PDHonline Course M156 (4 PDH)

Process Plant Insulation & Fuel Efficiency

Instructor: A. Bhatia, B.E.

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PDH Online | PDH Center

5272 Meadow Estates Drive
Fairfax, VA 22030-6658
Phone & Fax: 703-988-0088
www.PDHonline.org
www.PDHcenter.com

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Course Content

Part 1 Introduction & Overview

It is important that due regard to required levels of thermal insulation be given at the initial design stages of process plant. With the advent of technology in insulating materials, many upgraded alternatives are available to engineers for application in industry.

This course reviews the above criteria together with the types, characteristics and properties of various thermal insulation materials. There is an outline of energy conservation and therefore the cost savings.

What is thermal insulation?

Insulation is defined as a material or combination of materials, which retard the flow of heat by performing one or more of the following functions:

1. Conserve energy by reducing heat loss or gain.
2. Control surface temperatures for personnel protection and comfort.
3. Facilitate temperature control of a process.
4. Prevent vapor flow and water condensation on cold surfaces.
5. Increase operating efficiency of heating/ventilating/cooling, plumbing, steam, process and power systems.
6. Prevent or reduce damage to equipment from exposure to fire or corrosive atmospheres.

The temperature range, within which the term "thermal insulation" will apply, is from -73.3ºC (-100ºF) to 815.6ºC (1500ºF). Typically all applications below -73.3ºC (-100ºF) are termed *"cryogenic,"* and those above 815.6ºC (1500ºF) are termed *"refractory". Usually* 2300° F is the maximum temperature for which insulation is applied.

Where is thermal insulation installed?

Thermal insulations are materials that insulate the components of mechanical systems.

In buildings such as commercial offices, apartments, shopping centers, schools, hospitals, and hotels, mechanical insulation is installed to improve the energy consumption of the buildings' cooling and heating systems, domestic hot and chilled water supply, and refrigerated systems including ducts and housings.

For industrial facilities, such as power plants, refineries, and paper mills, insulation is installed to control heat gain or heat loss on process piping and equipment, steam and condensate distribution systems, boilers, smoke stacks, bag houses and precipitators, and storage tanks.

Benefits of Insulation

Thermal insulation in process plant serves three main purposes viz. Safety, Meeting Process Requirements and Energy conservation.

Safety

Insulation reduces the surface temperature of piping or equipment to a safer level, resulting in increased worker safety and the avoidance of worker downtime due to injury or shock.

Thermal insulation is one of the most effective means of protecting workers from second and third degree burns resulting from skin contact for more than 5 seconds with surfaces of hot piping and equipment operating at temperatures above 136.4°F (ASTM C 1055). Insulation reduces the surface temperature of piping or equipment to a safer level as required by OSHA, resulting in increased worker safety and the avoidance of worker downtime due to injury. The recommended safe touch temperature of surfaces falls in ranges 120 to 150°F.

When designing an insulation system for personnel protection, the surface temperature becomes critical. The surface temperature can increase both from outside solar heat gain and from within as heat radiates outward from a hot pipe.

When specifying insulation consider the ambient conditions that will create the hottest surface temperature, such as summer weather with no wind and a metal jacketing material.

Also important to consider is the elevation of piping and will personnel will come into contact with it. If the pipe is 20 feet above ground, or in an area that is inaccessible to personnel, there may be minimal human safety concern. Limited human presence may only require a sign or a fabricated guard.

The type of surface can play a role in deciding what surface temperatures should be used in the case of operative’s safety and the following are recommended limits:

Non-metallic surfaces within reach of operators without need of ladders etc.	*65° C max.*
Metallic surfaces as above	*55° C maximum*
Metallic and non-metallic surfaces accessible by ladders etc.	*50° C max.*
Limit for extremely cold surfaces	*Minus 10° C min.*

Where the above limits are not likely to be met by insulated or non-insulated surfaces protection should be provided for the operators in the form of an effective guard- say an open mesh screen with mesh size such that no accidental contact can be made with the protected surface.

Fire Safety

Apart from the safety of operative there could be the possibility of fire risk where combustible materials are in proximity of the hot surfaces.

Used in combination with other materials, insulation provides:

1) Fire stop systems designed to provide an effective barrier against the spread of flame, smoke, and gases at penetrations of fire resistance rated assemblies by ducts, pipes, and cable.
2) Electrical and communications conduit and cable protection

Process Control

In other cases, insulation can help maintain process temperature to a pre-determined value or within a predetermined range by reducing heat loss or gain. Any undue loss of heat can seriously affect operation, product quality or mean the need for larger heat exchanger surfaces at the receiving end with resulting higher capital costs.

Process control is usually a critical design consideration in many industrial environments and can be relevant with both hot and cold piping. The questions that need to be asked here are:

1. What is the worst-case temperature to which the system will be subjected?
2. What are the temperature limitations of the process being controlled?
3. What are the consequences in terms of the cost and safety of lost process control?

There are of course many different processes requiring different temperatures and conditions and calculations must be carried out for each specific case. There are however some common principles, which should be borne in mind. The heat loss from say one meter of pipe will depend upon the temperatures of the gas or liquid being conveyed and the air around it. The level of insulation will obviously influence this heat loss per meter but at whatever level we fix the heat loss per meter by insulation, it will be constant as long as the internal temperature is maintained. However if the rate of flow is reduced and supplementary heating is not provided, the temperature drop at the delivery point will be in almost inverse proportion to the flow rate. For example halving the flow rate shall nearly double the temperature drop between source and point of delivery. Similarly the heat loss as a proportion of the flow will double i.e. a 10% heat loss will increase to nearly 20%.

Where flows are considerably reduced due to low loads at particular times, it is clear that much lower delivery temperatures than normal will be found. There may be some mitigating effect due to lower heat loss following from lower mean fluid or gas temperatures but not if the delivery temperature must be maintained by providing a higher initial temperature, that will increase the losses.

Hot Water & Steam Distribution Systems

Hot water or steam supply at rated temperatures and pressures could be a stringent process requirement for many industrial processes. Certain processes require uniform temperature in narrow tolerances to achieve proper chemical reaction; too much or not enough heat can completely nullify the chemical reaction or can result in liquid crystallization and the batch loss. For example, in the transport of liquid sulfur, if the temperature drops below its freezing point, the liquid becomes solid. The time and energy required to transform the sulfur back into a liquid and flowing state is more expensive than the cost of replacing the transport system altogether.

Cold Piping Systems

Process control is usually the most important guiding criteria when designing lower temperature insulation systems. In most cold processes (except for chilled water piping in climate control systems), the maximum allowable heat transfer for process control purposes is 30 to 40 Btu/h/ft. The consequences of exceeding this limit are so costly that a safety factor of 4 is frequently employed, resulting in a design limitation of 8 to 10 Btu/h/ft.

Energy Savings

Even if the two above criteria (safety & process control) are met the insulation conserves energy by reducing heat loss or gain. Substantial quantities of heat energy are wasted daily in industrial plants nationwide because of under insulated, under maintained or un-insulated heated and cooled surfaces.

The reduction of heat loss by insulation is a practical means of achieving substantial economies of energy. Some estimates have predicted that insulation in US industry alone saves approximately 200 million barrels of oil every year.

It is important that that the large financial benefits which are available to industry, by preventing heat loss through effective insulation, should be recognized and understood, and that appropriate action should be taken to achieve them.

This course reviews the above criteria together with up to date standards of insulation in subsequent sections.

Other benefits of insulation include:

Sound Attenuation

Insulation materials can be used in the design of an assembly having a high sound transmission loss. Special or standard insulation materials can be used to encase or enclose a noise generating source, forming a sound barrier between the source and the surrounding area.

Greenhouse Gas Reduction

Thermal insulation for mechanical systems provides immediate reductions in CO_2, NO_x and greenhouse gas emissions to the outdoor environment in flue or stack emissions by reducing fuel consumption required at the combustion sites because less heat is gained or lost by the system.

PART II- Insulation Properties

How does the insulation work?

In order to understand how insulation works, it is important to understand the concept of heat flow transfer. In general, heat always flows from warmer to cooler surfaces. This flow does not stop until the temperature in the two surfaces is equal.

Heat is 'transferred' by three different means: conduction, convection and radiation.

Insulation reduces the transference of heat.

Conduction

Conduction is direct heat flow through solids, which in fact is due to the movement of molecules.

Convection

Convection is the flow of heat (forced and natural) within a fluid. A fluid is a substance that may be either a gas or a liquid. The movement of a heat- carrying fluid occurs either by natural convection or by forced convection as in the case of a forced-air furnace.

Radiation

Radiation is the transmission of energy through space by means of electromagnetic waves. An example is the warmth we feel on our skin from the sun.

The basic requirement for thermal insulation is to provide a significant resistance path to the flow of heat through the insulation material. To accomplish this, the insulation material must reduce the rate of heat transfer by conduction, convection, radiation, or any combination of these mechanisms.

R-Value

The property of the thermal insulation by which it resists heat transfer is called thermal resistance. Insulation is measured in R-value. The higher the R-value, the greater shall be the insulating power.

To achieve higher total insulating power, R-values can be added together. For example, R-38 added to an R-11 results in R-49.

Thermal resistance is reciprocal of conductance. Conductance is defined as the amount of heat transmitted through a unit area of the material in a unit time through its total thickness and with a unit of temperature difference between the surfaces of the two opposite sides.

$$\text{Thermal Resitance} = \frac{\text{Thickness of Homogenous Body}}{\text{Conductivity of that body}}$$

$$\text{Heat Flow} = \frac{\text{Temperatre Difference}}{\text{Thermal Resistance}}$$

Materials vary widely in heat conducting properties. This is expressed by the term conductivity or k-value.

k- Value

k- Value is the material property, which measures conductivity. It is the same number regardless of the thickness of insulation. It is the quantity of heat transferred (BTU's) in a unit time (1 hr) through a unit area of unit thickness (l" thick * 12" wide * 12" long section of insulation) thereby lowering the temperature from the hot side to the cold side by 1 degree F. Thermal conductivity of a given material usually increases with rise in temperature. Materials with lower k-values are better insulators. Most manufacturers report their product's insulation value in k at 75°F mean temperature. Mean temperature is the inner surface temperature plus the outer surface temperature, divided by 2. As mean temperatures rise, so does the k-values of a product.

The conductivity of an insulation material (k value) for a material is not an absolute constant, since it will vary with

a. *Density (pore size, fiber diameter, shot content i.e. non-fibered particles of rock or glass wool)*

b. *Humidity or water content*

c. *The mean temperature at which it works (i.e.(T2+T1) /2)*

Usually, k factor increases as each of these parameters increases.

It is advisable to compute heat losses, on the basis of test values given by the manufactures of insulating materials. Thermal conductivity values for typical heat insulating material, resistant films and heating surfaces are shown below:

Material	***Density (kg/m^3)****	***Approximate conductivity values (kcal/m/hr/°C)****
Magnesia	*177-225*	*0.051 to 0.066*
Mineral Wool	*50-250*	*0.035 to 0.087*
Calcium Silicate	*160-320*	*0.049 to 0.079*
Aluminosilicates	*96*	*0.028 to 0.071*
Glass Fibers	*96*	*0.028 to 0.061*
Resistant Films		
Water at 0°C		*0.510*
Water at 95°C		*0.585*
Air		*0.0214*
Scale		*0.99 – 2.97*
Heating Surfaces @ 100°C		
Copper		*338*
Aluminum		*206*
Cast Iron		*27.8*
Steel ((0.5%C)		*44.7*
Brass		*89.3*

(*1 lb/ft^3 = 16.04 Kg/m^3 and 1 $Btu/hrft^2°F$ = 4.885 $Kcal/hrm^2°C$)

Key Properties of Thermal Insulation Products

Insulations have different properties and limitations depending upon the service, location, and required longevity of the application. Designers when considering the insulation needs of industrial or commercial applications take these into account.

1) **Thermal Resistance (R) (F ft2 h/Btu)**

   The quantity determined by the temperature difference, at steady state, between two defined surfaces of a material that induces a unit heat flow rate through a unit area. A resistance associated with a material shall be specified as a *material R*. A resistance associated with a system or construction shall be specified as a *system R*.

2) **Thermal Conductivity (k) (Btu in. /h ft2 F)**

   Thermal conductivity is defined as the quantity of energy that passes through 1 m^3 of insulation if there is a temperature difference between opposite surfaces of 1k. *The lower this value, the better is the thermal insulation performance.*

3) **Emittance (emissivity)**

Emittance is defined as the ratio of the total heat lost per unit of time through a unit area of the surface of a body to the total heat, which would be lost in the same unit area of a perfect blackbody. The surface emittance for a blackbody is 1. For surfaces other than that of a blackbody surface, the value of emittance is always less than 1. *Higher emittance signifies high heat transfer by radiation.* This parameter plays an important role for thermal insulation finishes. For Aluminum e = 0.05 at 100°F & 0.075 at 1000°F, Copper = 0.04 at 100°F & 0.08 at 1000°F, Steel = 0.20 at 100°F & 0.25 at 1000°F.

Emissivity property is significant when the surface temperature of the insulation must be regulated as with moisture condensation or personnel protection.

4) **Reflectance**

The ratio of radiant flux reflected by a body to that incident upon it

5) **Density (lb/f3) (kg/m3)**

The weight of a unit volume of insulation, such as pounds per cubic foot (kilograms per cubic meter)

6) **Temperature range (limits)**

Determines for which application a certain material is suitable. Temperature limits are defined by upper & lower temperatures within which the material must retain all its properties.

7) **Behavior in fire**

Fire performance ratings are based on "tunnel tests" in accordance with ASTM E 84, National Fire Protection Association (NFPA) test NFPA 255 or Underwriters laboratory test UL 723. Values of tunnel test can be as low as zero for flame spread and 50 for smoke developed which are generally acceptable. The Determination of behavior in fire can be divided in the following 6 subjects:

- *Surface burning Characteristics:* These are comparative measurements of flame spread and smoke development with that of select red oak and inorganic cement board. Results of this test may be used as elements of a fire-risk assessment, which takes into, account all of the factors, which are pertinent to an assessment of the fire hazard or fire risk of a particular end use.
- *Fire propagation:* The supplied electrical energy flow in watts, leading to ignition of the sample after 5 and 15 minutes in accordance with BS 476 Part 6 class O
- *Ignitability:* Samples are exposed to a temperature of 750°C +/- 10 °C and the flaming time is determined after 5 seconds in accordance with BS 476 Part 4.

- *Smoke development/Contents of smoke:* During the tests on fire propagation, the optical density of the smoke is measured by using a beam of light and photoelectric cells.
  It is known that the main cause of death in fire is suffocation by smoke. That is why it is quite confusing that international independent test institutes in general do not test on contents of smoke. The requirements are laid out in ISO 5660.
- *Surface spread of flame:* Measured the flame spread after 30 seconds, 1 minute and final flame spread after 10 minutes.
  - ✓ BS 476 Part 7 = Class 1
  - ✓ NFPA 255 = Class A
  - ✓ UBC 42-1 = Class 1
  - ✓ DIN 4102 = Class B1
  - ✓ NEN 6065 = Class 2
- *Fire Resistance/Endurance:* Capability of an insulation assembly exposed for a defined period of exposure to heat and flame (fire) with only a limited and measurable loss of mechanical properties. Fire endurance is not a comparative surface-burning characteristic for insulation materials.

7) **Compressive Resistance**

This is a measure of the material to resist deformation (reduction in thickness) under a compressive load. It is important when external loads are applied to an insulation installation.

