
Overview of Insulation Materials

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OVERVIEW OF INSULATION MATERIALS

Abstract

Substantial quantities of heat energy are wasted daily in industrial plants and buildings because of un-insulated, under maintained or under insulated heated or cooled surfaces. Thermal insulation reduces heat flow from one surface to another. For hot, or above ambient applications, thermal insulation reduces heat loss. On cold, or below ambient applications, the insulation generally serves the purpose of minimizing heat gain.

It is important that due regard to the required levels of thermal insulation be given at the initial design stages of process plant. In too many cases the insulation of process plant is an afterthought. Consequently there are cases where proper levels of thermal insulation cannot be installed.

This course reviews the types, characteristics and properties of various thermal insulation materials. There is an outline of energy conservation and therefore the cost savings. The course is divided into 6 sections:

PART – 1:	Introduction & Overview
PART - 2:	Insulation Characteristics and Selection Criteria
PART – 3:	Insulation Types and Materials
PART – 4:	Insulation Application on Piping and Equipment
PART – 5:	Economic Thickness of Insulation
PART – 6:	Recommended Best Practices
Annexure -1	Thermal Insulation Calculator References
Annexure -2	Codes & References

PART – 1: INTRODUCTION & OVERVIEW

The word “Insulation” derived from the Latin word for island (insula) is the noun describing material which insulates (cuts off) heat (or electricity) from its surroundings. It is a scientific noun and was first recorded in 1870.

Thermal insulation is defined as a material or assembly of materials used to provide resistance to heat flow. The temperature ranges within which the term "thermal insulation" will apply, is from -73.3°C (-100°F) to 815.6°C (1500°F). Typically all applications below -73.3°C (-100°F) are termed "cryogenic," and those above 815.6°C (1500°F) are termed "refractory". Usually 2300°F is the maximum temperature where insulation is applied.

Where is thermal insulation installed?

In buildings thermal insulation is installed on the building structure, roof, walls and attic spaces; as well as domestic hot water plumbing lines, chilled water supply and return lines and air distribution ducts to improve energy efficiency and to protect the building constructional elements against thermal impact and moisture related damage. Thermal insulation in winter minimizes heat loss and in summer reduces solar heat transmission.

For industrial facilities thermal insulation is installed on process equipment, piping, steam and condensate distribution systems, boilers, smoke stacks, bag houses, furnaces, kilns and storage tanks, etc for process control, energy efficiency and safety.

Why Is Insulation Required?

Principal uses of insulation are for personnel protection, process temperature control, prevention of condensation, and conservation of energy.

Personnel & Fire Safety

Insulation reduces the surface temperature to a safer level. Studies indicate that the skin contact for more than 5 seconds with hot surfaces at temperatures above 136.4°F (ASTM C 1055) could result in second or third degree burns. To date, there are no mandates or statutes that govern any upper temperature limit for personnel protection. However, many industries have accepted or adopted 125°F as a common practice.

Insulation for personnel protection is generally applied only in those areas accessible to persons during normal plant operation and maintenance, and applied to a high of 7 feet above or 3 feet from platforms or work areas. As an alternate, in some applications where there is clearly no justification for insulation, the fabricated guards may be employed to restrict personnel proximity to the hot surfaces.

Process Control

Providing a stable temperature flow throughout a process system is in many cases more important than any other design criterion. Some processes may only allow for a minimal temperature fluctuation, for example, liquefied gases must be kept below their boiling points. This is usually accomplished with a combination of pressure and insulation. If the temperature of the liquid gas is allowed to exceed the process control design parameters, the consequence is either a costly loss of gas through vaporization or a potentially hazardous buildup of pressure. Erratic performance of the insulation may be extremely costly to the owner because the process is compromised.

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.

Condensation Control

In cooling and/or chilled water distribution lines, the insulation is often the target of condensation when water vapor is driven from the outside air toward the cooler piping systems. In building air-conditioning applications, the moisture condensation can cause the discoloration or staining of ceiling panels, corrosion of cold piping, ducts, chillers, etc and pose health risks due to mold and fungus growth.

To prevent condensation, it is important to provide sufficient insulation to keep surfaces above the dewpoint temperature of air. Specifying sufficient insulation thickness with an effective vapor retarder system is the most effective means of providing a system for controlling condensation on the membrane surface and within the insulation system on cold piping, ducts, chillers and roof drains.

Sufficient insulation thickness is needed to keep the surface temperature of the membrane above the highest possible design dew point temperature of the ambient air so condensation does not form on the surface. The effective vapor retarder system is needed to restrict moisture migration into the system through the facing, joints, seams, penetrations, hangers, and supports.

Energy Savings

Insulation conserves energy by reducing or minimizing the heat loss or gain. Remember, insulation is merely a heat flow reducer, not a barrier to heat flow.

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.

Associated benefits of insulation include greenhouse gas reduction. Energy efficiency leads to reduction of CO₂, NO_x and other hazardous gas emissions to the outdoor environment.

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.

PART - 2: INSULATION CHARACTERISTICS & SELECTION CRITERIA

In order to understand how insulation works, it is important to understand the fundamentals of heat transfer. The flow of heat from one object to another is called heat transfer. There are three fundamental methods of heat transfer that must be considered when designing insulation: conduction, convection and radiation.

Conduction is the transfer of energy (heat) within a body (material) or between two bodies in physical contact. Heat is transferred through most metals very efficiently because metal is a good conductor. For example, when people first sit down on cold metal chairs, they instantly feel the discomfort that comes from the contact of a warm body with a cold chair as body heat is quickly transferred from the skin and through clothing to the chair by conduction. A good insulation material is a poor conductor.

Convection is a flow of heat due to the movement of air on or about the surface of a body or an object because of differences in the density, temperature, etc. For example, people usually detect a draft when standing close to a single glazed window in the winter. Air within the room tends to stratify so that the air near the ceiling is warmer because it has become less dense when heated and so it rises. This is natural convection. That warm air loses heat to the vertical window because heat flows from hot to cold. This air becomes cooler and denser, so it begins to sink. This is the draft felt by people and is another example of natural convection. Warm air entering a room from a supply duct is an example of forced convection.

Radiation is best described by referring to the warmth you feel when you stand in the sun or by a fire. Radiation is a process by which heat flows from a higher temperature body to lower temperature body by means of electromagnetic energy transfer. The intensity of emission depends on the temperature and nature of the body surface. The heat transfer by radiation becomes more significant as the temperature of the object rises. Any hot body emits radiation in a form of heat, which can be received by another solid body in the path of the heat radiation.

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

Key Terms

Heat transferred through insulation is primarily a function of the resistance of the insulation with respect to its thickness, the operating temperature of the surface being insulated, the surface characteristics of the outer membrane (emittance) and the ambient conditions involved. Before we proceed further, let's familiarize ourselves with few standard terms relating to heat transfer that will be useful in reviewing the insulation materials.

- 1) **Heat flow or heat flow rate Q:** the quantity of heat transferred to or from a system in unit time. Usually measured in Btu/h.
- 2) **Btu (British thermal unit):** the amount of energy required to raise 1 lb of water at 1°F (The equivalent metric designation is a joule, which is defined as the work done when the point of application of a force of 1 N is displaced a distance of 1 m in the direction of the force.)
- 3) **Thermal Resistance (R) ($F\ ft^2\ h/Btu$):** The property of material by which it resists heat transfer. The effectiveness of material (insulation) is usually expressed by what is called an R-factor or R-value. The higher the R-value, the greater the insulating power, meaning the better the insulation. For example, R-40 insulates better than R-30. 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. The resistance, or thermal resistivity of insulation is measured with an insulation tester, using a reference sample of known conductivity, with the results expressed in an equation, which is then converted to the more easily understood R-value.
- 4) **Thermal Conductivity (k) ($Btu\ in\ /h\ ft^2\ F$):** Thermal Conductivity is the ability of a material to transmit heat energy by conduction. Expressed as k- value, it is the same number regardless of the thickness of insulation. The **lower** this value, the better is the thermal insulation performance; in other words, materials with lower k-values are better insulators. The thermal conductivity of most insulating materials varies with temperature and bulk density. 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.

