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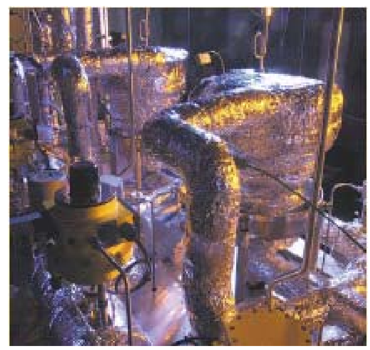
Tell us how you select insulation material and on what basis a decision is made concerning material selection and costs.

INSULATION:



Insulation is used in manufacturing processes and in buildings to prevent heat loss or heat gain. Although its primary purpose is an economic one, it also provides more accurate control of process temperatures and protection of personnel. It prevents condensation on cold surfaces and the resulting corrosion.

The most significant analysis of insulation involves determination of economical thickness. As in most engineering decisions, it is a trade-off between the insulation cost and the value of energy saved. The first step should be to eliminate all bare surfaces hot or cold by providing the optimum amount of insulation.

Insulation is the energy stabilizer - it keeps the wanted energy in and the unwanted energy out. It protects, controls and saves.

If the exposed surface is too hot to touch - it is wasting energy.

Selection of insulation material and a decision is made concerning material selection and costs depends on:

HEAT TRANSFER FUNDAMENTALS

Heat Transfer Methods

A hot object can lose heat in three ways:
* ***Radiation*** to the surroundings,
* ***Convection*** to the fluid surrounding it, and
* ***Conduction*** to other bodies that are in contact with it.

Radiation

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 form of heat, which can be received by other solid body in the path of the heat radiation. The earth receives all its energy from the sun by radiation. Radiation energy transfer plays an important role in high temperature applications such as metal melting and processing, kilns, ceramics curing and solar heating.

Convection

Convection is the process of energy transfer, which combines the action of heat conduction, energy storage and mixing motion. Convection is the most important mechanism of energy transfer between a solid surface and a liquid or gas. Typical examples include hot water boiler or hot air furnace operations.

Conduction

In conduction heat flow, energy is transmitted from a higher temperature region to lower temperature region by direct molecular contact without appreciable displacement of molecules. The observable effect of heat conduction is an equalization of temperature of two bodies in contact. However if the differences in temperatures are maintained by addition or removal of heat at different points a continuous flow of heat will be established.

Bare Surface Heat Loss

The heat loss from the bare surface of piping and equipment depends upon the temperature difference between the surface and the ambient air, and the total area of the surface. Heat loss from bare steel pipe and from bare flat surfaces can be estimated

Flat Surface Insulation

The purpose of any insulating material is to retard heat flow. To calculate the flow of heat through conducting or insulating material the following equation can be used:

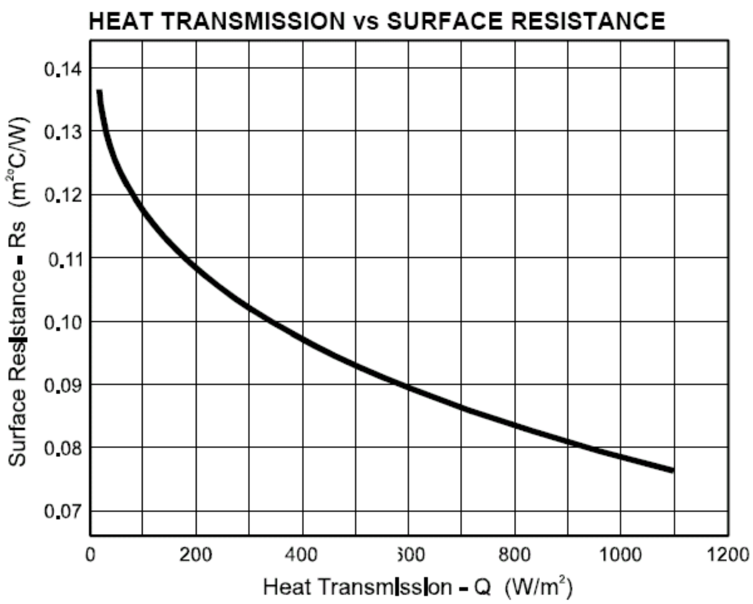
$$Q = \frac{\Delta T \times A}{(R + R_s)}$$

Where:
Q *= heat flow (Wh/h or W)*
ΔT *= Temperature difference across the medium (EC)*
A *= surface area (m) 2*
R_s *= Surface resistance (m EC/W)*
R *= thermal resistance (m EC/W)=* $\frac{t}{k}$ *where t = material thickness (m)*

Thermal resistance "R" is defined as the opposition to the passage of heat through the medium or in this case, through the insulating material.