8) **Thermal Expansion/Contraction and Dimensional Stability**

Thermal expansion/contraction is a concern both for insulation systems that operate continuously at below ambient conditions or systems that cycle between below-ambient conditions and elevated temperatures. Thermal contraction coefficients of insulation materials may be substantially different from those of the metal pipe. A large difference in the amount of contraction between the insulation and the piping may result in open joints of the insulation system. These open joints create a thermal short circuit and moisture flow paths at that point in the system that can degrade the system performance. Insulation materials that have large contraction coefficients, and do not have a high enough tensile strength or compressive strength to compensate, may experience shrinkage and subsequent cracking within the material. At the elevated temperature end of the cyclic process, the reverse is considered. High thermal expansion coefficients may result in warping or buckling of a material that for some insulation materials is permanent and irreversible. In this instance, the possibility of resulting stress on an external vapor retarder or weather barrier should be considered.

Long-term satisfactory service requires that the insulating materials, closure materials, facings, coating, and accessories withstand the rigors of temperature, vibration, abuse, and ambient conditions without adverse loss of dimensions.

9) **Water vapor permeability**

Water vapor permeability is an indication of the ability a material to allow the passage of water vapor through it. The lower the permeability, the higher is the resistance of the material to water vapor intrusion. Water vapor permeability can be a critical design consideration because water vapor has the ability to penetrate materials that are unaffected by water in the liquid form. Water vapor intrusion is a particular concern to insulation systems subjected to a thermal gradient. Driving forces are created due to pressure differences between ambient conditions and the colder operating conditions of the piping. These forces drive water vapor into the insulation system, where it may be retained as water vapor, condense to liquid water or condense and freeze to form ice. Thermal properties of insulation materials are negatively affected as the moisture or vapor content of the insulation material increases.

10) **Wicking**

Wicking is the tendency of an insulation material to absorb liquid due to capillary action. Wicking is measured by partially submerging a material and measuring both the amount of liquid that is absorbed and the amount of space by volume the liquid has consumed within the insulation material.

11) **Water vapor diffusion resistance**

Water is a good conductor and influences the thermal conductivity in a negative way in case of water absorption or water vapor diffusion. The ability of an insulation material to act as a barrier against water absorption or water vapor diffusion is important. Open cell or fibrous materials tend to perform worse in water absorption, water vapor permeability and wicking than do closed-cell materials. The amount of closed cell structure compared to open cell structure may be to some degree an indicator of the performance of the material; the value expresses the water vapor diffusion resistance of the insulation with a certain thickness compared to the water vapor diffusion resistance of a layer of air with the same thickness. The water vapor diffusion resistance of 1 m^3 of air = 1.

12) **Cleanability**

Ability of a material to be washed or otherwise cleaned to maintain its appearance.

13) **Temperature Resistance**

Ability of a material to perform its intended function after being subjected to high and low temperatures, which the material might be expected to encounter during normal use.

14) **Thermal Diffusivity**

The property of a material, which measures the time rate of temperature movement through it; In case of cyclic operations where rapid dissipation of temperature is desired, a high rate of thermal diffusivity is important. Conversely, when insulation is used as fire protection, a slow rate of thermal diffusivity is most important. It is not a measure of amount of heat or heat transfer and unit of measure is ft^2/hr.

15) **Weather Resistance**

Ability of a material to be exposed for prolonged periods of time to the outdoors without significant loss of mechanical properties

16) **Abuse Resistance**

Ability of a material to be exposed for prolonged periods of time to normal physical abuse without significant deformation or punctures

17) **Flexural Strength**

The property of a material, which measures its ability to resist bending (flexing) without breaking

18) **Corrosion Resistance**

Ability of a material to be exposed for prolonged periods of time to a corrosive environment without significant onset of corrosion and the consequential loss of mechanical properties

19) **Fungal Growth Resistance**

Ability of a material to be exposed continuously to damp conditions without the growth of mildew or mold

PART III- Selection of Insulating Materials

Whilst the main consideration of insulation is to reduce heat flow either from a hot source to ambient or from ambient to a cold process (low thermal conductivity and the thermal properties listed in part II), there is other specific application criteria.

Some of the conditions and desirable properties are;

a. Prolonged exposure to extreme operating temperatures – the insulation should not only remain physically strong but the insulating properties should be maintained. For low temperature insulation, the vapor barrier is important. Insulation system should reasonably adapt to pipe and equipment expansion at higher temperature.

b. Physical strength should be adequate to withstand delivery, storage, handling and application so that the original insulating properties are not adversely affected. Efficiency of joints, puncture resistance and ease of maintenance are critical.

c. Compressive strength should be sufficient to withstand loads imposed after installation such as foot traffic, ladders etc. However precautions can be taken by providing protection at places where loads can be expected.

d. Mechanical stability can almost be regarded as the properties of a), b) and c) above but it will include resistance to vibration and the ability to cope with any expansion and contraction.

e. Hazards to health during application, use or removal must be considered. The main consideration under this heading is the danger of inhalation of fine particles and insulation should be asbestos free.

f. Fire hazard: The danger from fire should be carefully considered when the choice of insulation is being made. In certain cases the insulating material itself may be sufficiently non-combustible but in other cases the use of suitable protection can reduce the risk. The generation of smoke can be particularly hazardous to fire fighting operation. Materials that can either support fire or give off smoke and hazardous gases should not be used.

g. Structure & Equipment Protection: In case of external fires, insulation safeguards and protects the structure elements, equipment and pipes. The steel building columns and beams are often coated with insulation sprays to enhance fire rating. ASTM E 119 provides the criterion.

h. Corrosion hazards can occur when insulation is either wetted due to leaks or to internal condensation. The hazard arises from soluble compounds in the insulation material and the material upon which the insulation used should be considered for its sensitivity to attack and if necessary suitable protected.

i. Weight and thickness of insulation; In some cases the additional weight of insulation may mean extra supports and the additional thickness may need more space in enclosed spaces such as ducts etc. The properties of the proposed insulation will need to be carefully considered on the economic basis bearing these two points in mind. However the use of light loose fill insulation to solve weight problems will have to bear in mind the requirements of d) above.

j. Resistance to chemical attack is important if there is danger of insulation becoming exposed to process chemicals particularly in the form of vapors.

k. For mass insulation types, the most important physical property is thermal conductivity. Materials with low thermal conductivity allow less heat to be transferred per unit time, per unit temperature difference per inch of thickness. All other items being the same, materials with lower thermal conductivities are better insulators. Commercially available mass insulations have thermal conductivities at 75°F mean temperature less than 0.5 Btu in/ (hr ft^2 °F).

l. For reflective insulation types, the important physical property is low surface emittance. Surfaces with low emittance have high reflectance. Reflective insulations have emittance values in the range of 0.04 to 0.1.

m. Life cycle costs: The insulation costs include purchase price, shipping & handling costs, fabrication cost, application cost, supervision cost, maintenance cost, overhead cost, insurance cost and service life & depreciation values. The analysis of life cycle costs is important to determine the type of insulation material, economical insulation thickness and savings achieved. In case insulation is applied to a critical process, reliability is a prime concern and in case energy conservation is deciding factor than savings per year as compared to installed costs is the most important factor.

n. Installation costs: The shape of the product, the degree of flexibility, the method of holding it in place and the sealing systems are the major characteristics that influence installation costs.

What to look for in selection of material?

1. Manufactured without the use of CFC's, HCFC's or PVC
2. Recyclable
3. Closed cell structure throughout the material
4. Consistently low conductivity value
5. Fulfilling the highest possible flammability standard requirements
6. Minor non-toxic smoke development in fire
7. Value for money
8. Guarantee on the properties of the material
9. Easy installation

The salient points are summarized below:

Chemical & Mechanical Properties Checklist

Characteristics	Remarks
Alkalinity (pH or acidity)	Significant when corrosive atmospheres are present. Also insulation must not contribute to corrosion of the system.
Appearance	Important in exposed areas and for coding purposes
Breaking load	In some installations the insulation material must "bridge" over a discontinuity in its support

Characteristics	Remarks
Capillarity	Must be considered when material may be in contact with liquids
Chemical reaction	Potential fire hazards exist in areas where volatile chemicals are present. Corrosion resistance must also be considered
Chemical resistance	Significant when the atmosphere is salt or chemical laden
Coefficient of expansion and contraction	Enters into the design and spacing of expansion/contraction joints and/or the use of multiple layer insulation applications
Combustibility	One of the measures of a material's contribution to a fire hazard
Compressive strength	Important if the insulation must support a load or withstand mechanical abuse without crushing. If, however, cushioning or filling in space is needed as in expansion/contraction joints, low compressive strength materials are specified
Density	A material's density affects other properties of that material, especially thermal properties
Dimensional stability	Significant when the material is exposed to atmospheric and mechanical abuse such as twisting or vibration from thermally expanding pipe
Fire retardancy	Flame spread and smoke developed ratings should be considered
Hygroscopic	Tendency of a material to absorb water vapor from the air

Characteristics	Remarks
Resistance to ultraviolet light	Significant if application is outdoors
Resistance to fungal or bacterial growth	Is necessary in food or cosmetic process areas
Shrinkage	Significant on applications involving cements and mastics
Sound absorption coefficient	Must be considered when sound attenuation is required, as it is in media centers, audio stations, hospital areas etc.
Sound transmission loss value	Significant when constructing a sound barrier
Toxicity	Must be considered in food processing plants and potential fire hazard areas.

PART IV- Insulation Types & Materials

Material Specifications

Insulators are poor conductors of heat and have low conductivity. Insulating materials owe their low conductivity to their pores while their heat capacity depends on the bulk density and specific heat. Structure of insulating material consists of minute pores containing large number of air cells. The resistance to heat transfer by the insulating material depends on the number of dormant or near dormant air cells packed in the mass. The air cell would be dormant, if its diameter is no larger than the mean free path, which for all practical purposes, could be taken as 0.09 microns. This is possible, if the insulating materials could be produced with very low fiber diameters and space between the fibers is so compressed as to be equal or less than the mean free path. Larger air cells are not dormant, and thus convection currents are set up, due to which air temperature rises, this in turn increases the air pressure and consequently the rate of heat flow. *This means that for higher temperatures, high-density material should be used.*

Types of Insulation

Thermal insulation materials can be divided into four types:

- Granular
- Fibrous
- Cellular
- Reflective

1) **Granular Insulation**

Granular insulation is composed of air or some other gas in the interstices between small granules formed into blocks, boards, or hollow cylinders. It is not considered a true cellular material since gas can be transferred between the individual spaces. Granular, fibrous and cellular types rely on enclosed air or gas and minimum solid conduction paths for their thermal properties. The examples of this insulation include:

- ✓ Magnesia
- ✓ Calcium silicate
- ✓ Diatomaceous earth i.e. siliceous particles
- ✓ Expanded vermiculite
- ✓ Perlite

- ✓ Vegetable cork
- ✓ Expanded polystyrene

2) **Fibrous Insulation**

Fibrous materials are composed of small diameter fibers, which finely divide the air space. The fibers are usually chemically or mechanically bonded and formed into boards, blankets, and hollow cylinders. The most widely used insulation of this type is glass fiber and mineral wool.

The examples of this insulation include:

- ✓ Fiber glass
- ✓ Rock wool
- ✓ Slag wool
- ✓ Mineral wool or mineral fiber
- ✓ Refractory ceramic fiber
- ✓ Alumina silica
- ✓ Asbestos

3) **Cellular Insulation**

Cellular insulation is composed of air or some other gas contained within foam of stable small bubbles and formed into boards, blankets, or hollow cylinders. Individual cells are separated from each other. The examples of this insulation include:

- ✓ Cellular glass
- ✓ Elastomeric foam
- ✓ Phenolic foam
- ✓ Polyethylene
- ✓ Polyisocyanurates
- ✓ Foamed Plastic such as Polystyrene
- ✓ Polyolefin
- ✓ Polyurethanes
- ✓ Polyimides
- ✓ Rubber
- ✓ Mastics

4) **Reflective insulation**

Reflective insulation is composed of numerous layers of parallel thin sheets or foil spaced to provide restricted air or gas spaces. This type of insulation resists heat transfer by reflecting radiant heat back towards the source of heat. The restricted air or gas spaces resist heat transfer by conduction and convection. Aluminum and stainless steel are most common materials. Moisture and corrosion resistance are the salient features of these materials.

Insulating Materials

Insulation materials fall into two broad categories: organic foams; and inorganic materials.

Organic foams include polystyrene, polyurethane, polyisocyanurate, phenolic foam, expanded nitrile rubber and polyethylene foam. The organic foams are very common type of insulating materials for low temperature service.

The principle inorganic materials are mineral wool, fiberglass, calcium silicate, cellular glass, micro porous silica, magnesia, ceramic fiber, vermiculite and perlite. The inorganic materials are utilized in both low and high temperature services.

These are described briefly in turn.

1) Organic Foams

a. ***Phenolic foam*** is a phenol-based material that has been reacted with formaldehyde and cured with sulphuric acid to give closed cell foams with a density of about 40 kg/m3. It has a very low thermal conductivity and is used at operating temperatures from –180°C to +120°C. It is able to provide the same thermal performance as other insulations at a reduced thickness. It has the best fire classification of the foam-based materials and does not drip or melt when exposed to flame. It is produced in blocks for cutting to size and is typically used in the pipe work sector, for example for air conditioning ducting. The comparatively low thickness of the material saves space and makes it useful for the manufacture of sandwich panels for, for example, dry lining, roofing and external insulation. Phenolic foam insulation has the following properties:

- ✓ This product can be manufactured to meet the flame-spread index of 25 or less and the smoke developed index of 50 or less when tested according to ASTM E84.
- ✓ ASTM C 1126 lists a temperature range from -290°F to +250°F.
- ✓ Thermal Conductivity is Btu/h-ft^2 (°F/in) as tested by ASTM C177 or ASTM C518 are
  - 0.13 at +75°F mean temperature

- 0.15 at +120°F mean temperature

The water vapor permeability of the un-faced material as tested per ASTM E96; Procedure A is 2.0 perm-inches or less.

b. ***Polyurethane (PUR)*** is produced in a variety of forms from a mixture of agents and additives. It has a very low thermal conductivity and, in most forms, has a similar application cost to that of mineral wool products. Composite PUR products will be slightly more expensive but the installation costs are much lower, such that installed costs will be directly comparable with mineral wool insulation. It has a temperature range of –185oC to +110oC.

c. ***Polyisocyanurate (PIR)*** is chemically related to PUR but is more expensive and has better fire performance. It is used primarily for insulating medium-temperature pipe work and equipment in the petrochemical, gas and process sectors, but is also used extensively in buildings, refrigerated vehicles, tankers, ducting and other pipe work. It has a temperature range of –185°C to +140°C. Polyisocyanurate insulation has the following properties:

✓ Polyisocyanurate insulation has low thermal conductivity, is lightweight and has excellent compressive strength. These products can be manufactured to meet the flame-spread index of 25 or less and the smoke developed index of 50 or less when tested according to ASTM E84.

✓ ASTM C591, Standard Specification for Unfaced Rigid Cellular Polyisocyanurate Thermal Insulation specifies material requirements. ASTM C591 lists its temperature range from -297 to +300 °F.