Thermal conductivity values for typical heat insulating material, resistant films and heating surfaces are indicated below:

Material	Density (lbs/ft ³)*	Approximate conductivity values (Btu/h ft °F)*
Magnesia	11 – 14	0.034 to 0.044
Mineral Wool	3 - 15	0.023 to 0.058
Calcium Silicate	10 -20	0.033 to 0.053
Alumino-silicates	6	0.019 to 0.048
Glass Fibers	6	0.019 to 0.040
Resistant Films		
Water at 0°C		0.343
Water at 95°C		0.393
Air		0.014
Scale		0.66 – 1.99
Heating Surfaces @ 100°C		
Copper		227
Aluminum		138
Cast Iron		18.68
Steel ((0.5%C)		30.0
Brass		60.0

(*1 lb/ft³ = 16.04 Kg/m³ and 1 Btu/h ft²°F = 4.885 Kcal/h m²°C)

- 5) **Emittance (E):** the ratio of the radiant flux emitted by a specimen to that emitted by a black body at the same temperature and under the same conditions. The surface emittance for a blackbody is “1”. For surfaces other than that of a blackbody surface, the value of emittance is always < 1. Higher emittance signifies high heat transfer by radiation.
- 6) **Radiance:** the rate of radiant emission per unit solid angle and per unit projected area of a source in a stated angular direction from the surface (usually the normal).
- 7) **Reflectance:** the fraction of the incident radiation upon a surface that is reflected from the surface.

Heat Transfer Mechanism

The main requirement of an insulating material is that it shall have **low** thermal conductivity. This is generally an intrinsic property of the insulating material but the structure of the material may also make an important contribution to the insulating effect. If the material is porous, conduction through it is partly through the air contained in the small pores, which are so small that convection is minimized, and the heat transfer through the air is primarily by conduction. As gases (excluding hydrogen) are the worst conductors of heat, the air contained in the pores contributes significantly to the lower conduction.

Heat Transfer Equation

Steady-state, one dimensional heat flow through insulation systems is governed by Fourier's law:

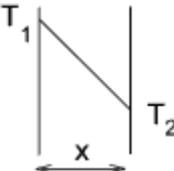
$$Q = -k \cdot A \cdot dT/dx$$

Where,

- Q = Rate of heat flow, Btu/hr
- A = cross sectional area normal to heat flow, ft²
- k = thermal conductivity of the insulation material, Btu-in/h ft²°F
- dT/dx = temperature gradient, °F/in

Heat Gain / Loss from Flat Surfaces

For flat geometry of finite thickness, the heat transfer from flat surface to the surrounding air can be expressed as:

$$Q = kA \frac{T_1 - T_2}{x}$$


For practical purposes the equation reduces to:

$$Q = A \cdot (T_1 - T_2) / (x/k + 1/f)$$

Where,

- Q = Heat transfer from the outer surface of insulation in Btu/hr
- A = Area of heat flow, ft^2
- T_1 = Hot face temperature, $^{\circ}\text{F}$
- T_2 = Surrounding air temperature, $^{\circ}\text{F}$
- x = Thickness of insulation, in
- k = Thermal conductivity of insulation, $\text{Btu/h ft } ^{\circ}\text{F}$
- $1/f$ = Surface resistance factor
- L/k = Thermal resistance of insulation expressed as "R"

The thicker the insulation, the lower will be the heat transfer rate. Also the lower the thermal conductivity or the k value; the higher will be the R value; or greater the insulating power.

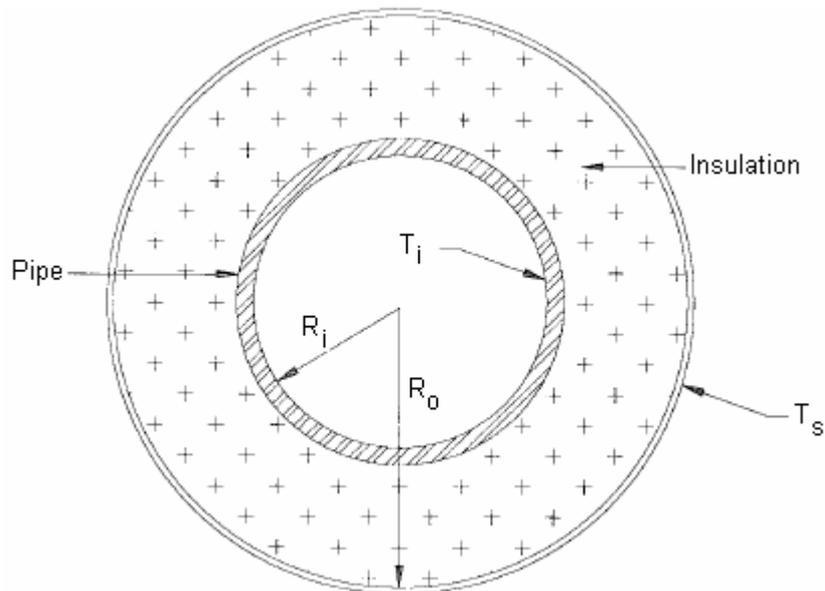
The thermal conductivity of insulation changes as the difference in temperature between the hot surface and the ambient temperature changes. *The thermal conductivity value of a material is taken at the mean temperature $(T_1 + T_2)/2$ and it varies with mean temperature, material density, and with moisture absorption.*

Heat Gain / Loss from Cylindrical Surfaces like Pipes

We have learnt that by adding more insulation to a wall always decreases heat transfer. The thicker the insulation, the lower will be the heat transfer rate. This is expected, since the heat transfer area " A " is constant and adding insulation always increases the thermal resistance of the wall without affecting the convection resistance.

Adding insulation to a cylindrical piece or a spherical shell, however, is a different matter. Unlike flat surfaces, the inner and outer surface areas for pipes are different and therefore the heat transfer equation is different. The additional insulation increases the conduction resistance of the insulation layer but decreases the convection resistance of the surface because of the increase in the outer surface area for convection. The heat transfer from the pipe may increase or decrease, depending on which effect dominates.

Consider a cylindrical pipe of inner radius R_i carrying a fluid at T_i . The pipe is insulated with a material whose thermal conductivity is k and outer radius is R_o . Heat is lost from the pipe to the surrounding medium at temperature (T_s).



Cross-section of an insulated pipe

The rate of heat transfer from the insulated cylindrical pipe to the surrounding air can be expressed as:

$$Q = \frac{k A_o (T_i - T_s)}{R_o \ln (R_o / R_i)}$$

Where

- Q = Heat transfer from the outer surface of insulation in Btu/hr
- k = Thermal conductivity of insulation, Btu/h ft °F
- A_o = Area of outer surface, ft²... [2 * pi * R_o * L]
- T_i = Inside operating temperature, °F
- T_s = Outside ambient temperature, °F
- R_i = Bare pipe radius (inner radius), in
- R_o = Radius of insulated surface (outer radius), in
- L = linear length, ft

- \ln = Natural logarithm

The term $[R_o \ln (R_o/R_i)]$ is sometimes called the "equivalent thickness" of the insulation layer. Equivalent thickness is that thickness of insulation, which, if installed on a flat surface, would yield a heat flux equal to that at the outer surface of the cylindrical geometry.

Since heat loss through insulation is a conductive heat transfer, there are instances when adding insulation actually increases heat loss. The thickness at which insulation begins to decrease heat loss is described as the '*critical thickness.*' This is discussed further in section-5 "Economic Thickness of Insulation".

SELECTION CRITERIA

There are many types of insulation available, making it incredibly difficult to choose. While the main consideration of insulation is to reduce heat flow either from a hot source to ambient or from ambient to a cold process, selecting an insulation material for a particular application requires an understanding of the various other characteristics associated with available materials.

