane.

The importance of this decision becomes apparent when considering insulation of a "hot" tank such as vegetable oil storage in cold locations, or a "cold" or refrigerated tank such as liqufied natural gas and cryogenic tanks. Figure 5 shows the direction of vapor drive that could be present through the insulation. With a cold tank, atmospheric humidity is driven towards the tank wall. If a vapor barrier is not used, passage is unobstructed and some vapors will eventually condense someplace within the foam, causing loss of insulating efficiency, or by freezing and causing physical damage. The moisture that passes through the insulation and condenses or freezes at the foam/tank interface will cause physical damage and loss of adhesion. Thus it can be seen that "cold" tank insulation should be protected by

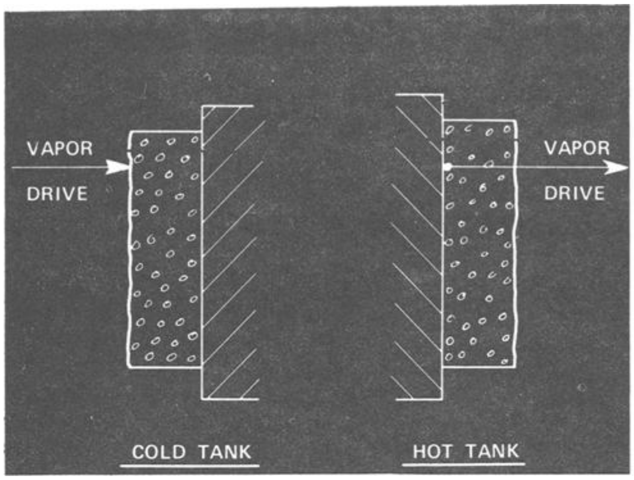


Figure 5. Vapor drive direction will vary with hot or cold tanks. Vapor barriers should be used with cold tanks; a "breathable" coating should be used with hot ones.

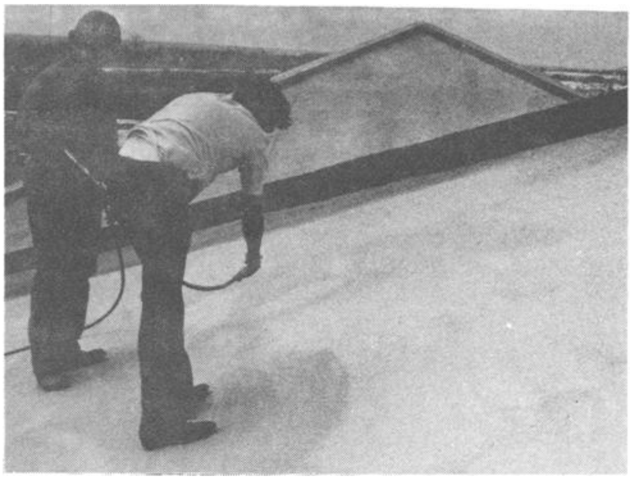


Figure 6. One-component silicone rubber coating being sprayed over a polyurethane foam.

Table 2. Coatings for polyurethane foam.

Generic Type of Coating	Vapor Permeability	Components	Dry Film Build (mils)	Number of Coats	Primer Required on Foam?
Vinyl	Vapor Barrier	One	15 minimum 20 typical	2	Yes
Hypalon	Vapor Barrier	One	15 minimum	2	No
Butyl	Vapor Barrier	Two	20 minimum	2	No
Urethane Elastomer	Breathable	Two	15 minimum 20 typical	2	No
Silicone (two-part)	Breathable	Two	20 minimum	2	Yes
Silicone (one-part)	Breathable	One	15 minimum	2	No

an exterior vapor barrier to completely eliminate passage of water vapor.

In the case of a "hot" tank, the vapor drive is to the outside, thus any moisture or vapors present within the foam need an escape route. If a vapor barrier is used here, bubbles or blisters tend to form between the coating and the foam, eventually leading to failure of the insulation system. This insulation, therefore, calls for a breathable coating; one with a perm rating at least as great as the foam itself.

There are also hybrid systems. For example, suppose a vapor barrier is required on a cold tank but a particular coating that happens to be a breather is preferred due to some other consideration such as superior weatherability or resistance to particular environments such as acids. In this case, it is possible to get the best of both worlds by using a vapor barrier basecoat followed by a breather as a top coat. An example of such a system would be a butyl/silicone system.

Three breathable coatings and three vapor barriers

The types of coatings available are summarized in Table 2. There are three generic types of coatings that can be considered to be vapor barriers—vinyls, Hypalons, and butyls. Of these, vinyls and Hypalons are one-component systems, while the most common butyls used are two-component. All three of these coating types require two coats. The vinyls need, in addition, a primer to promote adhesion to the foam surface. Hypalon can be used alone over foam, but many times it is used as a top coating over another base coating such as neoprene.

Three major types of coatings can be considered breathable—two-part urethanes, one-part silicones, and two-part silicones. The one- and two-part silicones also differ in their cure mechanism, which results in some differences in their performance properties. Urethane elastomers usually do not require a primer when coating urethane foam. Figure 6 shows a tank insulated with polyurethane foam and silicone coating being applied. #

J. C. Smith received his B.S. in chemistry from Grove City College and an M.B.A. from Central Michigan Univ. He has worked for Dow Corning Corp. for the past seven years developing applications for silicone room temperature vulcanizing elastomers, including the development of a silicone rubber coating for polyurethane foam roofing. He is currently a technical service and development representative for the firm, responsible for applications and product development for silicone sealants and coatings in the construction industry.

J. S. Kummins is a construction industry specialist with Dow Corning Corp. in Atlanta, Ga. He has responsibility for technical service and marketing of the firm's line of silicone sealants and coatings used in the construction industry. Kummins, who has authored many papers on silicone applications and has been issued one patent, received his B.S.Ch.E. from Northeastern Univ.