✓ Thermal Conductivity in Btu/h-ft^2 (°F/in) as tested by ASTM C177 or ASTM C518 are

- 0.19 at 0°F mean temperature
- 0.20 at +75°F mean temperature
- 0.21 at +120°F mean temperature

✓ The water vapor permeability of the un-faced material as tested per ASTM E96; Procedure A is 4.5 perm-inches or less.

d. ***Expanded Nit rile Rubber (ENR)*** is a flexible, closed-cell rubber extensively used in chilled and refrigerated applications, industrial H&V as well as domestic heating and plumbing. By volume it is more expensive than mineral wools but is normally used in thinner layers and so is directly competitive in terms of installed cost. It is resistant to moisture and has a temperature limit of around +150°C.

e. ***Polystyrene foam*** is available in two forms: EPS and XPS. Both are closed-cell foams resistant to water penetration and have excellent thermal insulating properties. The advantages of EPS are its relatively low production cost and price (lower than that for mineral wools), its lightweight and high dimensional stability. It is non-toxic and non-irritant. Its main use is in building applications (cold storage and housing) and in refrigeration pipe work. XPS costs more to produce than EPS but has higher compressive strength and water resistance, making it suitable for load bearing and draught proofing applications. It is used principally in structural applications (roofing, flooring and walling applications and in cold storage and refrigerated transport). These foams are, however, used in virtually all applications where temperatures will not exceed +75°C. Polystyrene foam insulation has the following properties:

- ✓ Polystyrene insulation is lightweight and has good compressive strength. This product does not meet the smoke developed index of 50 or less when tested according to ASTM E84. The test yields a flame-spread index of 25 or less and a smoke developed index of 115.
- ✓ ASTM C 578, Standard Specification for Rigid Cellular Polystyrene Thermal Insulation specifies material requirements. ASTM C 578 lists its temperature range from -65 to +165°F.
- ✓ Thermal Conductivity in Btu/h-ft^2 (°F/in) as tested by ASTM C177 or ASTM C518 are
  - 0.24 at +75°F mean temperature
  - 0.26 at +120°F mean temperature
- ✓ The water vapor permeability of the un-faced material as tested per ASTM E96; Procedure A is 1.5 perm-inches or less.

f. ***Polyethylene foam*** is widely used in domestic heating and plumbing. Its production cost is lower than nitrile rubber but it tends to be unsuitable for process plants. Its temperature limit is around +100°C.

2) Inorganic Materials

a. ***Fiberglass*** pipe insulation is a molded, heavy density, one-piece insulation made from inorganic glass fibers bonded with a thermosetting resin. It is produced in 3' lengths with or without a jacket. It is used on mechanical and process piping in power, process and industrial applications, and in commercial and institutional buildings. Most fiber glass pipe insulations can be used on systems from 0º to 1000º F. Fiber glass insulation boards and blankets are thermal and acoustical insulation products available plain, or with a FSK or ASJ jacketing. They are used for heating and air-conditioning ducts, power and process equipment, boiler and stack installations, wall and roof panel systems, tanks, piping, valves, etc.

b. ***Rock and/or slag fibers*** are bonded together with heat resistant binder to produce high-density mineral fiber or wool and are available in loose blanket, board, pipe sections and molded shapes. It can be used in a wide range of applications for hot and cold piping ranging from –120ºF to 1200º F. The material has a practically neutral pH, is noncombustible, and has good sound control qualities. This product is frequently used in high temperature industrial process power plants, power stations, petrochemical complexes, etc for steam and process pipe work – and for commercial hot/cold water systems. It is produced in two half cylinders and can be supplied either plain or with a FSK type facings. It comes in 3' lengths in pipe sizes from 1/2" IPS to 20" IPS.

c. ***Calcium silicate*** is a dense micro porous granular insulation made of lime and silica, reinforced with organic and inorganic fibers and chemically set into molded forms. As solid material calcium silicate has a high compressive and flexural strength. Because of this, it has certain application benefits: it is very rigid; it is long lasting once installed; and it can be taken off and put back again (for example, to repair an enclosed pipe). However, being heavier and more solid than, say, mineral wool, calcium silicate takes longer to install. Calcium silicate is water absorbent. However, it can be dried out without deterioration. The material is noncombustible and used primarily on hot piping and surfaces. Jacketing is field applied. Calcium silicate's temperature limit is 1,000°C, though it is most efficient as insulation in the range 37.8ºC to 648.9ºC (100ºF to 1200ºF). Typically, calcium silicate is used as back-up insulation in the refractory industry, for exterior pipe work, in a wide range of boilers, ducting and process pipe work and as panels in storage heaters. It tends not to be used in the domestic building sector, although plasterboard based on calcium silicate is sometimes used in structural applications. Calcium silicate is more expensive to produce than mineral wool; like-for-like factory gate prices for mineral wool are lower than those for equivalent calcium silicate products.

d. ***Cellular glass*** is an alumina-silicate glass with a closed cell structure that contains carbon monoxide or carbon dioxide. As a result of its structure, it is resistant to water vapor and has a high compressive strength and good chemical resistance. It is non-combustible, can be formed into a wide variety of shapes and is particularly effective at very low temperatures. Although suitable for a wide range of building applications, its production cost is high. It is typically used in process plant applications, although it is also used in roofing applications in process plants or in high load-bearing situations. It can withstand temperatures of up to 430°C.

Cellular Glass has excellent compressive strength but it is rigid. It is fabricated to be used on piping and vessels. When installed on applications that are subject to excessive vibration, the inner surface of the material may need to be coated. The coefficient of thermal expansion for this material is relatively close to that of carbon steel. When installed on refrigerant systems, provisions for expansion and contraction of the insulation are usually only recommended for application that cycle from below ambient to high temperatures. For outdoors or direct buried applications, a jacketing or mastic coating is recommended.

Cellular glass insulation has the following properties:

- ✓ Conform to ASTM C552 and is suitable for temperatures from -450°F and +800°F (–260°C to 430°C)
- ✓ Density per ASTM C303 can vary between 6.3 and 8.6 lb/ft^3. Density does not greatly affect the thermal performance of cellular glass
- ✓ Average compressive strength per ASTM C165: 490 kPa
- ✓ Flame spread index and smoke developed index when tested according to ASTM E84 is 5 and 0 respectively
- ✓ Water vapor transmission: Zero
- ✓ The water vapor permeability as tested per ASTM E96, Procedure A is less than 0.005 perm-inches
- ✓ Material is noncombustible, non-absorptive and resistant to many chemicals
- ✓ Linear expansion coefficient: 8,5 x 10 -6 / °C
- ✓ Thermal Conductivity in Btu/h-ft^2 (°F/in) as tested by ASTM C177 or ASTM C518 are
    - 0.27 at 0°F mean temperature
    - 0.31 at +75°F mean temperature
    - 0.33 at +120°F mean temperature

c. ***Micro-porous silica*** is an ultra-fine powder of amorphous silica that is structured and bonded to give a very small cavity size. Micro porous silica is effective within a temperature range of +400°C to +1,000°C and its structure can be designed to prevent the passage of infrared radiation. It has exceptionally low thermal conductivity but is considerably higher cost than mineral wool. It is usually mixed with ceramic fiber and opacifiers to produce shapes and panels for use in the refractory industry or for fire protection use in the power, aerospace and process plant industries. It is used in preformed panels in the manufacture of storage heaters, gas boilers, ceramic hobs, etc.

d. ***Ceramic fiber*** is blown alumina silica made from blends of high purity alumina and silica. The fiber is non-crystalline and can be converted into a number of shapes. It has a high operating temperature, and fiber with up to 95 per cent alumina content. Ceramic fibers are pressed into a blanket for use up to 1700°C. Ceramic fiber has a low density and good resistance to thermal shock. It can be used in applications where rapid heating is followed immediately by rapid cooling, as in the refractory industries. It is sometimes used domestically in appliances such as central heating, boilers and storage heaters. Its cost is considerably higher than that of mineral wool.

e. ***Expanded vermiculite*** is a naturally occurring material, the main constituent of which is magnesium silicate. When heated to 1,000°C to drive off the water of crystallization, it produces a lightweight, granular material that is stable, inert and has a high melting point. It is mostly used with cementitious binders to produce sprays or boards as a fire protection product.

f. ***85% Magnesia:*** This is light calcinated magnesium carbonate with 15% amosite asbestos, molded into standard pip sections and other shapes. It is excellent, robust and economical in operation, but requires protection from the weather. It should not be used on surfaces whose temperature is over 300°C. This disadvantage can be overcome by interposing a thin layer of special cement between magnesia and the hot surface. Use of Magnesia as insulation has become obsolete these days.

g. ***Expanded Silica or Perlite*** is made from inert siliceous volcanic rock and produced by processes that result in sealed cells. As a result of its closed cell structure, the material does not retain moisture. It is classified as chemically inert, and has a neutral Ph of 7; it will not react with condensation on the exterior of chilled water lines.

   These are made by centrifugal spinning process from molten slag or mineral rocks. In its expanded form, perlite has strength and water penetration resistance. It is often used as a form of loose fill insulation or in plaster-based products for process plant insulation because of its thermal conductivity properties at low temperatures. A compressive strength of about 100psi means that it is not easily damaged during pipeline repair and maintenance. It can be used up to 650°C and are available in the form of mattresses, blankets, molded sections and insulating boards. In addition to its excellent thermal properties, Perlite insulation is relatively low in cost, easy to handle and install, and does not shrink, sag, swell, warp, or slump. The material has high resistance to substrate corrosion.

   Because it is an inorganic material, it is rot and vermin proof. Perlite is noncombustible, meets fire regulations, and can lower insurance rates. It has no health related, handling, or disposal issues when used in manufacturing plants. For more reading on Perlite technical data, refer to ASTM 610.

Typical thermal insulating materials for use in temperature range of 50 to 1000 deg are listed in tables below along with conductivity value curves.

h. ***Flexible Elastomerics*** are soft and flexible. Foamed resins combined with elastomers produce a flexible cellular material. It is suitable for use on non-rigid tubing. It is lightweight and has low vapor permeability. Flexible Elastomerics insulation has the following properties

- ✓ ASTM C534, Standard Specification for Preformed Flexible Electrometric Cellular Thermal Insulation in Sheet and Tubular Form, specifies flexible electrometric material requirements. These products can be manufactured to meet the flame-spread index of 25 or less and the smoke developed index of 50 or less when tested according to ASTM E84.
- ✓ Flexible elastomeric sheet is normally limited to service between -70°F up to +180°F. Around - 20°F flexible elastomeric insulation becomes stiff, but this does not affect its thermal performance or water vapor permeability.
- ✓ The water vapor permeability as tested per ASTM E96, Procedure A is 0.1 perm-inches or less.
- ✓ Elastomeric insulation is cost efficient for low temperature applications with no jacketing necessary. Resiliency is high. Consideration should be made for fire retardancy of the material.
- ✓ Thermal Conductivity in Btu/h-ft2 (°F/in) as tested by ASTM C177 or ASTM C518 are
  - 0.25 at 0°F mean temperature
  - 0.27 at 75°F mean temperature
  - 0.29 at 120°F mean temperature

Reasons why different types are used

1. Difference in application
2. Spend able income
3. Availability
4. Acquaintance with products
5. Labor skills

6. Technical know-how
7. Quality consciousness
8. Local regulations and restrictions

PART V- Classification of Insulating Materials

Temperature is the most popular classifying guide, because temperature is first element to be considered while planning and designing insulation systems. As such insulation materials are classified into three general categories:

1) High temperature thermal insulation
2) Intermediate temperature thermal insulation
3) Low temperature thermal insulation

A. High Temperature Thermal Insulation

The high temperature application range is 600ºF through 1500ºF (315ºC through 815ºC) and is commonly used in turbines, breechings, stacks, exhausts, incinerators, boilers etc. High temperature insulation conserves heat and protects workers. 2300° F is the maximum temperature for which insulation is applied. Above that refractory is used.

Materials for use at relatively high temperatures

- Mineral Fiber Slabs (110 kg/m^3)
- Mineral Fiber Spray (240 kg/m^3)
- Calcium Silicate (190 to 220 kg/m^3)
- Fiber glass
- Alumino Silicate Fibers (200 kg/m^3)
- Silica Fibers, loose fill (96 kg/m^3)
- Opacified Silica Aerogel (250 kg/m^3)

B. Intermediate Temperature Thermal Insulation

The intermediate temperature application range is as follows:

1. 61ºF through 211ºF (16ºC through 99ºC) -- Hot water and steam condensate.
2. 212ºF through 600ºF (100ºC through 315ºC) -- Steam, high temperature hot water.

Materials for use at intermediate temperatures

- Mineral Fiber Slabs (typically 48 kg/m^3; 90 kg/m^3 up to 750°F and 110 kg/m^3 above 750°F)
- Mineral Fiber Spray loose fill (64 kg/m^3)
- Calcium Silicate (190 to 220 kg/m^3)

- Magnesia (190 kg/m^3)
- Foamed Glass (145 kg/m^3)
- Alumino Silicate Fibers (96 kg/m^3)
- Silica Fibers (96 kg/m^3)
- Opacified Silica Aerogel (250 kg/m^3)

C. Low Temperature Thermal Insulation

The low temperature insulation application range is as follows:

1. 60ºF through 32ºF (15ºC through 0ºC) -- Cold or chilled water.
2. 31ºF through -39ºF (-0.6ºC through -39ºC) -- Refrigeration or glycol.
3. -40ºF through -100ºF (-40ºC through -73ºC) -- Refrigeration or brine.
4. -101ºF through -450ºF (-73ºC through -267ºC) -- cryogenic.

Materials for use for cold insulation

- Expanded polystyrene (32 kg/m^3)
- Polyurethane (32 kg/m^3)
- Isocyanurate (48 kg/m^3)
- Expanded Polyvinyl chloride (PVC) (80 kg/m^3)
- Phenolic Foam (36 kg/m^3)
- Cork (112 to 192 kg/m^3)
- Mineral fibers
- Cellular glass
- Aluminum foil spaced with a glass mat in vacuum or spaced with glass paper in vacuum.
- Foamed Glass (145 kg/m^3)
- Expanded perlite (48 kg/m^3)

<u>HVAC, Refrigeration & Lo-Lo Temperature Systems</u>

Low temperature insulation covers the range from HVAC, refrigeration and chilled water systems to the cryogenic region. The direction of heat flow is inward in low temperature insulation, causing condensation, sweating and freezing problems.

Problems associated with condensation are wetness around the pipes or the equipment and the related thermal degradation or corrosion. In building air-conditioning applications, the moisture condensation can cause the discoloration or staining of ceiling panels, and pose health risk due to mold and fungus growth.

If water is allowed to migrate within the insulating system, it can adversely impact the k-value of the insulation, as the k- value of water (4.15) is much greater than the k-value of insulation (usually less than .35). Water vapor in insulation reduces insulation effectiveness and if condensed or frozen, can harm the insulation permanently.

For operating temperature ranges less than +32° F, if moisture is allowed to migrate to a point in the insulating system, the water shall freeze. The k-value of ice is 15.4, which is much greater than the water (4.15) and the k-value of insulation (usually less than .35). As more water vapor is absorbed, the thermal conductivity of the insulation material moves higher which leads to lower surface temperatures. These lower surface temperatures lead to more condensation, which may eventually lead to insulation system freeze-up, frost-ups and "popping off" of the insulation material due to ice formation. Considering that refrigeration systems may operate at temperatures of -70°F or colder, the problem may be severe.

Note that the heat gain is more costly to deal with, than the heat loss. Therefore, it is important to install a vapor barrier over insulation to prevent moisture ingress on cold surfaces. It is also generally economically beneficial to install thicker insulation for low temperature surfaces than for high temperature surfaces. *The underlying principle for insulating low temperature surfaces is to keep the external surface above the dewpoint of water vapor in the air.* Specifying sufficient insulation thickness to keep surfaces above the dewpoint temperature of air is necessary to prevent condensation and thereby limiting corrosion on cold piping, ducts, chillers and roof drains.

In very dry climates, the insulation system can prevent condensation most of the time. However, even in the driest desert, dew settles on the ground in the early morning hours. When dew settles on the surface of the insulation system, it is considered condensation.

In humid regions, it is not feasible from a financial or practical standpoint to consider designing an insulation system to prevent condensation 100 percent of the time. The insulation thickness required to achieve this would be unrealistic. Suitable vapor retarder must be considered.