The following insulation properties are the primary consideration when choosing the type and form of insulation for specific projects:

1. Thermal conductivity "k": The lower the thermal conductivity or the k value; the higher will be the R value; or the greater the insulating power.
2. Temperature limits: Upper and lower temperatures within which the material must retain all of its properties.
 - a. For materials to be used at temperatures below about 50°F, attention should be paid to the relevant limiting minimum as well as to the limiting maximum temperatures, and to the effects of possible excessive shrinkage, embrittlement, and porosity, in addition to resistance under conditions of occasional heating for cleaning and defrosting purposes.
 - b. For materials to be used at elevated temperatures typically above 300°F, many factors can result in deterioration including: linear shrinkage under heat, loss of compressive strength during heating, and the effects of vibration and possible self-heating phenomena.

3. Ambient Conditions: Check the ambient conditions under which the insulation system will operate. You need to determine the ambient temperature, relative humidity (RH) (if you are trying to design for condensation control), wind speed and sometimes the amount of rainfall. Again, just like understanding operating temperature, think about possible extremes. Designing an insulation system for condensation control at 50 percent is going to fail if the environment occasionally sees 90 percent RH.
4. Emissivity: 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 . The temperature of insulation's outer surface must be considered where insulation is used for personnel protection or where excessive surface temperatures might cause ignition of fumes or gases. On low temperature installations, surface temperatures must be above dewpoint to prevent condensation and drip. The emissivity property of insulation finishes is significant in these cases. High emissivity is recommended on finishes used for personnel protection treatments.

Besides thermal properties other features of significance include:

1. Alkalinity (pH or acidity): Significant when corrosive atmospheres are present. Insulation must not contribute to system corrosion.
2. Appearance: Important in exposed areas and for coding purposes.
3. Breaking load: In some installations, the insulation material must "bridge" over a discontinuity in its support. The property of a material which measures its ability to resist bending (flexing) without breaking is called the "flexural strength" of insulating material.
4. Capillarity: This must be considered when a material may be in contact with liquids. 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.
5. Chemical resistance: A selected insulation shouldn't be chemically reactive to the metal over which it is applied. This is significant when the atmosphere is salt or chemical laden. Corrosion resistance must also be considered. Basically, insulation installed on steel should be neutral or slightly alkaline. Insulation installed on aluminum should be neutral or slightly acidic.

6. Coefficient of expansion and contraction: This enters into the design and spacing of expansion and contraction joints and/or the use of multiple-layer insulation applications.
7. Combustibility: This is one of the measures of a material's contribution to a fire hazard.
8. Compressive strength: This is important if the insulation must support a load or withstand mechanical abuse without crushing. Compressive resistance is important where the insulation must support a load without crushing (e.g., insulation inserts in pipe hangers and supports). If, however, cushioning or filling in space is needed in an expansion or contraction joint to take up a dimensional change, lower values of compressive resistance are desirable. ASTM Standard C165 is used to measure compressive resistance for fibrous materials, and ASTM Standard D1621 is used for foam plastic materials.
9. Density (lb/ft³): A material's density affects other properties of material especially thermal properties. Insulating materials owe their low conductivity to their minute pores that divide an air space into very small pockets, thereby minimizing solid and gas conduction and radiation, and for most applications, eliminating convection. The bulk density for most thermal insulating materials falls within the range 0.6 to 20 lbs/ft³. Materials of **high** bulk density should be selected for use in high temperature applications; whereas materials of **low** bulk density should be selected for use in low temperature applications as well as for installations requiring rapid heat-up or cool-off of insulated surfaces.
10. Fire retardancy: Flame spread and smoke developed ratings should be considered. Some of the insulation materials often used for refrigeration systems are entirely of organic composition and thus can constitute a fire hazard, or they can emit smoke and toxic fumes. The steel building columns and beams are often coated with insulation sprays to enhance fire rating. ASTM E 119 provides the criterion. Fire performance rating of insulating materials is 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 tests can be as low as "0" for flame spread and "50" for smoke developed, which are generally acceptable. The Determination of behavior in a fire can be divided into 6 subjects: 1) Surface burning Characteristics; 2) Fire propagation; 3) Ignitability; 4) Smoke development/Contents of smoke; 5) Surface spread of flame; and 6) Fire Resistance/Endurance.

11. Health Hazards: 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. Insulation should resist mildew or mold growth on continuous basis to damp conditions.
12. Hygroscopicity: The tendency of a material to absorb water vapor from the air. While closed-cell materials, e.g. cellular glass, can have low water vapor permeability characteristics, open-pore and fibrous insulating materials can absorb considerable quantities of water, which while present, can adversely affect the thermal conductivity and the effectiveness of the insulation.
13. Mechanical strength, resilience and durability: There are significant differences in the mechanical properties of insulation materials of different generic types and densities within a given type. In particular, some materials have a low compressive strength and may be easily damaged; for example, by foot traffic. When deciding which type of insulation to use, compressive strengths should be compared as well as comparing other material properties such as thermal efficiency. The selection of an outdoor system should also be made on the basis of its durability in withstanding the effects of sunlight and other environmental elements.
14. Resistance to ultraviolet light: This is significant if the application is outdoors.
15. Resistance to fungal or bacterial growth: This is necessary in food or cosmetic process areas.
16. Shrinkage: This is significant on applications involving cements and mastics.
17. Sound absorption coefficient: This must be considered when sound attenuation is required, as it is in radio stations, hospital areas, etc.
18. Sound transmission loss value: This is significant when constructing a sound barrier.
19. Specific Heat (Quantity of Heat Energy): All materials contain or absorb heat energy in different amounts. The quantity of heat energy or thermal capacity of a particular material is called its specific heat. The specific heat of a substance is defined as the amount of heat energy required raising one pound of the material by one degree Fahrenheit and is expressed as (Btu/lb/°F). The specific heat of most materials is constant at only one temperature and usually varies to some degree with temperature. Water has a specific heat of 1.0 and absorbs large quantities of heat energy. Air, with a

specific heat of 0.24, absorbs considerably less heat energy per pound. The best insulation in the world is a vacuum, and that has no specific heat at all. A process changing from hot to cold every few minutes (cyclic process) requires an insulation that has the ability to change temperature quickly and has very **low** mass to retain heat and **low** specific heat.

20. 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** thermal diffusivity is important. Conversely, when insulation is used as fire protection, a slow rate of thermal diffusivity is most important.
21. Thermal Expansion/Contraction and Dimensional Stability: Insulation systems are installed under ambient conditions that may differ from service conditions. When the operating conditions are imposed, metal surfaces may expand or contract differently from the insulation and finish applied. This can create openings and parallel heat & moisture flow paths that can degrade system performance. Lower values of compressive resistance are desirable when insulation is applied for expansion or contraction joint.
22. Toxicity: This must be considered where there is a possibility of spillage, leaks and accidental contamination of process chemicals. Insulation should be chosen such that it does not react to the chemicals. Special care should be taken to use non-absorbent insulation in the presence of combustible or toxic liquids.
23. 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.
24. Water vapor permeability: Water vapor permeability is an indication of the ability of 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 for cold surfaces and is of a particular concern to insulation systems subjected to a thermal gradient. Water is a good conductor and influences the thermal conductivity and other properties in a negative way.

Not all the above properties may be important for every application and therefore, many are not included in manufacturers' published literature. In some applications; however, some properties may assume extreme importance (such as when insulation must be compatible with chemically corrosive atmospheres.)

Geographic and Environmental Factors

It's important to know if a plant location is near an industrial complex, where potentially corrosive chemicals are present, or near coastal areas, which can affect the selection of insulation and weatherproofing materials along with application procedures. Insulated equipment located near a cooling tower or ash handling equipment will be exposed to a more corrosive environment than will the other plant equipment. Wind conditions (both positive and negative) must be considered in insulation design. The insulation material could be rigid enough to support the positive pressure of the weatherproofing, and supports must be strong enough to resist the negative pressure.