Thermal conductivity "k", on the other hand, is used to express the quantity of heat, which will flow across a unit area with the temperature difference of 1EC. (Units are W/mEC)

Surface Resistance R_s is the opposition to heat flow through the boundary layer between the insulation and the ambient air. The level of resistance provided by this surface film depends on the amount of heat flow through the layer. The R value can be determined from **Figure: 1**



Pipe Insulation

The heat flow through pipe insulation is similar in concept to flat surface loss, but somewhat different since the inner and outer surfaces of the insulation have different areas. This difference in the area must be taken into account in heat loss calculations. As the heat from the pipe flows outward through the insulation, the path of the heat flow becomes greater. This phenomenon has the effect of increasing the value of the thermal resistance. To compensate for this effect, an "equivalent thickness" of insulation must be used. The equation for the thermal resistance for piping insulation can be written as follows:

$$R = \frac{Equivalent\ Thickness}{Conductivity} = \frac{r_2 \ln \frac{r_2}{r_1}}{k} \quad (m^2\,{}^oC/W)$$

where:

r_2 = outside radius of insulation (m)

r_1 = inside radius of insulation (m)

ln = natural logarithm

INSULATION SYSTEMS

When contemplating the insulation of equipment, mechanical systems or buildings, it is helpful to think of an insulation system as having the following three components:
* Insulating material
* Protective covering or finish
* Accessories to secure, fasten, support and seal the insulation.

These components must be compatible for the insulation to function properly.

Insulating Materials:

Types and Forms of Insulation

Type indicates composition and internal structure, while ***form*** implies overall shape or application.
Types are normally subdivided into the following three groups:

* ***Fibrous insulation*** is composed of small diameter fibers, which finally divide the air space. The fibers may be parallel or perpendicular to the surface being insulated and they may be separated or bonded together. Glass, rock wool, slag wool and Alumina silica fibers are used. Glass fiber and mineral wool are the most widely used insulations of this type.

* ***Cellular insulation*** is composed of small individual cells separated from each other. The cellular material may be glass or foamed plastic such as polystyrene, polyurethane and elastomeric

* ***Granular Insulation*** is composed of small nodules, which contain voids or hollow spaces. It is not considered the true cellular material since gas can be transferred between the individual spaces. This type can be produced as a loose pourable material, or combined with a binder and fibers to make a rigid insulation.

Forms:
Insulation is produced in variety of forms suitable for specific functions and applications. The combined form and type of insulation determines the proper method of insulation. The forms most widely used are:

* ***Rigid board*** comes in blocks, sheet and preformed shapes. Cellular and granular insulations are produced in these forms.
* ***Flexible sheet,*** and preformed shapes. Cellular and fibrous insulations are produced in these forms.
* ***Flexible blankets***. Fibrous insulations are produced in flexible blankets.
* ***Cement*** (insulating and finishing). Produced from fibrous and granular insulations and cement. They may be of the hydraulic air setting or air-drying types.

Major Insulating Materials:

The following is a general inventory of the characteristics and properties of major insulating materials used in Industrial, Commercial and Institutional installations.

* ***Calcium Silicate*** is a granular insulating material made of lime and silica, reinforced with organic and inorganic fibers and molded into rigid forms. The temperature range covered is from 38 to 982 Deg.C. Flexural strength is good. Calcium Silicate is water absorbent. However, it can be dried out without deterioration. The material is noncombustible and used primarily on hot piping and surfaces. Jacketing is generally field applied.
* ***Cellular Elastomeric*** insulation is composed principally of natural and synthetic elastomers, or both, processed to form flexible, semi-rigid or rigid foam with predominantly closed cell structure. Upper temperature limit is 104 Deg.C.
* ***Cellular glass*** is fabricated into boards, pipe covering and other shapes. The service temperatures range from -40 to 482 Deg.C. This material has a low thermal conductivity at low temperatures, low abrasion resistance, good resistance to substrate corrosion, and good sound absorption characteristics.
* ***Fibrous glass*** are manufactured in variety of forms including flexible blankets, rigid and semi rigid boards and pipe covering. Service temperature range from -73 to 538 Deg.C depending on binder and structure.
* ***Foam plastic*** insulations are predominantly closed cellular rigid materials. Thermal conductivity may deteriorate with time due to aging because of the air diffusing into the cells. Foamed plastics are generally used in lower and intermediate temperature ranges.
* ***Mineral fibre and mineral wool*** is produced by bonding rock and slag fibres with heat resistant binder. The upper service temperature limit can reach 982 Deg.C. The material is noncombustible and is used in high and intermediate temperature ranges less than 200 Deg.C.
* **Refractory fibre insulations** are mineral and ceramic fibres, including alumina and silica, bound with extremely high temperature binders. They are manufactured in blanket or rigid brick form. Thermal shock resistance and temperature limits are high (up to 1000Deg.C).