Questions to ask relating to condensation are:

1. What is the average (and not the worst-case) summer ambient temperature the system will be subjected to? Use average summer conditions because the worst-case ambient weather conditions in the summer months, especially in coastal regions, are unrealistic to try to achieve condensation control.
2. What is the operating temperature of the process? On a cryogenic pipeline, for example, the insulation required to provide process control will usually exceed the insulation required to provide condensation control.

The success of an insulation system for cold piping is contingent upon several factors, which include:

- Correct refrigeration system design
- Correct specification of insulating material and thickness
- Correct installation of the insulation and related materials such as vapor retarders
- Workmanship of the insulation installer

Density, Thermal Conductivity, Service Temperature Values

The table below provides information on the typically recommended insulation materials density & thermal conductivity for specific service range.

Sno.	Insulation Material	Density (lbs/ft^3)	Thermal Conductivity (Btu/ft,hr,°F)	Service Temperature Limits of °F	
				Short term	Long term
1	Calcium Silicate	15 max	0.66 at 400 °F 1.25 at 1200°F	1500	1500
2	Cellular Glass	7.5 to 9.5	0.22 at 200 °F 0.81 at 500°F	940	800
3	Glass, fiber with organic blender	1.4 to 1.6	0.22 at 0 °F 0.62 at 400°F	450	450
		2.5 to 3.5	0.26 at 100 °F 0.50 at 400°F	450	450
		5.0 to 7.0	0.27 at 100 °F 0.46 at 400°F	450	450
4	Mineral fiber, class 3 with inorganic binders	7 to 12	0.30 at 100 °F 0.49 at 400°F	850 to 1000	850 to 1000
		16 to 20	0.36 at 100 °F 0.64 at 400°F	1200	1200
5	Mineral fiber, class 4 with inorganic binder	8 to 13	0.36 at 100 °F 0.64 at 400°F	1000 to 1200	1000 to 1200
6	Mineral fiber, class 5 with organic binder	12 to 25	0.40 to 200 °F	1800 to 1900	1800 to 1900
7	Mineral fiber, class 2 with inorganic binder	13 to 15	0.40 at 100 °F 0.90 at 1000°F	1500	1500
8	Expanded Polystyrene	1 to 1.5	0.24 at 0 °F 0.28 at 100°F	180	180
9	Polystyrene, cellular foam	1.75 to 2.2	0.20 at 0 °F 0.24 at 100°F	165	165

Sno.	Insulation Material	Density (lbs/ft^3)	Thermal Conductivity (Btu/ft,hr,°F)	Service Temperature Limits of °F	
				Short term	Long term
10	Polyurethane expanded foam	Up to 1.7	0.23 at 0 °F 0.27 at 100°F	230	200
		1.7 to 2.5	0.22 at 0 °F 0.26 at 100°F	220	200
		2.5 to 5.0	0.20 at 0 °F 0.24 at 100°F	220	200
11	Expanded silica with binders	13	0.40 at 0 °F 0.82 at 1000°F	1500	1500
12	Glass fiber without binder	11 to 12	0.26 at 0 °F 1.10 at 1000°F	1200	1200
13	Mineral fiber	8 to 12	0.49 at 300 °F 0.82 at 600°F	1200	1200
14	Mineral fiber with binders	7 to 9	0.30 at 100 °F 0.52 at 500°F	1000	1000
15	Perlite	5 to 8	0.29 at 100 °F 0.35 at 200°F 0.0087 at -200°F	1800	1800
16	Santocel Powder	6	0.0015 at -200°F	Cryogenic	Cryogenic
17	Santocel and Aluminum Powder	10	0.0027 at -200°F	Cryogenic	Cryogenic

Approximate Costs Idea

Approximate thermal resistances and costs of common types of insulation are listed in the table below.

Insulation Type	Thermal Resistance	Cost
3.5-inch fiberglass batt	11 ft^2-hr-F/Btu	\$0.30 / ft^2; \$1.10 /ft^2 *
¾-inch rigid blue Styrofoam board	5.2 ft^2-hr-F/Btu	\$0.32 /ft^2
½-inch rigid polyisocyanurate with foil facing	3.5 ft^2-hr-F/Btu	\$0.23 /ft^2
One-inch spray-on cellulose (meets fire-code)	5 ft^2-hr-F/Btu	\$0.75 /ft^2 *
2-inch spray-on polyurethane	9 ft^2-hr-F/Btu	\$4 /ft^2 *

2-inch steam pipe and tank insulation	5 ft^2-hr-F/Btu	\$10 /ft^2 *
Custom 1-inch insulated jackets for extruder barrels	4 ft^2-hr-F/Btu	\$67 /ft^2
1-inch ceramic fiber blankets (Tmax = 2000 F)**	(2.1-.45) ft^2-hr-F/Btu (@ 500 F-1800 F)	\$1.80 /ft^2

*includes installation

PART VI- Insulation Forms & Finishes

The insulation is required for a wide range of services and therefore they are produced in many forms.

1) Preformed

Fabricated in such a manner that at least one surface conforms to the shape of the surface being insulated. The preformed insulation could be either in form of board, block or sheet.

- ✓ *Board:* Rigid or semi-rigid self-supporting insulation formed into rectangular or curved shapes. Examples include; Calcium silicate, Fiberglass, Mineral wool or mineral fiber, Polyisocyanurates and Polystyrene
- ✓ *Block:* Rigid insulation formed into rectangular shapes. Examples include; Calcium silicate, Cellular glass, Mineral wool or mineral fiber and Perlite
- ✓ *Sheet:* Semi-rigid insulation formed into rectangular pieces or rolls. Examples include; Fiber glass, Mineral wool, Electrometric foam and Polyurethane
- ✓ *Pipe and fitting Insulation:* Pre-formed insulation to fit piping, tubing and fittings. Examples include; Calcium silicate, Cellular glass, Elastomeric foam, Fiber glass, Mineral wool or mineral fiber, Perlite, Phenolic foam, Polyethylene, Polyisocyanurates and Polyurethanes

2) Plastic Composition

Plastic insulation is categorized as a loose dry form, which is prepared by mixing with water. Examples include; Magnesia, calcium silicate, diatomaceous earth

3) Loose Fill

Insulation in the form of powdered granules, loose or pelleted fibers; this is typically used for pouring expansion joints. Examples include; Mineral wool or mineral fiber, Perlite and Vermiculite

4) Flexible

Flexible insulation materials lack rigidity and tend to conform to the shape of the surface against which it is laid. A flexible insulation is used to wrap different shapes and forms. Examples include; Low density mineral wool, Fiberglass, Mineral wool or mineral fiber and Refractory ceramic fiber

5) Foam

Liquid mixed at the time of application, which expands and hardens to insulate irregular areas and voids. Examples include; Polyisocyanurates and Polyurethane

6) **Textile**

Insulation in the form of rope, cloth etc Examples include; Asbestos, ceramic fiber ropes and fabrics

7) **Mattress**

Flexible insulation faced or totally enclosed with fabric, wire netting, expanded metals etc. Examples include Wire netted mineral wool mattress, Asbestos and Glass wool mattresses.

8) **Reflective**

Insulation comprising numerous layers or random packing of low emissivity foils. Examples include; Aluminum foil, stainless steel foil etc.

9) **Spray applied**

Insulation applied by machine in the form of spray. Insulation may be fibrous or granular material mixed with water or other suitable binder. This is typically applied on to the flat or irregular surfaces for fire resistance, condensation control, acoustical correction and thermal insulation. Examples include; Sprayed mineral fiber/ceramic fiber

Finishes

Protective coverings or finishes are required over the insulation for one or more of the following reasons:

1) ***Protection against mechanical damage:*** Rigid jacketing provides protection against mechanical abuse from personnel, equipment, machinery, etc.

2) ***Protection against weather or chemical attack:*** Protect the insulation from rain, snow, ice, sunlight, ultraviolet degradation, ozone and residues of chemical compounds in the atmosphere.

3) ***Protection against water vapor (Vapor Retarders):*** A vapor retarder is any material that limits the transmission of water vapor. Examples include; CPVC, FRP, Laminated foil-scrim membranes, Mastic, Metal, Plastic, PVC, Reinforced polyester resin.

   - Metallic foil or all service jacket (ASJ) type can be applied to the surface of the insulation by the manufacturer or field applied. This type of jacket has a low (0.02 perm-inches) water vapor permeability rating under ideal conditions. This low permeability is dependent upon complete sealing of all joints and seams.

- Laminated membrane retarder with rubber bitumen adhesive on a 4- to 6-mil polyethylene or PVC film. Very low perm ratings of 0.015 perms are published.
- You can buy faced insulation, which has the vapor retarder already attached. Types of faced insulation include:

✓ Kraft-Faced- Kraft paper coated with an asphalt adhesive

✓ Foil-Faced - foil-backed paper coated with asphalt adhesive

✓ Flame-Resistant Foil-Faced - foil-scrim-Kraft paper that is strong and resistant to flame spread.

4) ***Protection against weather and abrasion (Jacketing):*** The purpose of jacketing on insulated pipes and vessels is to protect the vapor retarder and the insulation to the adverse affects of weather and abrasion. Various plastic and metallic products are available for this purpose.

   Protective jacketing is required whenever piping is exposed to wash downs, physical abuse or traffic. Inside of buildings where ultraviolet degradation from sunlight is not a factor, the most popular type of jacketing is white PVC colors.

   Where very heavy abuse and/or hot, scalding wash downs are encountered a special CPVC material is required. These materials can withstand temperatures as high as 225°F, where standard PVC will warp and disfigure at 140°F.

5) ***Shielding thermal losses (Thermal Barriers):*** Thermal barrier materials are mostly made of aluminum, but also can include other forms of metal or alloys such as stainless steel (1800°F continuous) and inconell (2200°F continuous). Aluminum materials melt at 1227°F and are designed to be used as shields, not insulators. Moreover, aluminum reflects radiant heat away, often exceeding more than 90% efficiency with 1000°F of continuous radiant heat (radiant heat means it is placed with at least a minimum 1" air gap from heat source). Otherwise, they can withstand up to 500°F of a direct heat source. Cloth, tapes, and other aluminum heat shields all fall within the above mentioned parameters.

6) ***Retardation of flame spread:*** Fireproof cloth or spray prevents the fire or spread of fire.

7) ***Appearance:*** Chosen primarily for appearance value in exposed areas.

8) ***Clean ability:*** Providing the insulation with an easily cleaned surface

9) ***Identification:*** of pipe or vessel

Finishes can be of various types depending on the requirements of the system. Broadly speaking they can be split into two main types i.e. finishes suitable only for indoor use and finishes suitable for outdoor use where insulation is subject to normal weather conditions. The main requirement for weather resistant finishes will be ability to resist electrolytic corrosion and the ingress of water. There can be some other strange requirements such as the ability to resist the attack of animals, birds and vandals.

The effect of metallic finishes on surface temperature may mean that greater thicknesses of insulation are required to compensate for this type of finish.

Indoor finishes

Hard setting composition and self setting cement

These finishes should be applied over firm insulation such as preformed insulants. It is not recommended that this type of finish be applied over flexible insulants.

Textile fabrics

Woven scrim is normally only used as a protection of firm insulation (e.g. pipe sections) during handling and as a hinge for facilitating installation. It will therefore normally be provided with a further finish but if used by itself will require the fitting of metal bands as securement.

Lightweight canvas and bands

This is quite a common indoor finish for firm insulations. It should be finished with paint or a suitable insulation compound. The insulation should finally be secured by metal bands. The painting can provide useful color-coding for different services.

Heavy fabric

This finish is stretched into place on site. It provides a more durable finish than lightweight canvas and does not require the fitting of securing bands.

Plastic and elastomer sheets

Inside of buildings where ultraviolet degradation from sunlight is not a factor, the most popular type of jacketing is white PVC. PVC jacketing or other finishes may also be appropriate, depending upon the environment or other factors. PVC should be smooth, UV inhibited, in precurled rolls. The minimum thickness of PVC should be 0.030". Plastic sheets may be rigid or flexible.

Rigid plastics will normally be fixed to some framework. Thin rigid sheets with reinforcement may be flexible enough to use in the same way as sheet metal and this application is suitable with flexible insulation.

Flexible plastics and elastomer sheets are fixed with suitable adhesives. It is important that manufacturers recommended products and method are used as unless this is done good adhesion cannot be guaranteed. Plastic tapes with suitable adhesives may be usefully used on pipes especially those of small diameter.

Finish consists of applying minimum of 3 mm thickness with suitable reinforcement such as fabric or wire netting where necessary.

Mastics and coatings

Coatings, mastics and heavy "paints" are available as vapor retarders. These can be water-based emulsions, solvent based or solvent free. These finishes may be applied by trowel, brush or spraying. The perm ratings of the material are a function of the thickness applied. Some products are recommended for indoor use only while others are available for indoor or outdoor use.

The surface or ambient temperature at the time of application can be important and for best results temperatures below 5°C should be avoided although application can be carried out at lower temperatures with suitable precautions.

Metal sheets

Metal sheet finishes will provide good protection against mechanical damage and also against ingress of liquids such as oil and water. Metal jacketing may be smooth, stucco, embossed, or corrugated aluminum or stainless steel with a continuous moisture retarder.

They can provide local protection for the insulation in particularly vulnerable areas in which case they may also be applied over a less robust finish. The most commonly used material is aluminum, which is more liable to damage than steel, and should therefore not be used in areas liable to severe wear. Mild steel is an alternative, which is normally galvanized to prevent corrosion but other surface treatments can be used including painting. In certain cases the use of alloy steels may be justified.

Care should be taken that the metal finish is compatible with materials with which it comes into contact. Sheet metal whether applied to pipes or to vessels, may preferably be secured by metal bands.

Outdoor Finishes

The obvious requirement for outdoor finishes is that they should be weather resistant. The types of finish referred to under “indoor finishes” can be used but additional weatherproofing may be required to prevent ingress of moisture into the pipe insulation material.

Hard setting compositions and self setting cement

Both of these finishes will benefit from protection in the form of weather resistant finishes. Although the self-setting cement can withstand water it is not impervious to it. In the case of hard setting composition a priming coat is desirable due to the dusty nature of the composition.

The typical finish consists of applying mixtures of cement-sand or cement asbestos or asbestos plaster of paris, with a minimum thickness of 10 mm or as specified and reinforced with wire netting of minimum 20 mm mesh and 0.56 mm diameter or equivalent metal sheet.

Textile fabrics

As these finishes are not impervious to water they will need protection against weather.

Plastic and elastomer sheet

These finishes are weather resistant in themselves but great care must be taken to ensure that joints overlap well and are properly sealed.

Mastics and coatings

These finishes are weather resistant but care should be taken that conditions are right both during storage and installation.

Mastics should be applied in two coats (with open weave fiber reinforcing mesh) to obtain a total dry film thickness. The vapor retarder mastic system should extend by a minimum of 2" under any sheet type vapor retarder membrane where applicable. This is typically done at valves and fittings only. These systems must be tied into the rest of the insulation system or bare pipe at the termination of the insulation preferably with a 2-inch overlap to maintain the continuity of the entire system.

Insulating cement finishes

Insulating and finishing cements are a mixture of various insulating fibers and binders with water and cement, to form a soft plastic mass for application on irregular surfaces. Insulation values are moderate. Cements may be applied to high temperature surfaces. Finishing cements or one-coat cements are used in the lower intermediate range and as a finish to other insulation applications.

Metal sheets

Metallic type jackets are recommended for exposed roof mounted piping systems.

Roof piping should be jacketed with minimum 0.016-inch aluminum (embossed or smooth finish depending on aesthetic choice).