The National Weather Bureau, the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., U.S. meteorological services, sited data or similar service provides local weather data, which can be used in determining the minimum, maximum and average daily temperatures, wind, humidity and rainfall.

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 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.

When reviewing and comparing potential installation choices, the lowest price at installation isn't always the most economic choice. Adequate insulation thickness shall be based on the economic criteria of an energy analysis and a return on the owner's investment depending on the design criteria and current energy costs. In case insulation is applied to a critical process, reliability is a prime concern. In case energy conservation is the deciding factor, than savings per year as compared to installed costs is the most important factor. Refer to Annexure - 1 for the information regarding the calculation aids for economic analysis of insulating materials.

Standard Test Methods

Standard test methods for determining thermal transmission properties of insulation materials are covered in

- ASTM Standard Test Method C177, Steady-State Thermal Transmission Properties by Means of the Guarded Hot Plate
 - ASTM Standard Test Method C518, Steady-State Thermal Transmission Properties by Means of the Heat Flow Meter
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PART – 4: INSULATION TYPES & MATERIALS

There are many different types of insulation materials available; each having its own set of properties and performance characteristics. Broadly, thermal insulation materials can be classified according to their:

1. Types
2. Construction elements
3. Application

Classification of Insulating Materials on Types

Thermal insulation materials can be divided into four types:

- 1) Granular
 - 2) Fibrous
 - 3) Cellular
 - 4) Reflective
- 1) **Granular Insulation:** Granular insulation is composed of small nodules manufactured from loose or pourable material combined with a binder and fibers for a rigid product. This material is sometimes considered open-cell material, because gases can transfer between the individual spaces. This material is primarily used on hot pipes and is applied in the field by a jacket method. Examples of this insulation include:
- Calcium silicate
 - Insulating finishing cements
 - Perlite
 - Expanded polystyrene etc.
- 2) **Fibrous Insulation:** Fibrous insulation is composed of small diameter fibers that divide the air space horizontally and perpendicularly. These fibers may or may not be bonded together. The fibrous glass has a neutral pH factor, but the binder used for adhesion can have a positive pH factor. This material is non-combustible with positive sound absorption qualities. The most common fibrous insulation include:
- Fiber glass
 - Mineral wool or mineral fiber

- Refractory ceramic fiber
- 3) **Cellular Insulation:** Cellular insulation is composed of small individual cells of glass or formed plastic which are either interconnected or sealed from each other, to form a cellular structure. These formats can be fabricated into pipe insulation and shaped as needed for the application. The cellular material has a positive structural strength, but poor impact resistance. This insulation type is defined by the American Society for Testing and Materials guideline ASTM C 1427. The examples of this insulation include:
- Elastomeric foam
 - Phenolic foam
 - Polyethylene
 - Polyisocyanurates
 - Polystyrene
 - Polyurethanes
- 4) **Reflective insulation:** The reflective insulation consists of layers of reflective foil crimped on insulating surfaces. For reflective insulation, the most important property is to have low emittance or high reflectance. Typically aluminum or stainless steel is used as foil material. A reflective metal finish decreases the emissivity and retains more heat within the system. A dull finish increases the emissivity and thereby allows more heat to radiate from the system.

Classification of Insulation Materials based on Construction Elements

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

1. Organic foams include polystyrene, polyurethane, polyisocyanurate, phenolic foam, expanded nitrile rubber and polyethylene foam. These are very common types of insulating materials typically used for low temperature service.
2. Inorganic materials include 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.

Classification of Insulation Materials Based on Application

Temperature is the most popular classifying guide because it is the first element to be considered when planning and designing insulation systems. The Insulation can be classified into three groups according to the temperature ranges for which they are used:

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

High Temperature Thermal Insulation (600°F – above)

The high temperature application range is 600°F through 1500°F and is commonly used in turbines, breechings, stacks, exhausts, incinerators, boilers etc. 2300°F is the maximum temperature for which insulation is applied and over 2300°F applications such as melting furnaces refractory is generally used.

Materials used at relatively high temperatures (with typical densities)

- Mineral Fiber Slabs (7 lbs/ft³)
- Mineral Fiber Spray (15 lbs/ft³)
- Calcium Silicate (12 to 14 lbs/ft³)
- Fiber glass
- Alumino Silicate Fibers (12 lbs/ft³)
- Silica Fibers, loose fill (6 lbs/ft³)
- Opacified Silica Aerogel (16 lbs/ft³)

Materials of high bulk density are generally selected for use in high temperature applications; whereas materials of low bulk density should be selected for use in low temperature applications.

Intermediate Temperature Thermal Insulation (60 to 600°F)

The intermediate temperature application range is as follows:

1. 60°F through 211°F -- Hot water and steam condensate.
2. 212°F through 600°F -- Steam, high temperature hot water.

Materials used at intermediate temperatures (with typical densities)

- Mineral Fiber Slabs (typically 3 lbs/ft³; 6 lbs/ft³ up to 750°F and 7 lbs/ft³ above 750°F)
- Mineral Fiber Spray loose fill (4 lbs/ft³)
- Calcium Silicate (12 to 14 lbs/ft³)
- Magnesite (12 lbs/ft³)
- Foamed Glass (9 lbs/ft³)
- Alumino Silicate Fibers (6 lbs/ft³)
- Silica Fibers (6 lbs/ft³)
- Opacified Silica Aerogel (16 lbs/ft³)

Low Temperature Thermal Insulation (up to 60°F)

The low temperature insulation application range is as follows:

1. 60°F through 32°F -- Cold or chilled water
2. 31°F through -39°F -- Refrigeration or glycol
3. -40°F through -100°F -- Refrigeration or brine
4. -101°F through -450°F -- cryogenic.

Materials used for cold insulation (with typical densities)

- Expanded polystyrene (2 lbs/ft³)
- Polyurethane (2 lbs/ft³)
- Isocyanurate (3 lbs/ft³)
- Expanded Polyvinyl chloride (PVC) (5 lbs/ft³)
- Phenolic Foam (2.5 lbs/ft³)
- Cork (7 to 12 lbs/ft³)
- Mineral fibers
- Cellular glass
- Foamed Glass (9 lbs/ft³)
- Expanded perlite (3 lbs/ft³)

HVAC, Refrigeration & Lo-Lo Temperature Systems

Condensation and process control are the two main reasons for insulating low temperature surfaces. When equipment or piping operate at temperatures below the ambient air temperature, moisture in the air will condense or freeze on the cold surface or within or on the insulation.

The moisture vapor in the air outside of the insulation on a cold system is at a higher pressure than the moisture vapor inside the insulation. Following the rules from physics that all forces seek equilibrium, the higher-pressure moisture laden air from outside wants to flow through or around the insulation to reach the lower vapor pressure against the cold surface. Cold systems require special attention because one must design for protection against condensation and consider the affect of moisture vapor transmission.

Water vapor transmission (WVTR) is the rate of water vapor diffusion through a material. The **lower** the WVTR, the better will be the vapor retarder.

COMMON INSULATING MATERIALS

The following is the characteristics and properties of major insulation materials used in commercial and industrial installations.

Calcium Silicate

Calcium silicate is a granular insulation made of lime and silica, reinforced with organic and inorganic fibers, and molded into rigid forms. Service temperature range covered is 100°F to 1,200°F. It is light weight but has good flexural strength. Calcium silicate is water absorbent; however, it can be dried out without deterioration. The material is non-combustible and used primarily on hot piping, furnace walls, back-up refractory, flue lining and surfaces. Jacketing is field applied.

Fiberglass

Fiberglass is formed by bonding long glass fibers with a thermo setting resin to form blankets and batts, semi rigid boards, high density rigid boards and preformed pipe sections. It is available in two types:

- Fibrous: This type is available as flexible blanket, rigid board, pipe insulation and other premolded shapes. Service temperature range is -40°F to 100°F. Fibrous glass is neutral; however, the binder may have a pH factor. The product is non-combustible and has good sound absorption qualities.