Protective Coverings and Finishes:

The efficiency and service of insulation is directly dependant upon its protection from moisture entry and mechanical or chemical damage. Choices of jacketing and finish materials are based upon the mechanical, chemical, thermal and moisture conditions of the insulation, as well as cost and appearance. Protective coverings are divided into six functional types.
* ***Weather barrier*** - the basic function of the weather barrier is to prevent entry of water. If water is deposited within the insulation, its insulating properties will be significantly reduced. Applications consist of either a jacket of metal or plastic or a coating of weather barrier mastic.

* **Vapour retarders -** are designed to retard the passage of moisture vapour from the atmosphere to the surface of the insulation. Joints and overlaps must be sealed with a vapour tight adhesive or sealer. Vapour retarder are available in three forms:
Rigid jacketing reinforced plastic, aluminum or stainless steel fabricated to exact dimensions and sealed vapour tight.
Membrane jacketing metal foils, laminated foils or treated paper which are generally factory applied to the insulating material.
Mastic applications, either emulsion or solvent type, which provide a seamless coating but require time to dry.
Mechanical abuse covering - metal jacketing provides the strongest protection against mechanical damage from personnel, equipment and machinery. The compression strength of the insulation material should also be considered when assessing mechanical protection.

Low flame spread and corrosion resistant coverings - when selecting material for potential fire hazard areas, the insulation material and the jacketing must be considered as a composite unit. Most of the available types of jacketing and mastic have low flame spread rating. This information can usually be obtained from manufacturer's data. Stainless steel is the most successful in resisting the corrosive atmosphere, spills and leaks. Mastics are also generally resistant to corrosive atmospheres.
Appearance coverings and finishes - various coatings, finishing cements, fitting covers and jackets are chosen primarily for their appearance value in exposed areas. Typically for piping, jacketed insulation is covered with a reinforcing canvas and coated with mastic to give it a smooth even finish.
Hygienic coverings - coatings and jackets must present a smooth surface, which resists fungal and bacterial growth, especially in food processing areas and hospitals. High temperature steam or high-pressure water wash down conditions require jackets with high mechanical strength and temperature rating.

Accessories:

The term accessories is applied to the devices or materials serving one or more of the following functions:
Securement of the insulation or jacketing.
Insulation reinforcement for cement and mastic
Water flashing
Stiffening **-** metal lath and wire netting can be applied on high temperature surfaces before insulation is applied
Sealing and caulking
Expansion and contraction compensation **-** manufactured overlapping or slip joints; bedding compounds and flexible sealers.

TABLE-1:

BASIC TYPES OF INSULATION

Type	Form	Temp. Range	k-Factor*	Notes
Calcium Silicate	Pipe Covering Block Segments	up to 982°C	.066 at 150°C	Good mechanical abuse characteristics, non-combustible. Some are water absorbent.
Cellular Glass	Pipe Covering Block Segments	-267°C to 482°C	.077 at 150°C	Good strength, water and vapour resistant, non-combustible. Poor abrasion resistance.
Glass Fibre	Pipe Covering Board Blanket	to 455°C to 510°C	.035 at 24°C .050 at 150°C (varies, see manf. data)	Properties variable. Good handling and workability. May be water absorbent. Some are non-combustible.
Mineral Fibre	Pipe Covering Board	to 870°C	.035 at 24°C .061 at 150°C (conductivity varies with density)	Non-combustible, good workability, water absorbent.
Ceramic Fibre	Blanket or Board	to 1760°C	.30 at 93°C	Temperature range varies with manufacturer, style and type.
Cements	Hydraulic setting cement High temperature mineral wool Pointing and finishing cement (Mineral or Vermiculite)	to 650°C to 1040°C to 760°C	1.75 at 315°C .69 at 315°C .55 at 93°C	One coat application - Insulating and finishing. Slow drying, rough texture - filling and insulating. Used over basic insulation - smooth finish, usually 3.175 mm to 6.35 mm thick application.