Metal sheets are weather resistant either in themselves (e.g. Aluminum-although it may develop a white deposit) or when suitably treated (e.g. galvanized steel). However considerable care should be taken to prevent the ingress of water by proper positioning and sealing of joints etc. Although galvanizing provides a weather resistant finish for mild steel it is not everlasting and depending upon which galvanizing method has been used may require painting or other protection after some period of exposure. Plastic coated steels and alloys should last without further treatment.

For saline environments metal jacketing shall be stainless steel or sea water resistant aluminum alloy. For fire protection purposes the preferred jacketing material shall be stainless steel. Stainless steel metal jacketing shall be type AISI 316, 2B finish. Stainless steel sheets for pipes and vessels up to DN 450 shall have a thickness of 0.5 mm. For dimensions above DN 450 the thickness shall be 0.7mm.

Aluminum alloy jacketing shall be type A1Mn1 (AA 3103) or equal. Aluminum sheets for pipes and vessels up to DN 450 shall have a thickness of 0.7 mm. For dimensions above DN 450 the thickness shall be 0.9 mm.

Sealers, Tape

Joint sealers and tape shall be permanently flexible through a relevant temperature range and shall be capable of withstanding repeated expansion and contraction.

In summary, the choice of finish depends upon two the type of insulation to be covered. The finish should provide sufficient mechanical protection to the insulation. Conversely the insulation may provide sufficient strength for the finish. They should be compatible. Insulation finishes can also be used to enhance system appearance.

Weather Barrier and Vapor Barrier

The terms 'Weather Barrier' and 'Vapor Barrier' are often used interchangeably. This is because their primary function is to keep out the ingress of water. Water, in any of its forms: moisture, frost, ice, etc., results in degradation and is the primary enemy of an insulation system. However, weather and vapor barriers represent two very different functions.

Vapor barriers are essentially installed on cold systems. A cold system is defined as any system operating below ambient or below the dew point temperature. As moisture (humidity) always moves from warm to cold; the vapor barrier retards the flow of moisture (humidity) from passing through the insulation to the cold pipe. To qualify as a vapor barrier either permeance rating of insulation must be low below 0.1 or use of additional vapor coating shall be considered. The vapor retarder must be free of discontinuities and penetrations. The insulation and the vapor retarder will expand and contract with ambient temperature cycling. The vapor retarder system must be installed with a mechanism to permit this expansion and contracting without compromising the integrity of the vapor retarder.

As the effects of moisture (water) are much more dramatic on a cold system versus a hot system, it is imperative to install and maintain the vapor barrier. It is critical that no pinholes be present when completed.

Weather barriers protect the insulation and any jacket, which may be applied to the insulation from the elements; such as rain, snow, etc. A weather barrier appears in either jacket (cladding) or mastic form. It may cover (protect) a vapor barrier on a cold system or, be used alone (jacket/cladding) on an ambient or above ambient system. Typically ambient and above ambient operating systems are not totally sealed. They need to "breathe"; or allow any moisture to escape.

Vapor and moisture barriers are available as a mastic coating or as a jacket (cladding) system. It is important to identify the characteristics of each product when selecting the components of your insulation system and install the products per the manufacturers' direction.

Insulation Finishes & Emissivity as a Design Factor

Emissivity property is significant when the surface temperature of the insulation must be regulated.

Emissivity is defined as the relative power of a surface to emit heat by radiation. The emissivity (E) of a surface material is measured on a scale where a reflective material that is not emitting any radiant energy is rated at 0, and a non-reflective material that is emitting all of its radiant energy is rated as 1.

In a real world, both of these limits are impractical to attain, and measurements fall between these two extremes.

With insulation systems, the emissivity of the jacketing needs to be considered in relation to the insulation material to affect hot and/or cold piping systems with regard to heat loss or gain, surface temperature, condensation and more.

Radiation Emittance Table		
Weather Barrier or Surface Finish	**Conditions**	**Emissivity**
Aluminum Jacketing	Polishing Grey-Dull Oxidized	0.03 to 0.10 0.10 to 0.40 0.10 to 0.60
Aluminum Paint	New After Weathering	0.20 to 0.30 0.40 to 0.70

Radiation Emittance Table		
Weather Barrier or Surface Finish	**Conditions**	**Emissivity**
Asbestos Paper	Clean	0.90 to 0.94
Asphalt Asbestos Felts		0.93 to 0.96
Asphalt Mastics		0.90 to 0.95
Galvanized Steel Jacketing	New Bright Dull	0.06 to 0.10 0.20 to 0.60
Paints	White-clean Green-clean Gray-clean Black-clean	0.55 to 0.70 0.65 to 0.80 0.80 to 0.90 0.90 to 0.95
Painted Canvas	Color as Painted	Will be approximately the same as E for color of paint used
PVA Mastics	White-clean Green-clean Gray-clean Black	0.60 to 0.79 0.70 to 0.80 0.85 to 0.90 0.85 to 0.95
Roofing Felts		0.90 to 0.95
Stainless Steel Jacketing	Polished No. 4 mill finish Oxidized	0.22 to 0.26 0.35 to 0.40 0.80 to 0.85

High reflective metals have low emissivity (Polished Aluminum has 0.03 to 0.1, Polished Stainless Steel, 0.22 to 0.26, Dull Galvanized steel has 0.2 to 0.6, Roofing felt 0.9 to 0.95). The emittance of 0.1 is considered to be representative of aluminum jacketing. An emittance of 0.8 is considered to be representative of non-metallic surfaces.

A dull finish increases the emissivity and thereby allows more heat to radiate from the system. A reflective metal finish decreases the emissivity and retains more heat within the system. Depending on the particular temperature requirement of the process, the amount of heat transferred can be controlled by both insulation thickness and the emissivity of the jacketing.

Table below shows the variations of surface resistances (resistance to heat loss) for still air with different finishes.

Values for Surface Resistances for Still Air in h ft² °F / Btu (m² °C / W)				
$T_{SURFACE} – T_{AMBIENT}$		**Plain Fabric Dull Metal**	**Stainless Steel**	**Aluminum**
°F	°C	E = 0.95	E = 0.4	E = 0.2
10	5	0.53 (0.093)	0.81 (0.142)	0.90 (0.158)
25	14	0.52 (0.091)	0.79 (0.139)	0.88 (0.155)
50	28	0.50 (0.088)	0.76 (0.133)	0.86 (0.151)
75	42	0.48 (0.084)	0.75 (0.132)	0.84 (0.147)
100	55	0.46 (0.081)	0.72 (0.126)	0.80 (0.140)

With low emissivity of reflective metal finish, the resistance to heat loss increases or in other words retains more heat within the system. With dull finish of plain fabric the resistance to heat loss is low or it allows more heat to radiate from the system.

PART VII- Method of Application of Insulation

Since most of the insulation materials are fibrous and light, they have to be applied at the correct density without leaving void, and should be properly supported. Therefore, the correct method for application of insulation is equally relevant in order to minimize heat losses.

Methods of Application

All insulation materials should be applied so as to be in intimate contact with the surface to which they are applied. The edges, or ends of sections, shall butt up close to one another over their whole surface except in special applications.

While applying multilayer insulation, all joints shall be staggered and each layer shall be separately secured to the surface.

In consideration of possible pipeline movement with change in fluid temperatures, different pipes should be separately insulated.

The insulation shall be supported when applied to the sides of, or underneath large vessels or ducts or to long runs of vertical piping. Supports are welded either to the hot surface or to bands, which are then strapped round the surface. These supports serve to hold the insulation in place, prevent its slipping, or support it above expansion joints .In addition; they provide necessary anchorage for lacing wire or wire-netting which may be required to hold the insulation in place and/or to provide reinforcement for the insulation or a finishing material.

Surface preparation

Surfaces to be insulated should be free from all oil, grease, loose scale, rust and foreign matter and shall be dry and free from frost. Site touch-up of all shop coating including preparation and painting at field welds should be completed prior to the installation of the insulation.

Corrosion of any metal under any thermal insulation can occur for a variety of reasons.

Before application of the insulation, the surface is wire brushed to remove dirt, rust, scale, oil, etc. and dried. All surfaces are then brush coated with a suitable anti corrosive primer before insulating. Careful consideration at the time of the insulation system design stage is essential.

Application of Insulation

The following methods are available for application of flexible insulation, rigid insulation etc.

Flexible insulation: Flexible materials, namely mats or blankets faced on one or both sides with suitable facing material are applied by means of tie wire or metal bands or wire netting on the outer side, and are suitably laced.

Rigid Insulation: Rigid insulation material namely blocks or boards may be applied by means of suitable metal bands, or wire netting on the outer surface.

Thermal Insulating Cement: Thermal insulation cements are supplied in the form of a dry powder, which is mixed with water to form a soft mortar of even consistency suitable for application by hand or with a trowel.

Thermal insulating cements require heat for drying to ensure initial adhesion to the surface. All surfaces insulated with thermal insulating cements may, therefore be kept warm throughout the application of the insulation as per specifications by the manufacturer of the cement.

Loose fill insulation: This may be adopted by agreement between the purchaser and the applicator. Loose fill insulation is recommended for the following cases:

- Expansion/contraction joints in an application when rigid insulation has been used, or
- Specific areas of the equipment where conventional methods of application may not be possible and where packing a loose fill is the only possible method of providing insulation

Specific Applications

All welding and other hot work should be completed prior to the installation of the pipe insulation. All hydrostatic and other performance testing should be completed prior to the installation of the insulation.

Insulation of pipes, ducts, vessels, etc. may be suitably carried out by any one of the methods already mentioned. However, specific considerations pertaining to insulation of pipes, ducts, vessels area re detailed below.

Pipes: On continuous runs of 6 meters or more of vertical pipe, support rings are provided at not more than 3-meter intervals. Such rings encircle the pipe and the radial lugs thereon and with specified length equal to 75% of the total insulation thickness.

Ducts: When insulating is applied around the corners of the duct, care should be taken to counteract tendency for the material to thin down at these locations.

Vessels: All large vertical vessels with a height of 6 meters or more are provided with support rings, at not more than 3-meter intervals. Such rings encompass the vessel, and the radial lugs thereon have a length equal to 75% of the total insulation thickness. Extra insulation is provided over the support rings. This extends for 25cm on each side of the ring and is extended to 45 cm for watershed on the upper side.

Insulation Joint Sealant

All insulations operating at below ambient conditions should utilize a joint sealant. The joint sealant should be resistant to liquid water, water vapor, and be able to bond to the specific insulation surface. The joint sealant is applied as a full bedding coat to all sealant joints. A properly designed and constructed insulation/sealant/insulation joint will retard liquid water and water vapor migration through the insulation system.

Insulation for Fittings

Insulation for fittings, flanges and valves should be the same thickness as the insulation of the pipe and shall be fully vapor sealed. If the valve design allows, insulate valves to the packing glands. Stiffener rings where provided on vacuum equipment and/or piping should be insulated with the same thickness and type of insulation as specified for the piece of equipment or line.

Tracer Lines

When erecting tracer pipelines, it is necessary to maintain the closest possible contact between the main pipe and the tracer.

Care may be taken to prevent the insulation from filling any space between the main pipe and the tracer.

Whatever insulation is applied, the heat-traced pipe shall be wrapped with 0.05mm aluminum foil to protect the heating cables and improve the heat distribution. The wrapped pipe and tracer may then be insulated with flexible insulation of thermal insulating cement in the same way as an ordinary pipe.

Where heating cables penetrate the jacketing, edge protection shall be provided to prevent damage to the cable. A permanent sealer shall be applied in order to prevent ingress of water.

Expansion Joints in Insulation

Depending on the type of insulation used, the operating temperature and the nature of the plant, it may be necessary to provide expansion joints or vessels or pipes to prevent the insulation from rupturing or bucking when the hot surface expands or contracts.

In all cases where support rings are provide on vessels or vertical pipes for rigid insulation materials, the insulation shall be stopped short about 5 mm form each ring an the space between the insulation and the ring filed with flexible insulation material.

On horizontal pipes and vessels, insulated with rigid insulation materials or thermal insulation cements expansion joints filled with flexible insulation material should be provided at suitable intervals.

Flexible thermal insulation used at temperatures not exceeding 230°C, do not normally need expansion joints.

Where sheet metal is used as the finish material, the joints in the sheets over the expansion joints should not be secured with screws.

All other finishing materials may be carried over expansion joints in the insulation without a joint.

Jacketing

The purpose of jacketing on insulated pipes and vessels is to protect the vapor retarder and the insulation to the adverse affects of weather and abrasion. Protective jacketing is required whenever piping is exposed to wash downs, physical abuse or traffic.

Ambient temperature cycling will cause the jacketing to expand and contract. The jacketing must be installed with a mechanism to permit this expansion and contraction to occur without compromising the vapor retarder. The recommended way to secure the jacketing is to use a band type ring, which holds and clamps the jacketing in place circumferentially. Pop rivets, sheet metal screws, staples or any other item that punctures should not be used because they will compromise the vapor retarder.

If plastic type jacketing is used the minimum thickness of PVC should be 0.030" and for aluminum the thickness should be 0.016”.

Corrosion concerns

For corrosion to occur water must be present and the phenomenon is aggravated at high temperatures. Under the right conditions, corrosion can occur under all types of insulation. Improperly insulated systems create conditions that may promote corrosion. Examples include:

1. Annular space or crevice for the retention of water
2. Insulation material that may wick or absorb water
3. Insulation material that may contribute contaminants that may increase the corrosion rate

Insulating Carbon Steel Pipes

Most of the thermal insulation materials contain chlorides & sulfates, which may hydrolyze in water to produce highly corrosive acids. As a result the pipe surfaces decay due to corrosion, the rate of which is dependent on the moisture ingress and the temperature of the steel surface.

On the pipes, the two primary sources of water are infiltration of liquid water from external surfaces and condensation of water vapor on cold surfaces.

Infiltration occurs when water form external sources enter an insulated system through breaks in the vapor retarder system or breaks in the insulation itself. The breaks may be the result of incorrect installation, abuse or poor maintenance practices. Infiltration of external water can be reduced or prevented.

Condensation results when the metal temperature or the insulation surface temperature is lower than the dew point temperature. Insulation systems cannot always be made vapor tight, so condensation must be recognized in the system design.

This table lists protective coating systems generally used on the carbon steel systems. The end user should check the details on alternatives/coatings with a metallurgist or take an expert opinion of the coating supplier.

Protective Coating Systems for Carbon Steel Piping

Material	Temperature Range	Prime Coat	Intermediate Coat	Finish Coat
Carbon Steel	-50 to 140°F	7 to 10 mils metalized Aluminum	.05 to .075 mil of epoxy polyamide	5 mils high-build (HB) epoxy
Carbon Steel	200°F maximum	2 to 3 mils moisture-cured urethane aluminum primer	2 to 3 mils moisture-cured micaceous aluminum	Two 3 mil coats of acrylic urethane
Carbon Steel	-50 to 300°F	6 mils epoxy/phenolic or high-temperature rated amine-cured coal tar epoxy	N/A	6 mils epoxy/phenolic or high-temperature rated amine-cured coal tar epoxy

Insulating Copper Surfaces for Refrigeration Service

Copper tubing used extensively in low temperature refrigeration application is prone to localized corrosion known as “External Stress Corrosion Cracking (ESCC)”. The localized corrosion attack often occurs at the grain boundaries in the copper resulting in small crack, which advances under the influence of the tensile stresses into the metal.

ESCC occurs in the presence of four conditions:

1. The presence of oxygen (air)
2. The presence of a tensile stress, either residual or applied. In copper, stress can be put into the metal at the time of manufacture or during installation of a refrigeration system
3. The presence of a chemical corroding compound
4. The presence of water (or moisture) to allow the copper corrosion process to occur.