- **Cellular:** This type is available in board and block form capable of being fabricated into pipe insulation and various shapes. Service temperature range is -450°F to 900°F. It has good structural strength but poor impact resistance. The material is non-combustible, non-absorptive, and resistant to many chemicals. It is mainly used to insulate industrial ovens, heat exchangers, driers, boilers and pipe work.

Mineral Fiber (Rock and Slag Wool)

Rock and/or slag fibers are bonded together with a heat-resistant binder to produce mineral fiber or wool available in loose blanket, board, pipe insulation, and molded shapes. Upper temperature limits can reach 1,900°F. The material has a practically neutral pH, is non-combustible, and has good sound-control qualities. Mineral fiber has a wide density range and is available in matts, blankets and loose form or preformed for pipe insulation. It is chemically inert, non-corrosive, non-combustible and maintains mechanical strength during handling.

Expanded Silica (Perlite)

Perlite is made from an inert siliceous volcanic rock combined with water. The rock is expanded by heating; thereby, causing the water to vaporize and the rock volume to expand. The distinguishing feature which sets perlite apart from other volcanic glasses is that when heated to a suitable point in its softening range, it expands four to twenty times its original volume. This creates a cellular structure of minute air cells surrounded by vitrified product. Added binders resist moisture penetration, and inorganic fibers reinforce the structure. The material has low shrinkage and high resistance to substrate corrosion. Perlite is non-combustible and operates in the intermediate and high temperature ranges up to 1200°F.

Expanded perlite can be manufactured to weigh from 2 lb/ft³ to 15 lb/ft³ making it especially suitable in the manufacture of lightweight perlite concrete, insulating board, insulating plasters, cryogenic insulation, masonry wall insulation and as underfloor insulation.

Expanded Polystyrene

Expanded polystyrene (EPS) is a rigid and tough, closed-cell foam, usually white and made of pre-expanded polystyrene beads. It is rigid, lightweight, low cost and high dimensional stability. Familiar uses include molded sheets for building insulation, cool rooms and packing material. It is suitable for low/medium temperature ranges. ASTM C 578 lists its temperature range from -65 to +165°F.

Expanded polystyrene (EPS) has some disadvantages: It is combustible, has a low melting point, is UV degradable and is susceptible to attacks by solvents. In addition, it 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.

Polyurethane (PUR)

Polyurethane (PUR) is made by reacting isocyanates and alcohols. It is made in continuous slab or foamed in-situ. 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. Suitable for temperature ranges of -300°F to $+230^{\circ}\text{F}$

Polyurethane is mainly used in cool rooms, refrigerated transports, deep freezing cabinets, refrigeration piping and floor and foundation insulation.

Disadvantage: It is combustible and produces toxic vapors.

Elastomeric

Foamed resins combined with elastomers produce a flexible cellular material. It is available in preformed shapes and sheets. Elastomeric insulations possess good cutting characteristics and low water and vapor permeability. The upper temperature limit is 220°F . Elastomeric insulation is cost efficient for low-temperature applications with no jacketing necessary. Resiliency is high. Consideration should be made for fire retardancy.

Foamed Plastic

Insulation produced from foaming plastic resins creates predominately closed-cellular rigid materials. K-values decline after initial use as the gas trapped within the cellular structure is eventually replaced by air. Manufacturers' data should be checked for details. Foamed plastics are lightweight with excellent moisture resistance and cutting characteristics. The chemical content varies with each manufacturer. It is available in preformed shapes and boards and are generally used in the low and lower intermediate service temperature range -297°F to 300°F . This product is combustible and consideration should be made for fire retardancy of the material.

Refractory Fiber

Refractory fiber insulations are mineral or ceramic fibers, including alumina and silica, and bound with extremely high-temperature binders. The material is manufactured in blanket or rigid form. Its thermal shock resistance is high, its temperature limits reach 3,000°F, and it is non-combustible.

Ceramic Fiber

Ceramic fiber is made from highly purity alumina and silica grains melted in an electric furnace and blasted by high velocity gases into light fluffy fibers. It is suitable for very high temperatures approaching 2800°F. Mainly used to insulate furnace and kiln back-up refractory, fire boxes, glass feeder bowls, furnace repair, induction coil insulation, high temperature gaskets and wrapping material. The material is non-combustible.

Insulating Cement

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.

PHYSICAL FORMS

Thermal insulation is required for a wide range of services and can be provided in various physical forms as described below:

Insulation Forms	Materials
<p>Preformed: Fabricated in such a manner that at least one surface conforms to the shape of the surface being insulated.</p>	<p><u>Board:</u> Calcium silicate, Fiberglass, Mineral wool or mineral fiber, Polyisocyanurates and Polystyrene</p>
	<p><u>Block:</u> Calcium silicate, Cellular glass, Mineral wool or mineral fiber and Perlite</p>
	<p><u>Sheet:</u> Fiber glass, Mineral wool, Electrometric foam and Polyurethane</p>
	<p><u>Pipe & Fittings:</u> Calcium silicate, Cellular glass, Elastomeric foam, Fiber glass,</p>

Insulation Forms	Materials
	Mineral wool or mineral fiber, Perlite, Phenolic foam, Polyethylene, Polyisocyanurates and Polyurethanes
<p>Plastic Composition:</p> <p>Plastic insulation is categorized as a loose dry form which is prepared by mixing with water.</p>	Magnesia, calcium silicate, diatomaceous earth
<p>Loose Fill:</p> <p>Granular insulation can be supplied for packing, injecting, or pouring into irregular shaped voids. A typical application for this form of insulation is cavity wall insulation and for pouring expansion joints.</p>	Mineral wool or mineral fiber, Perlite and Vermiculite
<p>Flexible:</p> <p>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.</p>	Low density mineral wool, Fiber glass, Mineral wool or mineral fiber and Refractory ceramic fiber
<p>Foam:</p> <p>Liquid mixed at the time of application which expands and hardens to insulate irregular areas and voids.</p>	Polyisocyanurates and Polyurethane
<p>Textile:</p> <p>Insulation in the form of rope, cloth etc</p>	Asbestos, ceramic fiber ropes and fabrics
<p>Mattress:</p> <p>Flexible insulation faced or totally enclosed with fabric, wire netting,</p>	Wire netted mineral wool mattress, Asbestos and Glass wool mattresses.

Insulation Forms	Materials
expanded metals etc.	
<p>Reflective:</p> <p>Insulation comprising numerous layers or random packing of low emissivity foils.</p>	Aluminum foil, stainless steel foil etc.
<p>Spray applied:</p> <p>Insulation applied by machine in the form of spray. Insulation is mixed dry in the factory with inorganic fillers and binders and 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.</p>	Sprayed mineral fiber or vermiculate

PROTECTIVE COVERING AND FINISHES

Insulation over piping, equipment and vessels is generally always surface covered for mechanical protection and:

- 1) To prevent the entry of water, ice, snow or atmospheric residue into the insulation;
- 2) To prevent dispersal of insulation material to environment;
- 3) To improve the thermal characteristics of the insulation (shiny aluminum sheets have low emissivity values);
- 4) To resist electrolytic corrosion and the ingress of water vapor.
- 5) To improve the appearance of the insulated installation

Choices of jacketing and finish materials are based upon the mechanical, chemical, thermal and moisture conditions of the installation, as well as cost and appearance requirements. Typical covering materials include:

- 1) Aluminum foil - with bright polished outer surface.

- 2) PVC - Providing attractive facings to tiles and reducing moisture absorption.

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, whereas standard PVC will warp and disfigure at 140°F.

- 3) Glass fiber cloth - Used for decorative purposes, providing mechanical strength and fire resistance. Fire proof cloth or spray prevents the fire or spread of fire.
- 4) Wire netting is often used for wool type insulation providing enhanced mechanical strength and durability.