* *k-Factor = W/(m·C)*

TABLE-2:

Form	Method of Installation	Where Applicable	Advantages
Blankets: Batts or Rolls • Fiber glass • Rock wool	Fitted between studs, joists and beams	All unfinished walls, floors and ceilings	Do-it-yourself Suited for standard stud and joist spacing, which is relatively free from obstructions

Loose-Fill (blown-in) or Spray-applied • Rock wool • Fiber glass • Cellulose • Polyurethane foam	Blown into place or spray applied by special equipment	Enclosed existing wall cavities or open new wall cavities Unfinished attic floors and hard to reach places	Commonly used insulation for retrofits (adding insulation to existing finished areas) Good for irregularly shaped areas and around obstructions
Rigid Insulation • Extruded polystyrene foam (XPS) • Expanded polystyrene foam (EPS or bead board) • Polyurethane foam • Polyisocyanurate foam	Interior applications: Must be covered with 1/2-inch gypsum board or other building-code approved material for fire safety Exterior applications: Must be covered with weather-proof facing	Basement walls Exterior walls under finishing (Some foam boards include a foil facing which will act as a vapor retarder. Please read the discussion about where to place, or not to place, a vapor retarder) Unvented low slope roofs	High insulating value for relatively little thickness Can block thermal short circuits when installed continuously over frames or joists.
Reflective Systems • Foil-faced paper • Foil-faced polyethylene bubbles • Foil-faced plastic film • Foil-faced cardboard	Foils, films, or papers: Fitted between wood-frame studs joists, and beams	Unfinished ceilings, walls, and floors	Do-it-yourself All suitable for framing at standard spacing. Bubble-form suitable if framing is irregular or if obstructions are present Effectiveness depends on spacing and heat flow direction

Example-1:
A bare 10 m flat surface has a temperature of 140 Deg.C with ambient air at 20 Deg.C. Calculate the reduction in heat flow if this surface is insulated with 50 mm thick

Insulating material (t) having thermal conductivity (k) of 0.045 W/m Deg.C.
Bare surface unit heat loss is approximately 1,900 W/m .

Insulated surface unit heat loss is: (assume R_s = 0.1 for first trial)

$$Q = \frac{\Delta T}{R + R_s} = \frac{(140 - 20)}{1.111 + 0.1} = 99.1\,W/m^2$$

whe re:

$$R = \frac{t}{k} = \frac{0.050}{0.045} = 1.111\,m^{2o}C/W$$

Revised R = 0.118 m C/W per **Figure: 1** with Q = 99.1 W/m.
Revised surface unit heat loss is:

$$Q = \frac{\Delta T}{R + R_s} = \frac{(140 - 20)}{1.111 + 0.118} = 97.6\,W/m^2$$

This result is sufficiently accurate (an additional trial could be carried out if necessary). The reduction in heat loss for the total area is:

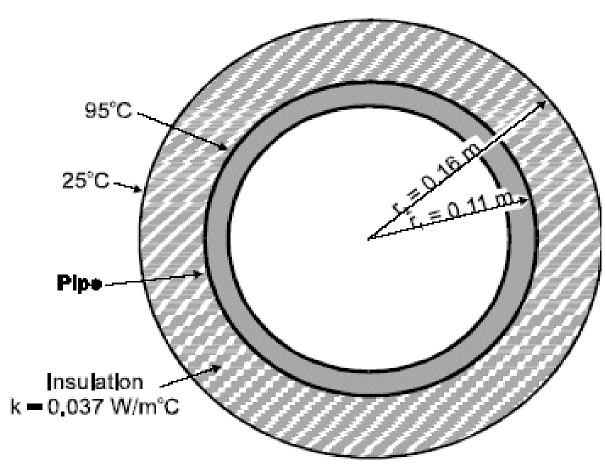
$$Q = (1{,}900 - 97.6)\ W/m^2 \times 10\ m^2 = 18{,}024\ W$$

Example-2:
Calculate the reduction in heat loss from 1 m length of 0.22 m diam pipe operating at 95 Deg.C. The insulation thickness is 50 mm with "k" value of 0.037 W/m Deg.C.
Assume an ambient air temperature of 25 Deg.C.
Bare pipe heat loss per (assuming 8 NPS pipe) is 575 W/m pipe length.