A number of precautions reduce the risk of ESCC in refrigeration systems:

- Properly seal all seams and joints of the insulation systems to prevent a path for condensation between the insulation and the copper tubing.
- Avoid introducing applied stress to copper during installation. Applied stress can be the result of any manipulation, direct or indirect, resulting in stresses in the copper tubing, for example applying stress to a copper tube to align with a fitting or physical damage to the copper prior to installation.
- Under no circumstances use chlorinated solvents such as 1, 1, 1-trichloroethane to clean a refrigeration system. Such solvents have been linked to rapid corrosion.
- Use no acidic materials such as citric acid or acetic acid (vinegar) on copper systems. Such acids are found in many cleaners.
- Make all soldered connections gas-tight, as a leak could result in failure to the section of insulated copper tubing. This prevents self-evaporating lubricating oil, and even refrigerants themselves, from reacting with moisture to produce corrosive acidic materials such as acetic acid.
- Choose the appropriate thicknesses of insulation for the environment and the operating conditions must be used to avoid condensation of the copper tubing.
- Never mechanically constrict or adhere the insulation to the copper. An example of mechanical constriction is the use of wire ties to compress the insulation. This operation may result in the pooling of water between the insulation and the copper tubing.
- Prevent extraneous chemicals or chemical-bearing materials such, such as corrosive cleaners containing ammonia and/or amine salts, wood smoke, nitrites and ground or trench water, from coming in contact with the insulation or copper.
- Prevent the entrance of water between the insulation and the copper. Where the layout of the system is such that condensation may form and run along un-insulated copper by

gravitational force, the beginning run of insulation must be adhered completely to the copper and sealed or vapor stops installed.

- Use copper that complies with ASTM B 280. Buy copper from a reputable manufacture.
- When pressure testing copper tube systems, take care not to exceed the specific yield point of the copper.
- When testing copper for leaks, use only a commercial refrigerant leak detector solution specifically designed for that purpose. It must be assumed that all commercially available soap and detergent products contain ammoniac or amine materials, all of which contribute to the formation of stress cracks.
- Replace any insulation that has become wetted or saturated with refrigerant lubricating oils. Such oils can react with moisture to form corrosive materials.

Insulating Stainless Steel Surfaces

Insulated austenitic stainless steel surfaces operating at temperature above 70°C (~160°F) are liable to external stress corrosion, and cracking in the presence of chlorides. As most thermal insulating materials contain chlorides and may also pick up chlorides from the atmosphere, it is necessary to take precautions when insulation is applied to stainless steel piping and equipment. Thermal insulation provides a medium to hold and transport the water with its chlorides to the metal surface.

It is recommended that a barrier be placed between the insulation and the stainless steel to prevent chlorides that may be leached out from being deposited on the stainless steel. The usual practice is to apply and fit aluminum foil no thinner than 0.06mm before the insulation is applied.

Painting treatments may also be applied to stainless steels before insulation is applied. Furthermore, stainless steel surfaces should be adequately water proofed to prevent ingress of water.

Hanger Supports on Straight Horizontal Runs

Hangers need to be spaced to incorporate allowable loading of both the piping as well as the insulation material. ASME B31 standards establish basic stress allowances for the piping material. The loading on the insulation material is a function of its compressive strength. The suggested maximum spacing between pipe support for horizontal straight runs of standard and heavier pipe at maximum operating temperatures of 750°F (400°C) is presented in a table below.

Note that the spacing does not apply where concentrated loads are placed between supports such as flanges, valves, specialties, etc. The compressive strength of the insulation material may or may not be comparable to support loading at these distances. In actual stress calculations, the force (PSI) on the bearing area of the insulation should be calculated, and than compared to the compressive strength of the insulation.

Suggested Pipe Support Spacing for Straight Horizontal Runs

Pipe O.D. (in)	Standard Steel Pipe /water	Standard Steel Pipe /steam	Copper Tube /water
1/2	7	8	5
¾	7	9	5
1	7	9	6
1-1/2	9	12	8
2	10	13	8
2-1/2	11	14	9
3	12	15	10
4	14	17	12
6	17	21	14
8	19	24	16
10	20	16	18
12	23	30	.
14	25	32	.
16	27	35	.
18	28	37	.
20	30	39	.
24	32	42	.

Source: Adapted from MSS Standard SP-69 and ASME B31.1

In refrigerant piping, typically band style or clevis hangers are used in conjunction with rolled metal shields or cradles. Although the shields are typically rolled to wrap the outer diameter of the insulation in an arc of 180°, the bearing area is calculated over a 120° arc or the outer circumference of the insulation multiplied by the shield length. If the insulated pipe is subjected to point loading such as resting on a beam or a roller, the bearing area arc is reduced to 60° and multiplied by the shield length. In this case, rolled plate may be more suitable than sheet metal. Provisions should be made to secure the shield on both sides of the hanger (metal band), and the shield should be installed centered within the support.

Protection Shields for Insulated Pipes for Band type Hangers

Nominal Pipe Size (in)	Shield Length (in)	Shield Thickness (gage/in)
1/2 to 3-1/2	12	18/. 048
4	12	16/. 060
5-6	18	16/. 060
8	24	14/. 075

Source: Adapted from MSS Standard SP-69, (Note: For point loading, increase shield thickness and length)

PART VIII- Recommended Best Practices

The use of insulation should be one of the first considerations in the design of plant. In too many cases insulation is an after thought and this leads to inadequate levels of thermal insulation due either to restricted space or lack of necessary supports.

The application of the insulation is as important as the thermal properties of the insulation. Recommendations below are based on the industry wide practices based on engineering and economic considerations.

1. A good principle is that all surfaces above 60°C (140°F) should be insulated, and most of those above 50°C (~120°F). This principle applies not only to pipes but also to their associated valves, flanges and fittings such as pipe supports. It should be noted however that insulation would often be justified at lower temperatures than 50°C.
2. Fiberglass or a polyurethane insulation is most common material for low temperature service. Expanded polystyrene is highly inflammable and should be avoided for indoor service such as air-conditioning ducts. Jacketing shall be of stainless steel or aluminum.
3. Fiberglass, mineral fiber or calcium silicates are most common materials used for hot service application. It is recommended to use calcium silicate to insulate the regular hot surfaces and fiberglass or mineral fiber (flexible form) for irregular hot surfaces.
4. Limit the outside surface temperature to 60°C (140°F) for hot surfaces particularly in vicinity of personnel space.
5. For cold service, limit the outside surface temperature 3 to 6°F above dew point temperatures.
6. All insulation must be stored in a cool, dry location and be protected from the weather before and during application. Vapor retarders and weather barriers must be installed over dry insulation.
7. Select & apply insulation/finishes such that it will not suffer damage due to impact, wear or weather. The ability of the insulation to withstand these assaults must be considered together with the use of suitable finishes.
8. Proper on site supervision need to be provided. Too often good quality insulation is not as efficient as it should be because of being applied under poor conditions. Both the storage and installation are important with regard to physical damage or the effect of water.
9. Surfaces should not be left un-insulated just for convenient access. Insulation should be applied so that there are no open joints; overlapping of two-layer insulation should be carried out.

10. Heat losses by conduction to supports should be eliminated as far as possible. The use of insulated pipe supports will prove well worthwhile.
11. The provision of supports for the fixing of insulation must be considered at the design stage. Not only is it more convenient to fix supports during fabrication but the fact that insulation needs to be installed means that sufficient space has been allowed for it and access allowed for its fixing and maintenance.
12. Whole economics of insulation must be looked at during the design stages. It is important to freeze the economic thickness together with the type of finish necessary to withstand physical and chemical attack.
13. While computing the economic thickness, it is not enough to look only at the heat loss and decide on certain thicknesses. It must also be borne in mind that insulation takes up space and also has weight so the thickness of insulation can mean larger ducts and supports, which will all, add to the capital cost. Also additional or stronger supports may be required which again add to the capital cost.
14. The “fibers” used for acoustic systems could be ceramic fibers, mineral fibers or mineral wool.
15. When insulating vessels, tanks, columns etc, man ways shall be provided with removable covers of the same insulation thickness as the shell insulation. Covers shall be secured to the shell insulation and sealed to provide vapor tight joints.
16. Pipes, fittings and valves shall be insulated with pre formed pipe insulation. Sections shall be cut from standard blocks, fitted and wired in place. Flanges should be insulated with the same insulation thickness as the thickness on adjoining pipe run, vessel, machinery or fitting. In order to avoid frost formation or condensation on pipe supports, insulated prefabricated pipe supports shall be used. All fabricated pipe, valve and fitting coverings shall have dimensions and tolerances in accordance with ASTM C585 and ASTM C450.
17. Fireproofing is sometime needed specifically in hazardous environment and P&C industry to prevent damage to piping, vessels and equipment in a hydrocarbon fire situation. If the material strength of equipment is reduced by being subjected to a fire, this must be taken into account in the evaluations, of regulations relating to explosions and protection of installations in the petroleum activities. With regard to evaluations of depressurizing time, a recognized standard such as API RP 521 may be used. If passive fire protection is used, the material strength can be retained for a longer period of time and thereby affect the depressurizing time.
18. Only metallic weatherproofing shall be used on fire proofing insulation. A weather proofing membrane can be installed under the metallic cladding to reduce the risk of water ingress and corrosion under insulation.

19. Within the same installation one should try to limit the number of pipe insulation systems by choosing alternatives that provides combinations of sufficient personnel protection, heat insulation, cold medium conservation, fire protection and noise insulation when and as required. All materials should be tested and approved in the actual combination. Extrapolations of test results are not acceptable. New systems or combination of materials shall be subject to relevant fire tests prior to acceptance.
20. Depending on the particular temperature requirement of the process, the amount of heat transferred can be controlled by both insulation thickness and the emissivity of the jacketing. When designing a system, consider in detail how emissivity affects personnel protection, process control and the surface temperature of cold systems for condensation control. The emittance of 0.1 is considered to be representative of aluminum jacketing. An emittance of 0.8 is considered to be representative of non-metallic surfaces.
21. A dull finish increases the emissivity. By using a jacketing with a higher emissivity value, the amount of insulation needed to achieve the desired surface temperature can be decreased, reducing the initial investment. The trade-off is that as more heat escapes from the system via the higher E material, more energy, and thus more dollars, will be required to maintain the system temperature throughout its life.
22. Apply mastics on the vessel sidewalls or tank top heads, irregular shapes such as fittings, valves and flanges and sometimes on pipe covering; especially in a cryogenic type service. Mastic coatings, when installed, are installed in two layers. This requires brushing or spraying a tack coat; usually 3-4 gallons per 100 square feet. A mesh fabric is then embedded into the mastic to provide strength to the product. Then a finish coat of 3-4 gallons per 100 square feet is then applied in the opposite direction of the first coat.
23. Apply laminated vapor barrier jackets on pipeline insulation and protect with a cladding or weather barrier jacket; such as PVC for indoor and Aluminum for outdoor locations.
24. Proper sealing of each jacket is of the utmost importance. Note that the Kraft paper liner on aluminum is a moisture barrier, not a vapor barrier. The Kraft paper is a liner to provide protection from the effect of dissimilar metals.
25. *Personnel Protection:* The solution in achieving lower temperature on hot pipes & other surfaces is to either use more insulation or to increase the emissivity of the jacketing. Using a dull textured finish will increase the emissivity and thereby allows more heat to escape through the jacketing to the outside atmosphere thereby lowering the surface temperature. A reflective metal finish decreases the emissivity, thereby retaining the heat and increasing the surface temperature.

26. *Condensation Control:* On cold pipes, a dull-finished jacketing with higher emissivity results in a warmer outside temperature. This is the goal, so there is less of a difference between the pipe temperature and the ambient air, thereby reducing the likelihood of condensation. A low-emissivity, reflective jacketing will reflect the cold back into the system, thereby keeping the surface temperature cooler. This increases the vapor drive toward the pipe and results in increased condensation potential. It is important to select closed cell insulation materials on below ambient systems.

27. *Corrosion Control:* Corrosion of any metal under any thermal insulation can occur for a variety of reasons. Carbon steel corrodes not because it is insulated, but because it is contacted by aerated water and/or a water-borne corrosive chemical. Insulated surfaces, which operate below 25°F, do not present major corrosion problems. However, equipment or piping operating either steadily or cyclically at or above these temperatures may present significant corrosion problems. These problems are aggravated by inadequate insulation thickness, improper insulation material, improper insulation system design and improper installation of insulation. The outer surface of the pipe should be properly prepared prior to the installation of the insulation. With any insulation, the pipe can be primed to minimize the potential for corrosion. Specific guidelines are detailed in previous section VII- "Method of application of insulation".

Insulation Installation Guidelines

1) Where multiple layers of insulation are used, all joints should be staggered. Insulation should be applied with all joints fitted to eliminate voids. Large voids should not be filled with vapor sealant or fibrous insulation, but eliminated by refitting or replacing the insulation.

2) Where insulation exceeds 65mm thickness two layers will often be used. In all cases of multi-layer insulation, joints should be staggered.

3) All joints, with the exception of contraction joint locations and the inner layer of a double layer system, should be sealed with either the proper adhesive or a joint sealer during installation. Each line should be insulated as a single unit. Adjacent lines shall not be enclosed within a common insulation cover.

4) Open cell or high permeance insulations may require special protection during installation. All insulation applied in one day should have at least one coat of the specified vapor retarder mastic applied the same day. If impractical to apply the first coat of vapor retarder mastic, the insulation must be temporarily protected with a moisture retarder, such as an appropriate polyethylene film, and sealed to the pipe or equipment surface. All exposed insulation terminations should be protected before work stoppages.

5) Vapor stops should be installed using either sealant or the appropriate adhesive at all directly attached pipe support locations, guides, anchors and at all locations requiring potential maintenance, such as valves, flanges and instrumentation connections to piping or equipment. If for any reason valves or flanges are required to be left un-insulated until after plant start-up, temporary vapor stops should be installed using either sealant or the appropriate adhesive.

6) When applicable, the innermost layer of insulation should be applied in two half sections, secured with 3/4" wide pressure sensitive filament tape banding spaced at 9" maximum centers applied with a 50% overlap. Single and outer layers above 18" outer diameter, and where inner layers are applied in radiuses and beveled segments, should be secured by 3/8" wide stainless steel bands at 9" maximum centers. The bands shall be firmly tensioned and sealed.

7) Insulation on long vertical pipe runs shall be supported on rings spaced on 6400 mm maximum centers installed on the piping. Width of rings shall be half the thickness of the insulation material.

8) Irregular surfaces and fittings should be vapor sealed by applying a thin coat of vapor retarder mastic or finish with a minimum wet film thickness as recommended by the manufacturer. While the mastic or finish is still tacky, an open weave glass fiber reinforcing mesh should be laid smoothly into the mastic or finish and should be thoroughly embedded in the coating. Care should be taken not to rupture the weave. The fabric should be overlapped a minimum of 2" at joints to provide strength equal to that maintained elsewhere. Before the first coat is completely dry, a second coat should be applied over the glass fiber reinforcing mesh with a smooth unbroken surface. The total thickness of the mastic or finish should be in accordance with the coating manufacturer's recommendation.

9) Some installations may require the use of an expansion or contraction joint. These expansion/contraction joints are normally required in the innermost layer of insulation. Expansion/contraction joints may be constructed by using a 1" break in the insulation. All joints should then be tightly packed with fibrous insulation material. The insulation should be secured on either side of the expansion/contraction joint with stainless steel bands that have been hand tightened. Cover the expansion/contraction joint with an appropriate vapor retarder and properly seal.

10) All longitudinal and circumferential laps should be seal welded using a solvent welding adhesive. The laps should be located at 10:00 o'clock or 2:00 o'clock positions. On pitched lines, the jacketing should be installed with a minimum 2” overlap arranged to shed any water in the direction of the pitch. Only stainless steel bands should be used to install this jacketing (1/2" X 0.02" 304 stainless) and spaced every 12 inches.