Vapor retarders are designed to retard (slow down) the passage of moisture vapor from one side of its surface to the other. To qualify as a vapor barrier, either permeance rating of insulation must be below 0.1 or an additional vapor coating should be considered. Joints and overlaps must be sealed with a vapor tight adhesive or sealer free of pin holes or cracks.

Fire resistance can be applied to insulation systems by the use of jacketing and/or mastics. Fire resistant materials are determined by flame spread and smoke generated.

Insulation Finishes & Emissivity as a Design Factor

With insulation systems, the “emissivity” of the jacketing is a significant property especially when the surface temperature of the insulation must be regulated.

The emissivity (E) of a surface material is measured on a scale 0 to 1, 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 the real world, both of these limits are impractical to attain, and measurements fall between these two extremes.

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

Radiation Emittance Table		
Weather Barrier or Surface Finish	Conditions	Emissivity
Aluminum Jacketing	Polishing	0.03 to 0.10
	Grey-Dull	0.10 to 0.40
	Oxidized	0.10 to 0.60
Aluminum Paint	New	0.20 to 0.30
	After Weathering	0.40 to 0.70
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	0.06 to 0.10
	Dull	0.20 to 0.60
Paints	White-clean	0.55 to 0.70
	Green-clean	0.65 to 0.80
	Gray-clean	0.80 to 0.90
	Black-clean	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	0.60 to 0.79
	Green-clean	0.70 to 0.80
	Gray-clean	0.85 to 0.90
	Black	0.85 to 0.95
Roofing Felts		0.90 to 0.95
Stainless Steel Jacketing	Polished	0.22 to 0.26
	No. 4 mill finish	0.35 to 0.40
	Oxidized	0.80 to 0.85

Depending on the specific temperature requirement of the process, the amount of heat transferred can be controlled by both insulation thickness and the emissivity of the jacketing.

The 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 $h \text{ ft}^2 \text{ }^\circ\text{F} / \text{Btu}$				
$T_{\text{SURFACE}} - T_{\text{AMBIENT}}$		Plain Fabric Dull Metal	Stainless Steel	Aluminum
$^\circ\text{F}$	$^\circ\text{C}$	$E = 0.95$	$E = 0.4$	$E = 0.2$
10	5	0.53	0.81	0.90
25	14	0.52	0.79	0.88
50	28	0.50	0.76	0.86
75	42	0.48	0.75	0.84
100	55	0.46	0.72	0.80

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 – 4: INSULATION APPLICATION ON PIPING & EQUIPMENT

The temperature in pipelines and thermal process equipment must be maintained within acceptable limits, heat losses must be minimized, and the whole process should be reliable, durable and safe. 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 and tables that provide recommended thicknesses of insulation based on 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.

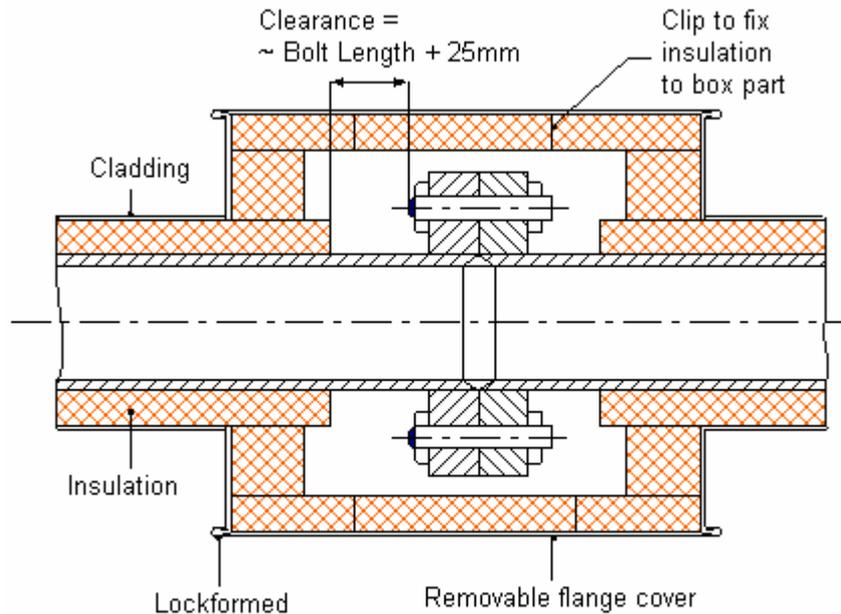
Insulating Flanges and Valves

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 un-lagged while insulating the piping systems. Un-lagged flanges are a source of considerable heat loss. As a rule of thumb, the heat loss from an uninsulated flange would have a heat loss of about 0.5 m of same size un-insulated pipe, and an uninsulated valve could have more than twice this.

Some insulating contractors recommend that flanges should not be lagged on the grounds such 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 and 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 6 mm pipe at the bottom of the box to give an early warning of leak. The lagging of flanges is one of the best ways of stopping leaks too.

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:



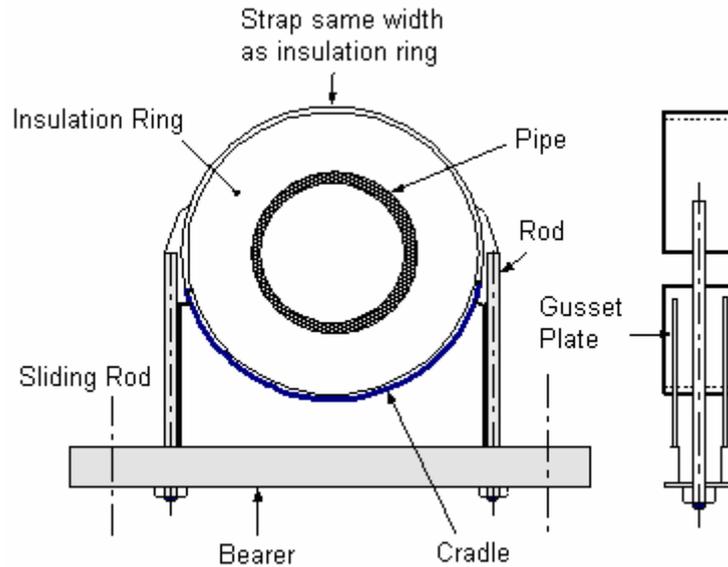
Typical Method of Insulating Pipe Flanges

Another inexpensive alternative is wrapping the valve in fiber cladding which should have an exterior vapor lock. The correct amount of cladding to use can be easily determined by simply measuring the surface temperature of the insulation when in service. Sufficient cladding should be applied 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 that they are positioned 15 mm 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

To give a glimpse of energy loss due to poor or inadequate insulation, Tables 1, 2 and 3 below provide data of heat losses through uninsulated bare pipes and 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.

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 are assumed. One year operation is considered at 8320 hours of operation. Thermal conductivity for carbon steel is considered at 326 Btuin/ft² hr °F at 200°F and 267 Btuin/ft² hr °F at 800°F.

Table 2: All parameters are the same as Table 1 except wind velocity is zero.

Table 3: All parameters are the same as Table 1 except wind velocity is 0 and surface emittance is 0.9

Table 1 indicates the equivalent loss in dollar terms and Table 2 indicates the possible dollar savings if the pipes were insulated. The tables shown are 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
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

Nom. Pipe Diameter (inches)	Process Temperature (°F)					
	200	400	600	800	1000	1200
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
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

Nom. Pipe Diameter (inches)	Process Temperature (°F)					
	200	400	600	800	1000	1200
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) The higher the surface emittance, the higher will be the heat losses and the lower will be the surface temperatures.

Insulating Carbon Steel Pipes

With regards to 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 from external sources enter an insulated system through breaks in the vapor retarder system or breaks in the insulation itself.

Insulation on Cold Pipes

We have already referred to the problems of pipes carrying liquid in low ambient conditions and low flow rates. Wet insulation has **higher** thermal conductivity and lower insulation values. Also, 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 early due to corrosion.

Insulation thickness must be sufficient to keep the outside surface of the insulation above the dew point of the surrounding air. In addition to the required thickness of insulation, a vapor tight membrane must be properly applied to the insulation. As a general rule, the insulation thickness for condensation control is much greater than the thickness required for conservation of energy.