Typical Insulated Pipe

$$r_2 = \frac{0.22}{2} + 0.05 = 0.16\,m$$

$$r_1 = \frac{0.22}{2} = 0.11\,m$$



$$R = \frac{r_2 \ln\frac{r_2}{r_1}}{k} = \frac{0.16 \times \ln\left(\frac{0.16}{0.11}\right)}{0.037} = 1.62\,m^2\,^oC/W$$

Insulated surface unit heat loss is: (assume R_s = 0.1 for first trial)

$$Q = \frac{\Delta T}{R + R_s} = \frac{(95 - 25)}{1.62 + 0.1} = 40.7\,W/m^2$$

Revised R = 0.127 m C/W per Figure: 1 with Q = 40.7 W/m.

Revised surface unit heat loss is:

$$Q = \frac{\Delta T}{R + R_s} = \frac{(95 \quad 25)}{1.62 + 0.127} = 40.1\,W/m^2$$

This result is sufficiently accurate (an additional trial could be carried out if necessary).

Heat flow for 1 m insulated pipe length is based on the outside surface area (A) of insulated pipe:

$$A = 2\pi\, r_2 \times 1 \text{ m length} = 2\pi\,(0.16 \text{ m})(1 \text{ m}) = 1.01 \text{ m}^2$$

Heat flow for 1 m insulated pipe is:

$$Q = \text{unit heat loss} \times \text{area} = 40.1\ W/m^2 \times 1.01\ m^2/m = 40.3\ W/m \text{ pipe}$$

The reduction in heat loss for 1 m pipe length is:

$$Q = (575 - 40.3)\ W/m^2 \times 1\ m = 534.7\ W/m \text{ pipe length}$$

Example-3:

Insulate Bare Piping

An NPS 2 branch steam main, 20 mtr. Long, is not insulated. Steam temperature is 125 Deg.C. (Ambient temperature is 25 Deg.C, providing a 100 Deg.C temperature difference.) Estimate the potential energy and dollar savings if the main is insulated with 63 mm thick cellular glass insulation. The steam system operates 2,880 hours per year. The interpolated heat loss with 63 mm cellular glass installed would be 29 W/m. The heat loss from the same un-insulated pipe is approximately 300 W/m.

The annual reduction in heat loss due to the addition of insulation would be:
= (300 - 29) W/m x 20 m x 2880 h/y
= 15,609,600 Wh/y = 15,609.6 kWh/y = 56,194.6 MJ/y
The cost of this steam energy is estimated at Rs 0.361 /MJ
Cost Savings = 56,194.6 MJ/y x 0.361 /MJ = Rs 20,286 */y*
Estimated cost to supply and install the insulation is Rs18, 000

Simple Payback = 18000/ 20286= 0.887years=0.9years

Example-4:

Insulate Non-insulated Vessel

A tank 2m long x 1m wide x 1m deep, is not insulated, even though the tank was maintained at 175 Deg.C for 8760 hours per year. (Assume 25 Deg.C ambient temperature.)

Estimate the potential energy and cost savings if the vessel was insulated with a 100 mm thickness of mineral fibre insulation.

Vessel Surface Area = A (top) + A (sides) + A (bottom) = 10 m2

With a flat surface at 150 Deg.C temperature difference with 100 mm mineral fibre, the heat loss is 65 W/m. The bare flat surface heat loss is about 2,650 W/m . The calculated annual reduction in heat loss due to the addition of insulation is:

= (2650 - 65) W/m x 10 m2 x 8760 h/y 2
= 226,446,000 W/y = 226,446 kWh/y

On the basis that the vessel is heated with electric immersion heaters and the energy cost for electricity is Rs 3.20 /kWh, the annual potential dollar savings may be calculated.

Annual Savings = 226,446 kWh/y x Rs 3.20/kWh = Rs 7,24,627.2

The estimated cost to supply and install 100mm fibre insulation on the top, sides and bottom of the tank is ***Rs 2,17,417.86***

Simple Payback = 217417.86 / 724627.2 = 0.3 years

Conclusion

Insulation with proper Insulating material to proper application contribute main role for protection, controls and saves.

*******END*******

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