(For more details on installation requirements refer to section VII-"Method of application of insulation".)

Codes & References

Most common insulation specifications can be referred from one or more of the following standards:

1) American Society for Testing of Materials (ASTM) Specifications:

Equipment insulation shall be manufactured to meet ASTM C 553, ASTM C 612, or ASTM C 1393 for sizes required in the particular system.

- ✓ ASTM C 553, "Standard Specification for Mineral Fiber Blanket Insulation for commercial and Industrial Applications"
- ✓ ASTM C 612, "Standard Specification for Mineral Fiber Block and Board Thermal Insulation"
- ✓ ASTM C 1393, "Specification for Perpendicularly Oriented Mineral Fiber Roll and Sheet Thermal Insulation for Pipes and Tanks"
- ✓ ASTM C-534 Specification for Preformed Flexible Elastomeric Cellular Thermal Insulation in Sheet and Tubular Form
- ✓ ASTM C-552 Specification for Cellular Glass Thermal Insulation
- ✓ ASTM C-578 Specification for Rigid, Cellular Polystyrene Thermal Insulation
- ✓ ASTM C-1126 Specification for Faced and un-faced Rigid Cellular Phenolic Thermal Insulation
- ✓ ASTM C-591 Specification for un-faced Preformed Rigid Cellular Polyisocyanurate Thermal Insulation
- ✓ ASTM C 1136, "Standard Specification for Flexible, Low Permeance Vapor Retarders for Thermal Insulation
- ✓ ASTM C-450 Practice for Prefabrication and Field Fabrication of Thermal Insulating Fitting Covers for NPS Piping, Vessel Lagging, and Dished Head Segments
- ✓ ASTM C-585 Practice for Inner and Outer Diameter of Rigid Thermal Insulation for Nominal Sizes of Pipe and Tubing (NPS System)
- ✓ ASTM E-84Test Method for Surface Burning Characteristics of Building Materials
- ✓ ASTM E-96 Test Methods for Water Vapor Transmission of Materials

Various other specific product or end use insulation categories can also be found in other ASTM guidelines

2) Insulation materials furnished and installed hereunder shall meet the fire hazard requirements of applicable building codes when tested in composite form per one of the following nominally equivalent test methods:

- ✓ American Society for Testing of Materials ASTM E 84
- ✓ Underwriters' Laboratories, Inc UL 723, CAN/ULC-S102-M88
- ✓ National Fire Protection Association NFPA 255

3) Insulation materials furnished should meet the minimum thickness requirements of National Voluntary Consensus Standard 90.1 (1999), "Energy Efficient Design of New Buildings," of the American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE). However, if other factors such as condensation control or personnel protection are to be considered, the selection of the thickness of insulation should satisfy the controlling factor.

4) British standards 3958 Part 1-5, provides k- values and permitting inherent variations in product quality, dimensional tolerances and accuracy of fit on application acceptable for typical insulating materials (magnesia, calcium silicate and mineral wool). Other British Standards referred is BS 5970: 1981

5) The installation of all materials used for thermal insulation should be carried out in accordance with the Midwest Insulation Contractors Association's (MICA) National Commercial and Industrial Insulation Standards, Omaha, NE.

6) National Association of Corrosion Engineers. 1997. Corrosion under Insulation. NACE International, Houston, TX.

7) SofTech2. Naima 3E Plus. 1996. Grand Junction, CO.

The above best practices and guidelines provide brief overview of the recommended requirements and design features. This guideline may be followed unless state or local building codes or manufacturer instructions dictate otherwise. A qualified engineer may be consulted to specify both the insulation material and the insulation thickness based on specific design conditions.

PART IX- Insulation Applications on Plant & Equipment

Pipes & Fittings

The insulation of pipes is probably one of the most common forms of industrial insulation. Preformed sections are most widely used, which make installation much easier and ensure that correct thicknesses have been applied.

There are various standards & tables that provide recommended thicknesses of insulation based the operating and limiting temperatures. But it must be noted that these generic values are based on certain parameters, which may have different values in different locations. The two main variables are the cost of the fuel and the cost of installing the insulation, which means that the standard values may no longer be applicable every time and at every location.

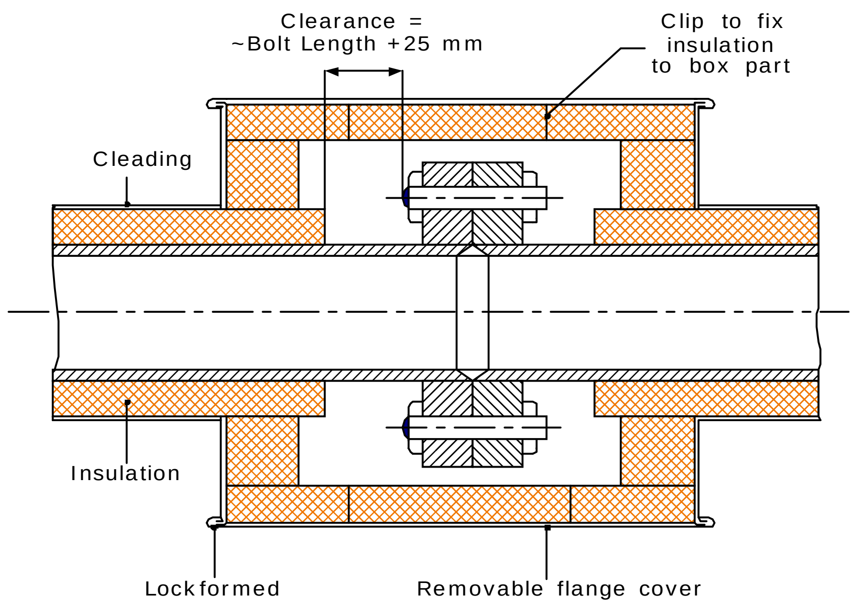
It is important that attention is also paid to the proper insulation of flanges and valves. Some engineers generally commit the error of leaving the flanges and valves unlagged while insulating the piping systems. In fact some insulating contractors recommend that flanges should not be lagged on the grounds that maintenance is facilitated and leaks are more easily detected. This practice is no longer tenable as easily removable preformed molded box insulation sections are now available to fit any size of flange & fittings. The molded block is placed around the flange/valve, and then either wired, or clamped together. The problem of leaks is also not a concern as the molded box section is removable and could be provided with 6mm pipe at the bottom of box to give an early warning of leak. The lagging of flanges is one of the best ways of stopping leaks too.

Unlagged flanges are a source of considerable heat loss. Valves, having a large surface area, lose proportionally more heat. As a rule of thumb, the heat loss from uninsulated flange would have the heat loss as about 0.5 m of same size un-insulated pipe and an uninsulated valve could have more than twice this.

Ideally the thicknesses of insulation on flanges and valves should be the same as for the pipe they serve but looking at the practical constraints as to what can be fitted, it is sometime better to fit the reduced thickness rather than forcibly fitting the higher thickness.

Before insulation on fittings is undertaken, insulation of the pipe, with its protective finish, must be completed. The insulation is stopped short of the fitting on both sides of the fittings so as to allow withdrawal of belts, without disturbing the insulation. The fitting is then insulated.

A typical method of insulating flanges with molded blocks is shown below:



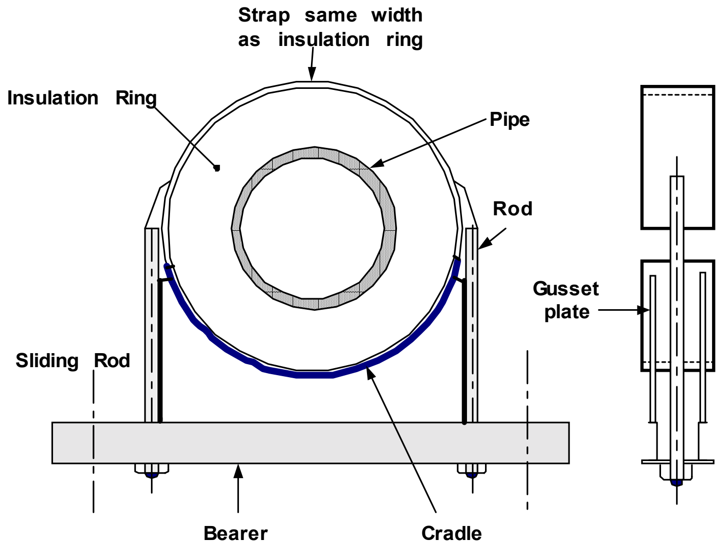
TYPICAL METHOD OF INSULATING PIPE FLANGES

Another inexpensive alternative, is wrapping the valve in fiber cladding, the cladding should have an exterior vapor lock. You can easily determine the correct amount of cladding to use by simply measuring the surface temperature of the insulation when in service. Apply enough cladding to ensure the external temperature of the applied insulation is 120°F or less.

It is important to remember that insulation may need supporting. Vertical piping shall need additional supports for insulation above bends, flanges and valves. In the case of flanges and valves, the supports should be so positioned as to allow ease of maintenance. The supports (bars, angles or studs) should be welded to the pipe and shall be of sufficient length so as to come to 15mm below the surface of the insulation.

Pipes can also lose heat to their supports and the use of insulated supports is recommended. It should be borne in mind that the support and its structure can cause considerable heat loss. When possible, the pipe support mechanism should be located outside of the insulation. Supporting the pipe outside of the protective jacketing eliminates the need to insulate over the pipe clamp, hanger rods, or other attached support components. This method minimizes the potential for vapor intrusion, and thermal bridges within the system as a continuous envelope surrounds the pipe.

A typical method of using insulated support using U-bolt cradle is shown



U - BOLT CRADLE USING INSULATION RING

We have already referred to the problems of pipes carrying liquid in low ambient conditions and low flow rates. Heat tracing may be required in such applications. The need for trace heating may also occur in the case of oil-fired boiler plant particularly those using heavy fuel oil. The heavy fuel oil needs to be heated to reasonable pumping temperature to maintain viscosity and flow ability to the burner.

The use of finishes has already been discussed. It cannot be emphasized enough that finishes should be suitable to their environment. Good insulation can be ruined by the ingress of water or harmful chemicals. Where the temperatures or the conditions at the point of delivery of the medium being conveyed is important, the thickness of insulation on pipes should not only reflect the normal conditions of ambient temperatures and flow rates but also the full regard should be paid to adverse ambient conditions such as low temperatures, wind and rain and to low flow rates of the medium itself.

To give a glimpse of energy loss due to poor or inadequate insulation, the tables #1, 2 & 3 below provide data of heat losses through uninsulated bare pipes and the insulated pipes. The heat losses are given in million BTUs per year from one linear foot of pipe or one square foot of flat surface. These tables use data from the published correlations for the outside heat transfer coefficient and include the effects of wind and thermal radiation from the exterior surface.

A heat loss computer program published by the American Society for Testing and Materials (ASTM) is used to calculate losses from insulated surfaces. Uninsulated surface heat losses were calculated using equations published by Incropera and DeWitt.

Table-1: The heat loss rate in million BTUs per square foot is based on ambient temperature of 70°F, a wind speed of 10 MPH and outside surface emittance of 0.8. Flat surface conditions and characteristic length of 10 feet assumed. One year operation is considered @ 8320 hours of operation. Thermal conductivity for carbon steel considered is 326 Btuin/ft^2 hr °F at 200°F and 267 Btuin/ft^2 hr °F at 800°F.

Table- 2: all parameters same as table-1 except wind velocity is nil (zero).

Table-3: all parameters are same as table-1 except wind velocity is 0 and surface emittance is 0.9

The table #1 indicates the equivalent loss in dollar terms and the table #2 indicates the dollars savings possible, had the pipes were insulated. The data shown below is a guide to economically justified insulation thicknesses; however, it is advisable to do an engineering analysis for specific cases.

Table-1

Heat-Loss Rates from Uninsulated Surfaces with 10 MPH Wind Velocity and 0.8 Exterior Surface Emittance (millions of BTUs per Linear foot per year)

Nom. Pipe Diameter (inches)	Process Temperature (°F)					
	200	**400**	**600**	**800**	**1000**	**1200**
½	2.4	6.4	11.2	17.2	25.1	35.3
1	3.1	8.4	15.0	23.6	35.0	50.0
2	4.5	12.4	22.7	36.5	55.4	81.0
3	6.2	16.2	30.0	49.1	75.5	111.5
4	7.4	20.6	36.2	59.9	92.9	138.2
5	8.6	24.1	44.9	71.0	111.0	165.9
6	9.7	27.4	51.4	85.2	128.7	193.2
8	11.7	33.5	63.4	105.9	166.2	243.4
10	13.8	39.7	75.7	127.4	201.0	302.2
12	15.7	45.4	87.0	147.4	233.7	352.8

Nom. Pipe Diameter (inches)	Process Temperature (°F)					
	200	400	600	800	1000	1200
16	18.7	54.4	105.2	179.5	286.5	434.7
20	22.7	65.2	127.1	218.4	350.7	534.7
24	25.7	76.2	149.6	256.8	414.2	633.8

Table-2

Heat-Loss Rates from Uninsulated Surfaces with Zero Wind Velocity and 0.8 Exterior Surface Emittance (millions of BTUs per Linear foot per year)

Nom. Pipe Diameter (inches)	Process Temperature (°F)					
	200	400	600	800	1000	1200
½	0.6	2.2	4.7	8.6	14.4	22.7
1	0.9	3.2	7.1	13.0	21.9	34.6
2	1.5	5.5	12.1	22.5	38.3	60.8
3	2.1	7.7	17.2	32.3	55.1	87.7
4	2.6	9.7	21.7	41.0	70.0	111.5
5	3.2	11.8	26.5	50.0	85.6	136.6
6	3.7	13.8	31.1	59.0	101.1	161.4
8	4.7	17.5	39.8	75.7	130.0	207.6
10	5.7	21.5	48.9	93.2	160.3	256.0
12	6.6	25.1	57.4	109.7	188.9	302.0
16	8.2	31.0	71.2	136.4	235.5	377.1
20	10.0	38.2	87.9	169.0	292.4	469.1

Nom. Pipe Diameter (inches)	Process Temperature (°F)					
	200	**400**	**600**	**800**	**1000**	**1200**
24	11.8	53.2	118.0	201.4	349.2	560.8

Table – 3

Heat-Loss Rates from Uninsulated Surfaces with Zero Wind Velocity and 0.9 Exterior Surface Emittance (millions of BTUs per Linear foot per year)

Nom. Pipe Diameter (inches)	Process Temperature (°F)					
	200	400	600	800	1000	1200
½	0.6	2.3	5.1	9.4	15.8	24.9
1	0.9	3.5	7.6	14.2	24.0	38.1
2	1.6	5.9	13.1	24.7	42.1	67.2
3	2.2	8.3	18.8	35.5	60.7	96.9
4	2.8	10.5	23.7	45.0	77.2	123.3
5	3.4	12.7	28.9	54.9	94.5	151.1
6	4.0	14.9	34.0	64.8	111.6	178.6
8	5.0	19.0	43.5	83.3	143.6	229.7
10	6.1	23.3	53.5	102.6	177.1	283.3
12	7.2	27.3	62.9	120.9	208.9	334.4
16	8.8	33.8	78.1	150.4	260.5	417.7
20	10.8	41.6	96.5	186.5	323.8	519.9
24	12.8	57.4	128.4	222.5	386.8	621.9

Interpreting the tables above, the conclusions are:

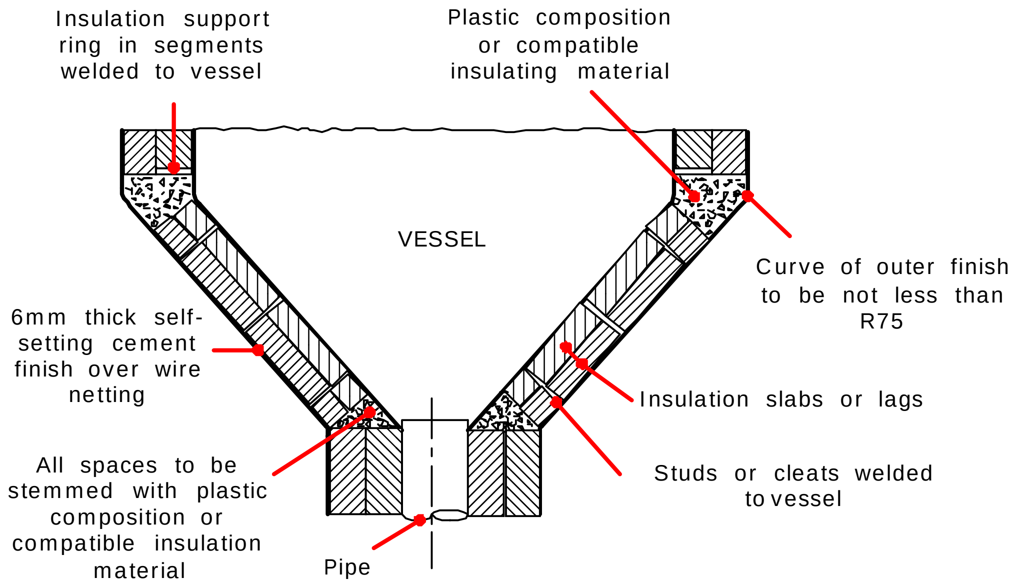
1) *With increase of wind velocity, the heat losses increase. Piping located outdoors is prone to higher heat losses than the piping located indoors.*

2) *Higher the surface emittance, higher shall be the heat losses and lower shall be the surface temperatures.*

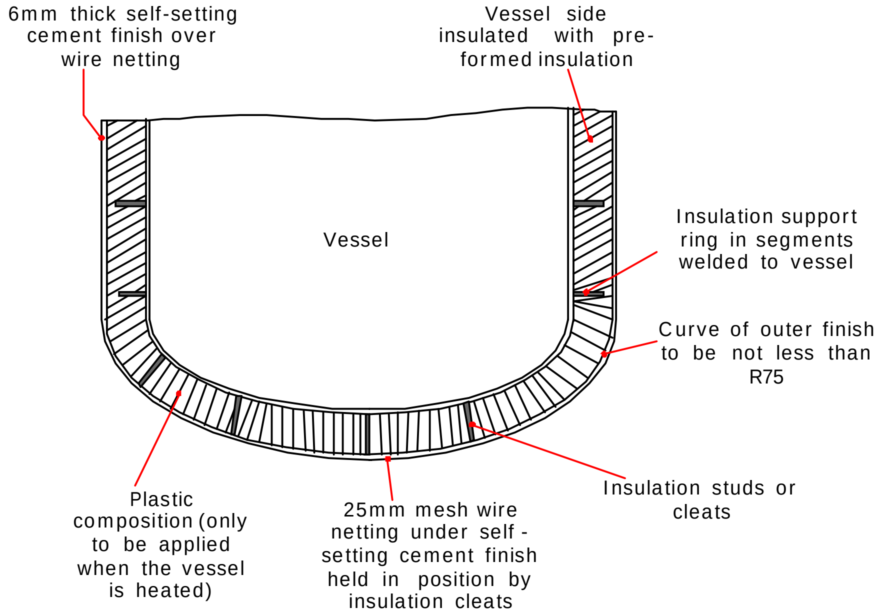
Vessels

The insulation of vessels is often neglected until the plant arrives on site. In these situations, it may well be that the correct levels of insulation cannot be applied and that onsite welding of studs for supporting the insulation may be difficult. It is important therefore to design the insulation during conceptual phase so that at least the supporting studs can be fixed in the fabrication shop itself and that sufficient space is left not only to apply the correct levels of insulation and proper finishes but also to allow space for their maintenance.

The profusion of different shapes and sizes of vessels means that most insulation will be made to measure but certain typical methods of insulation are shown…



TYPICAL METHOD FOR INSULATING VESSELS WITH CONICAL BOTTOM



TYPICAL METHOD FOR INSULATING DISHED ENDS OF VESSEL

Insulation of all vessels shall be supported on rings with a distance of 900 mm c/c installed on the vessel. Rings shall also be provided around nozzles above DN 200 mm.

Studs or cleats are to be welded to the bottom of the vessel at approximately 300mm intervals. After applying an initial coating of plastic insulation, insulation blocks cut to suitable lengths may be used to build up insulation to correct thickness. Block insulation shall be fastened with mechanically tightened metal bands or with bonding adhesive.

Vessels of diameter 60" and smaller shall be insulated as piping.

Certain vessels come into the category of open topped tanks and these can lose considerable amounts of heat through evaporation. This heat loss can be reduced to less than half by the use of a floating blanket of balls. Not only will the actual heat loss be less but the improvement in the local atmosphere may mean that ventilation can be reduced.

Following aspects should be noted for vessels insulation:

- Flat heads are not allowed on top of vertical vessels.
- Removable insulation covers shall be provided for removable vessels heads.
- The bottom heads of skirt-supported vessels may be covered with flat metallic jacketing.
- Jacketing for flanges and valves shall be formed such that it sheds water.
- Longitudinal seams of metal jackets on horizontal or sloping pipelines shall be located maximum 60 degrees away from the lowest point of the circumference.

- All seams on metallic jacketing shall be provided with a metal seam sealant to become waterproof.

Boiler Plant

The insulation of boiler plant is normally carried out by the manufacturer of the boilers generally at the shop or in certain cases is applied onsite after erection of the plant. The field insulation shall be fundamentally at two places. One purpose will be to insulate the hot working medium, which will normally be water or steam form-losing heat to surrounding air. The other will be to insulate the areas where only the hot gases would have their containing surfaces exposed to the surrounding air- an example of this is combustion chambers or flues.

In the first application the insulation will be provided in the form of mineral fiber slabs fixed to the outside surface of the boiler shell. It shall suitably protect the outer sheath. On older boiler plant this insulation may get damage with time and use. If this is the case it should not automatically be replaced with the same thickness of insulation. The new thickness should be calculated based on the prevailing fuel prices.

Insulation of gas flues (Stack/chimney)

The insulation of stack/chimney may be carried out for two reasons. One is the safety aspect from the point of view high external surface temperatures and the other is from the need to keep internal surface temperatures above the dewpoint of the gases being conveyed for corrosion control purposes.

From the point of boiler plant or furnace energy efficiency, the exit flue gas temperatures shall be as low as possible so that every bit of energy is extracted from the fuel. But there is limit to this. The SO_x and NO_x constituents of flue gas tend to form acid due to condensation of flue gas below ~120°C which can result in corrosion of chimney. The flue stack shall therefore need to be insulated in such a way that the flue wall temperature is above the dew point of gasses. Problems can arise particularly on light loads when flue gas velocities and temperatures are both naturally low.

The vertical sides and bottom of the flue may be insulated with low density mineral fibers, supported on studs and reinforcing mesh, but the areas which may be subject to wear or loading should be of minerals such as calcium silicate or dense mineral fibers.

Care should also be taken at any access points such as temperature probes or sampling points. Any expansion joints should also be adequately insulated to prevent corrosion.

Insulation of instrument and instrument tubing

For insulation of instruments, insulated cabinets with hinged doors shall be used. Instrument tubing of max DN 25 may be insulated with cellular rubber for temperatures up to 212°F. For temperatures above 212°F, glass fiber rope and jacketing may be used.

Furnaces & Kilns

Furnaces & Kilns particularly depending on heat treatment or melting applications operate at very high temperatures. The high temperature insulation application range is 600ºF through 1500ºF (315ºC through 815ºC). 2300° F is the maximum temperature for which insulation is applied. Above that refractory is used.

The insulation of furnaces or kilns is a more complicated subject than normal items of plant where insulation can be applied over the hot surfaces. There are two broad categories of furnaces viz. continuous furnaces and intermittent batch type furnaces.

Whichever category of furnace is used, the heat losses result from

1. The loss through the furnace walls due to conduction, radiation and convection.
2. The loss due to the thermal mass of the furnace storing unnecessary heat

There is however a difference between continuously operated and intermittently operated furnaces. In furnaces operated continuously at full working temperature, the heat loss through the walls is far greater than the heat required to heat up the mass of the furnace. In furnaces heated and cooled intermittently, the loss thorough heat stored in the mass of the furnace (and dissipated each time the furnace is cooled) may be much greater.

The problem is thus different in different configuration of furnace. In continuous or long time cycle furnaces the insulating problem is to prevent heat loss through the walls and roof. In intermittent or short time cycle furnaces, it is to reduce the heat storage loss whilst still not neglecting the external surface loss.

The striking benefits of the application of insulation to a furnace can be seen from the following example:

A refractory brick walled furnace with walls of a nominal 9" thickness and an internal wall temperature of 2000°F will lose 145 BTUs per square feet. With a nominal 4" of insulation the heat loss will be reduced to 32 BTUs per square feet and with nominal 8" insulation to 18 BTUs per square feet.

Heat losses can also be reduced to certain extent by increasing the thickness of the refractory brick but this is not very effective as this method adds significant cost to the furnace structure. It is much better to use insulation.

But a word of caution:

The insulation of furnaces should not be adopted without careful consideration of the consequences and the changes in refractory temperatures that may result. .

Effect of insulation on refractory temperatures:

If the outer wall of a furnace is insulted, heat losses shall reduce or more heat is retained within the system. This means that in practice, the average temperature of the refractory walls increases even when the fuel consumption is reduced to maintain the same internal furnace temperature. This can result in the refractory or insulation becoming overheated so that:

a. The refractory may melt and the furnace collapse

b. The insulation may be spoiled or made ineffective

The effect of insulation on our example furnace would be as follows:

The interface temperature that is the temperature of the face between the refractory brick and the insulation would increase considerably. With no insulation the refractory external temperature would be 500°F. With nominal 4” insulation it would be 1650°F and with nominal 8” insulation it would be 1800°F.

Whilst a refractory built into a wall or roof can be operated with its face above the safe temperature as long as the bulk of the brick is at a temperature low enough to stand up to conditions, evening up the temperature over the thickness of the brick by applying insulation to the outside may set up very dangerous conditions.

For this reason it is recommended that furnace builders or the manufactures of insulating bricks should always be consulted before the insulation of high temperature furnace is undertaken.

PART X- Optimum Economic Thickness

As the temperature of a surface increases, heat loss increases. Therefore the thickness or effectiveness (in terms of thermal conductivity) or both, must be stepped up accordingly.

Just to give a glimpse of energy loss, consider an example;

A 100 m (330 ft) length of bare 50mm (2") steam pipe operated on a process at 100°C (212°F) will waste 3500 gallons of oil per year costing about $ 5000. This could be cut to $ 500 per year by using 38mm (1½") thick insulation round the pipe – a preventable cost of $4500 every year.

In the example above, the same pipe would be wasting 10000 gallons of oil per year if uninsulated and operating at 200°C (392°F). The use of 50 mm (2") insulation would cut this to around 800 gallons- a preventable cost of about $13800 per year.

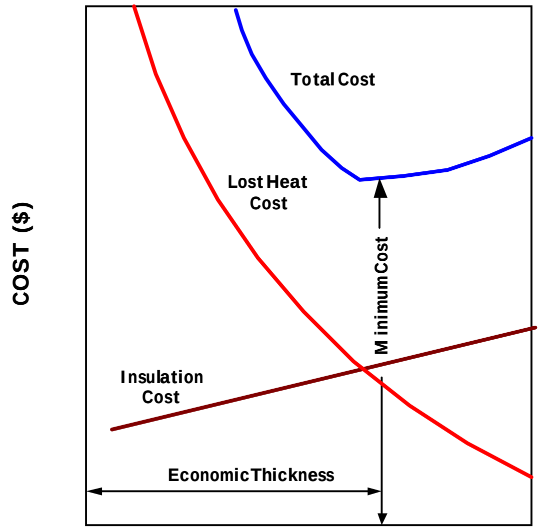
Does this mean that if you step up insulation thickness or select high performance insulation, further savings can be achieved!

Not really. While computing the economic thickness, it is not enough to look only at the heat loss and decide on certain thicknesses. There are economic concerns like; the increased capital expenditure on account of higher thickness of insulation may not provide savings proportionate to the investment. The return on insulation costs (payback) in term of fuel savings could be unacceptably low.

Therefore there is a definite limit beyond which it is not prudent to increase the thickness. *This limit is defined as an "Acceptable or Economic thickness" of insulation and is defined as that thickness of insulation at which the costs of heat loss plus the installed cost of insulation is at a minimum over a period of time.* Economic thicknesses are determined from the value of energy that is saved, the cost and performance of insulation.

General advice on the standard insulation thickness that should be applied is available though various tabulated data, charts and nomograms. These are a useful starting point but it cannot take into account the individual circumstances. Numerous parameters such as the cost of fuel, efficiency of combustion, heat content of fuel, annual hours of operation, average ambient temperature, type & estimated cost of insulation, payback period etc. influence the economic selection.

Each firm has different fuel and insulation costs and thermal efficiencies. The effectiveness of insulation follows the law of diminishing returns. The economic thickness shall result in the lowest overall cost of insulation and heat loss combined over a given period of time. The figure below demonstrates this principle.



ECONOMIC INSULATION THICKNESS

It must be realized that the figure above is merely an idealized representation. In reality insulation costs will be a series of steps as the insulation is supplied in standard thicknesses. Similarly the heat loss will follow the same pattern, as this too is dependent on the insulation thickness. The reciprocal of the amount of insulation used, for instance, 1, ½, 1/3, 1/4… the first insulation is most valuable, with every succeeding increment less so. It follows that the total cost must reflect both these types of step change.

A detailed analysis is justified for systems that operate at elevated temperatures or if large surface areas are involved. Certain firms will also affect the calculation by using discounted cash flow, life cycle analysis, depreciating costs, maintenance costs, future fuel prices etc.

Quick Evaluation of Insulation Levels

Though surface temperature of the insulation does not indicate absolutely its effectiveness, yet the following norms may be adopted to evaluate the use of improving insulation levels.

For a well-insulated surface, ΔT (temperature difference) between the surface temperature of insulation and ambient air should be less than the values indicated in the following table

Desirable Δ T between Surface Temperature and Ambient Temperature

Finish	Pipe diameter < 4 inches		Pipe diameter > 4 inches	
	Operating Temp < 480°F	Operating Temp > 480°F	Operating Temp < 480°F	Operating Temp > 480°F
Bright Aluminum, Galvanized Steel	< 15	< 15	< 15	< 20
Dull Finish (cloth), Cement, Rough Sheet	< 10	< 10	< 15	< 15

Recommended Insulation Thickness for Cylindrical and Flat Surfaces

For quicker evaluation of insulation levels required, the following approach may be adopted. Table below depicts the insulation level required for insulating hot surfaces (pipes and flats) as a rough guideline for small and medium industries.

Temperature	Pipe				Flat (inches)
	1" dia	2" dia	3" dia	4" dia	
Up to 212°F	1	1½	2	2½	3
212 to 300°F	1½	2	2½	3	4
300 to 392°F	2	2½	3	4	5
392 to 482°F	2	3	4	5	6
482 to 572°F	2½	3½	4½	6	7

Note: The above insulation thickness is for mineral wool backed by a bright metallic surface

Fixing the thickness of insulation simply on economic grounds alone is not the only criteria. The level of insulation may well be based on safety from the point of view of surface temperature and the process conditions of delivery temperatures.

Refer to Part-II of this course titled *"Insulation Audit and the Economic Thickness of Insulation"* for further reading.