All insulation 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.

The table below lists protective coating systems generally used on the cold pipes. The end user should check the details on alternatives/coatings with a metallurgist or obtain an expert opinion from 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	0.05 to 0.075 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 Stainless Steel Pipes/Surfaces

Insulated austenitic stainless steel surfaces operating at temperatures above 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.

Insulation on Pipes carrying Viscous Fluid

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.

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 0.05 mm 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.

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 supports for horizontal straight runs of standard and heavier pipe at maximum operating temperatures of 750°F is indicated 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, then compared to the compressive strength of the insulation.

Suggested Pipe Support Spacing (FT) for Straight Horizontal Runs

Pipe O.D. (in)	Standard Steel Pipe /water	Standard Steel Pipe /steam	Copper Tube /water
1/2	7	8	5
3/4	7	9	5

Pipe O.D. (in)	Standard Steel Pipe /water	Standard Steel Pipe /steam	Copper Tube /water
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

Nominal Pipe Size (in)	Shield Length (in)	Shield Thickness (gage/in)
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).

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 to prevent the insulation from rupturing or buckling when the hot surface expands or contracts.

In all cases where support rings are provided on vertical pipes for rigid insulation materials, the insulation shall be stopped short about 5 mm from each ring and the space between the insulation and the ring should be filled 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 below 450°F **does 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 from 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

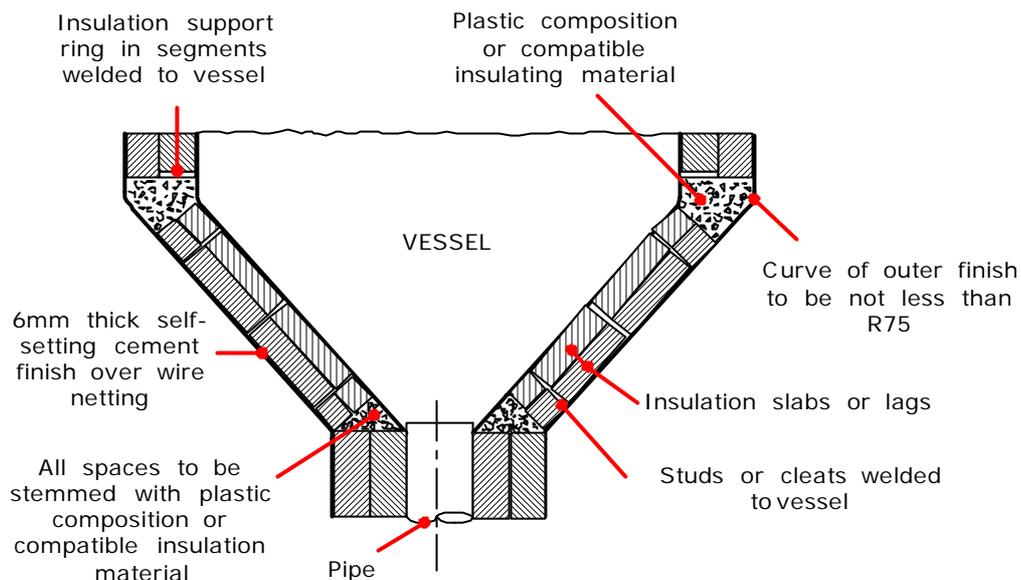
other item that punctures should not be used because they will compromise the integrity of the vapor retarder.

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

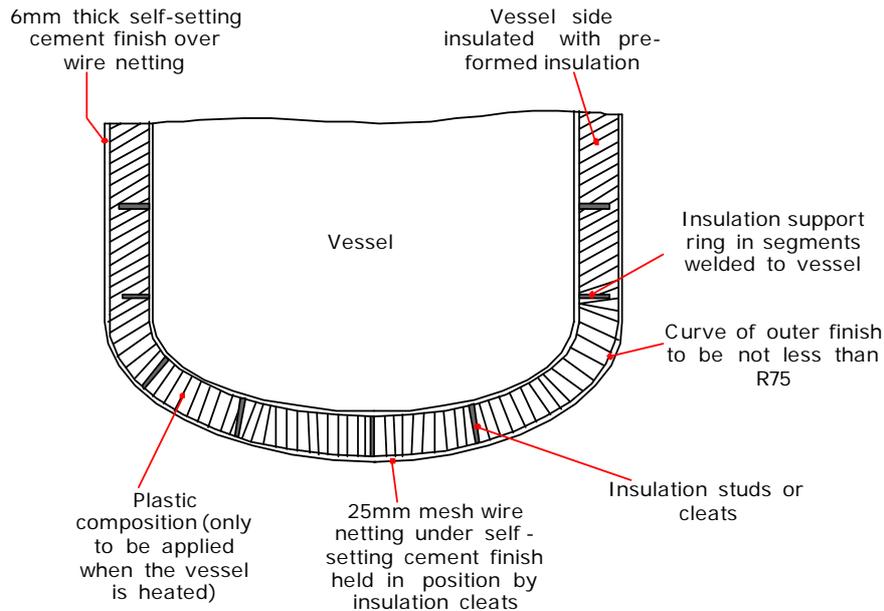
Vessels

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 the 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 below:



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 300 mm 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.

The 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 a maximum of 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 water proof.

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 fundamentally serve two purposes: One purpose will be to insulate the hot working medium which will normally be water or steam from 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 an older boiler plant, this insulation may get damaged 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 of 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 view 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. However, there is a 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 the 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, and supported on studs and reinforcing mesh. However, 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 600°F through 1500°F (315°C through 815°C). 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: 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 through heat stored in the mass of the furnace (and dissipated each time the furnace is cooled) may be much greater.

The problem thus varies with different configurations of the 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, the problem is to reduce the heat storage loss while 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.

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 insulated, 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.

While 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 a high temperature furnace is undertaken.

SPECIAL CONSIDERATIONS

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.

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.

Surface preparation

Surfaces to be insulated should be free from 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.

Method 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.

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.

Refer to Part -6: "Recommended Best Practices".

PART – 5: ECONOMIC THICKNESS OF INSULATION

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 this example:

A 100 m (330 ft) length of bare 50 mm (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 around 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!

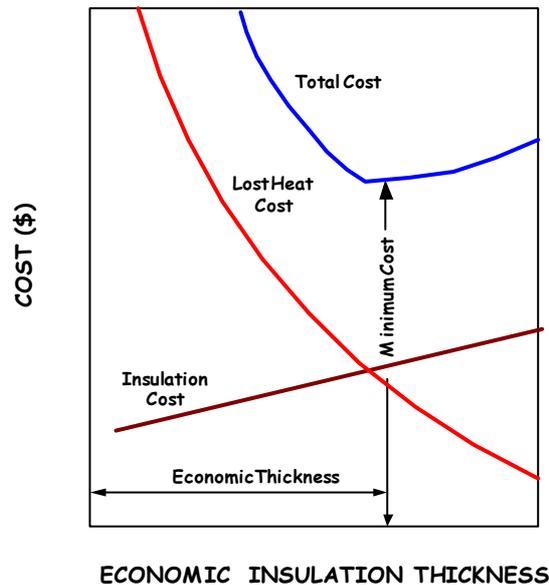
Not really. While computing the economic thickness, it is not enough to look only at the heat loss and decide on certain thicknesses. There are economic concerns such as the increased capital expenditure on account of higher thickness of insulation may not provide savings proportionate to the investment. 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. They are a useful starting point but 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 and 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:



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. Where the reciprocal of the amount of insulation used, for instance, 1, 1/2, 1/3, 1/4, etc; the first insulation is the 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 ΔT 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. The 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 thicknesses are 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 details.

PART – 6: 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 to either restricted space or lack of necessary supports.

The application of the insulation is as important as the thermal properties of the insulation. The 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, as well as most of those above 50°C (~120°F). This principle applies not only to pipes but to their associated valves, flanges and fittings such as pipe supports. It should be noted however that insulation will 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 to use 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 the vicinity of personnel space.
- 5) For cold service, limit the outside surface temperature 3°F 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 and 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 onsite 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 regards 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 worth while.
- 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 attacks.
- 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. Therefore the thickness of insulation can mean larger ducts and supports which will 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, manways 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) Fire proofing is sometimes 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 weather proofing 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) Mastics should be applied on the vessel side walls 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) Laminated vapor barrier jackets should be applied on pipeline insulation and protect with a cladding or weather barrier jacket; such as PVC for indoor locations 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 Section VII- "Method of application of insulation" above.

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

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. The 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.

The above 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.

Course Summary

Insulation reduces the rate of heat flow between objects and the surroundings at different temperatures. Insulation can be used to regulate process temperatures, protect workers from serious injury, and save thousands of dollars in energy costs.

The most important characteristics of an insulation material is low thermal conductivity, low tendency toward absorbing water, and of course the material should not be expensive. The type of insulation selected should be able to withstand whatever conditions it will experience without degradation. In process industry, the most common insulators are various types of calcium silicate or fiberglass. Calcium silicate is generally more appropriate for temperatures above 437°F, while fiberglass is generally used at temperatures below 437°F.

Insulation is used to perform one or more of the following functions:

- Reduce heat loss or heat gain to achieve energy conservation.
- Protect the environment through the reduction of CO₂, NO_x and greenhouse gases.
- Control surface temperatures for personnel and equipment protection
- Control the temperature of commercial and industrial processes.
- Prevent or reduce condensation on surfaces.
- Increase operating efficiency of heating/ventilation/cooling, plumbing, steam, process and power systems.
- Prevent or reduce damage to equipment from exposure to fire or corrosive atmospheres.
- Reduce noise from mechanical systems.

There are many factors to consider when thinking about insulation. The insulation itself should be a low thermal conductivity material with low water vapor permeability and it should be non-wicking. Insulation finishes with low emissivity materials such as polished Aluminum shall reduce heat losses through radiation.

Insulation materials and the cladding shall be installed in such a way that water does not enter the insulation material or between the insulation and the pipe / equipment surface during design life. Surfaces to be insulated shall be clean and dry. The application of the insulation shall not be started before the mechanical completion certificate for coating has been issued.

Annexure -1

Thermal Insulation Calculator References

The spreadsheet available at www.wbdg.org/design/midg_design_ece.php illustrates the relationships between energy, economics, and emissions for insulated systems. It estimates the heat flows through vertical flat surfaces and for horizontal pipe applications.

Inputs Required:

- Surface area in square feet for equipment or length of piping and pipe size
- Operating temperature in °F
- Ambient temperature in °F
- Wind speed in mph (guidance provided with calculator)
- Insulation type (calculators provide for a selection of five major types)
- Insulation installed cost (calculators provide typical values)
- Emittance of surface (guidance provided with calculator)
- Expected useful life of the insulation system in years
- Operating hours per year
- Efficiency of fuel conversion as a percentage (guidance provided with calculator)
- Fuel type and cost (calculators provide for a selection of five major types and typical cost for each).

Outputs: Based on input, calculators will provide the following by thickness, in inches, of insulation:

- Surface temperature in °F
 - Heat loss in Btu/hr
 - Cost of fuel in dollars per year
 - Installed insulation cost (estimated)
 - Payback in months
 - Annual return as a percentage (Simple IRR)
 - CO₂ emissions in Metric Tons/year.
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Financial Calculator

The spreadsheet calculator www.wbdg.org/design/midg_design_mifc.php provides an estimate of the financial returns related to investments in mechanical insulation: Simple Payback in years, Internal Rate of Return (IRR or ROI), Net Present Value (NPV), and annual and cumulative Cash Flow. It can be used for an overall mechanical insulation project or for a small mechanical insulation investment such as insulating a valve or replacing a section of insulation.

Inputs: Users will need to input:

- Initial cost of the investment in dollars
- First year energy savings in dollars per year
- Energy cost escalation rate as a percent per year
- Estimated economic life in years
- Discount rate as a percentage.

Outputs: Based on input, the calculator will provide:

- Simple payback period in years
- Internal rate of return (IRR or ROI) as a percentage
- Net Present Value (NPV) in dollars
- Annual and cumulative cash flows.

Time to Freezing for Fluid in an Insulated Pipe

The spreadsheet www.wbdg.org/design/midg_design_tffc.php estimates the time for a long, fluid-filled pipe (no flow) to reach the freezing temperature.

It is important to recognize that insulation retards heat flow; it does not stop it completely. If the surrounding air temperature remains low enough for an extended period, insulation cannot prevent freezing of still water or of water flowing at a rate insufficient for the available heat content to offset heat loss. Well-insulated pipes, however, may greatly extend the time to freezing.

Inputs Required:

- Initial temperature of fluid in °F
- Freezing temperature of fluid in °F
- Ambient temperature in °F
- Density of fluid, pcf (guidance provided)
- Specific heat of fluid in Btu/(lbm·°F) (guidance provided)
- Inside diameter of pipe and insulation in inches (guidance provided)
- Outside diameter of insulation in inches (guidance provided)
- Thermal conductivity (k) of insulation (guidance provided).

Outputs: Based on input, the calculator will provide the estimated time to freeze point in hours.

Temperature Drop

The spreadsheet www.wbdg.org/design/midg_design_tdc.php estimates the temperature drop (or rise) of a fluid flowing in a duct or pipe.

An example is the use of insulation to minimize temperature change (either temperature drop or rise) of a process fluid from one location to another (e.g., a hot fluid flowing down a pipe or duct).

Inputs Required:

- Entering fluid temperature in °F
- Ambient temperature in °F
- Flow rate of fluid in lbm/h
- Specific heat of fluid in Btu/lbm·°F (guidance provided)
- Length of pipe or duct run in feet
- Outside perimeter of pipe or duct, including insulation, in feet
- Overall heat transfer coefficient in Btu/h·ft²·°F.

Outputs:

- Temperature drop
- Leaving fluid temperature.

Simple Heat Flow Calculator

The spreadsheet www.wbdg.org/design/midg_data_shfc.php estimates the heat flow through insulation for flat or cylindrical systems given the temperatures on each side and the effective conductivity of the insulation material.

Inputs Required:

- Temperature of hot and cold surface in °F
- Conductivity of material, Btu-in./(hr·ft²·°F)
- Area for flat geometry in square feet
- Thickness for flat geometry in inches
- Area for cylindrical geometry (outer surface) in square feet
- Inner and outer radius for cylindrical geometry in inches.

Outputs: The heat flow in Btu/hr.

Controlling Surface Temperature with Insulation Calculator

The spreadsheet www.wbdg.org/design/midg_data_stc.php estimates the thickness of insulation required to obtain a specified surface temperature given the boundary temperatures, the conductivity of the insulation material, and the surface coefficient.

Inputs Required:

- Operating temperature in °F
- Ambient temperature in °F
- Surface temperature in °F
- Effective conductivity of insulation, Btu-in./(hr·ft²·°F)
- Surface coefficient in Btu/ (hr·ft²·°F).

Outputs: Optimum thickness of insulation in inches.

Life Cycle Cost Analysis

The Department of Energy (DOE) website provides free software tools to run the analysis at www1.eere.energy.gov/femp/program/lifecycle.html. The same website lists a 2-hour online class on life-cycle cost analysis and a 2-day class on using the Building Life-Cycle Cost (BLCC) Programs.

A number of other design methods are available for selecting the most economical insulation. For example, 3E Plus Insulation Thickness software, developed jointly by DOE's Office of Industrial Technologies (OIT) and the North American Insulation Manufacturer's Association (NAIMA), can be used to calculate and select the insulation thickness for a variety of conditions.

Annexure -2

Codes & References

The most common insulation specifications can be referred to 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-84 Test 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 the 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.
