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Study of Thermal Insulating Materials And Costing of Economic Thickness of Insulation

KEYWORDS: Organic foams, 3E Plus Insulation Thickness software, volcanic rock, ETI

Sagarkumar Shah	Vinay Bhatt	Jinesh Shah
M.Tech Thermal, C/O PRATIK KIKANI, 42, Yogeshwar Society, Near Airport main gate, Rajkot-360007	M.Tech CAD/CAE, C/O PRATIK KIKANI, 42, Yogeshwar Society, Near Airport main gate, Rajkot-360007	M.Tech Thermal, C/O PRATIK KIKANI 42, Yogeshwar Society, Near Airport main gate, Rajkot-360007

Manojkumar Sheladiya	Pratik Kikani
M.Tech Thermal, C/O PRATIK KIKANI, 42, Yogeshwar Society, Near Airport main gate, Rajkot-360007	M.Tech Thermal, 42, Yogeshwar Society, Near Airport main gate, Rajkot-360007

ABSTRACT *This paper deals "How to select insulation material and on what basis a decision is made concerning material selection and costs" by giving brief write-up about Major insulation materials, criteria for material selection, economic selection, Properties, Applications, Economic thickness of insulation, Location, Design life, Economics of insulation, Case Study and Conclusion. The most important characteristics of any insulation material include a low thermal conductivity, low tendency toward absorbing water, and of course the material should be inexpensive.*

1. Introduction

Insulation - From the Latin word for island (insula). Insulation 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.

Insulation is defined as a material or combination of materials which retard the flow of heat. The materials can be adapted to any size, shape or surface. A variety of finishes are used to protect the insulation from mechanical and environmental damage, and to enhance appearance. Insulation materials fall into two broad categories: organic foams; and inorganic materials. The organic foams include polystyrene, polyurethane, phenol foam, polyethylene foam etc. The inorganic material includes mineral wool, calcium silicate, cellular glass, microporous silica, magnesia, ceramic fibre, vermiculite and Pearlite.

Many people overlook the importance of insulation in the process industry .For industrial facilities, such as power plants, refineries, and paper mills, mechanical thermal insulations are installed to control heat gain or heat loss on process piping and equipment, steam and condensate distribution systems, boilers, smoke stacks, bag houses and precipitators, and storage tanks. While placing insulation onto a pipe is fairly easy, resolving issues such as what type of insulation to use and how much is not so easy. Insulation is available in nearly any material imaginable. The most important characteristics of any insulation material include a low thermal conductivity, low tendency toward absorbing water, and of course the material should be inexpensive. In the process industry, the most common insulators are various types of calcium silicate or fiberglass. Calcium silicate is generally more appropriate for temperatures above 225° C (437° F), while fiberglass is generally used at temperatures below 225° C.

2. Major Insulation Materials

The following is a major insulation materials used in commercial and industrial installations

o 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 37.8°C to 648.9°C. Calcium silicate is water absorbent, noncombustible and used primarily on hot piping and surfaces.

o Glass

a. Fibrous: Available as flexible blanket, rigid board, pipe insulation and other premolded shapes. Service

Temperature range is -40.0°C to 37.8°C.Fibrous glass is neutral;however, the binder may have a pH factor.

It is noncombustible and has good sound absorption qualities.

b. Cellular: Available in board form capable of being fabricated into pipe insulation and various shapes. Service temperature range is -267.8°C to 482.2°C Good structural strength, poor impact resistance. It is noncombustible, non-absorptive and resistant to many chemicals.

o Mineral Fiber (Rock And Slag Wool)

Rock and/or slag fibers are bonded together with a heat resistant binder to produce mineral fiber. Upper temperature limit can reach 1037.8°C. The material has a practically neutral pH, is noncombustible, and has good sound control qualities.

o Expanded Silica, or Pearlite

Pearlite is made from an inert siliceous volcanic rock combined with water. The material has low shrinkage and high resistance to substrate corrosion. Pearlite is noncombustible and operates in the intermediate and high temperature ranges. The product is available in rigid pre-formed shapes and blocks.

o Elastomeric

Foamed resins combined with elastomers produce a flexible cellular material. Available in pre-formed shapes and sheets, elastomeric insulations possess good cutting characteristics and low water and vapor permeability. The upper temperature limit is 104.4°C. Elastomeric insulation is cost efficient for low temperature applications with no jacketing necessary.

o 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 cel-

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lular structure is eventually replaced by air. Foamed plastics are light weight with excellent moisture resistance and cutting characteristics. The chemical content varies with each manufacturer. Available in pre-formed shapes and boards, foamed plastics are generally used in the low and lower intermediate service temperature range -182.8°C to 148.9°C. Consideration should be made for fire retardancy of the material.

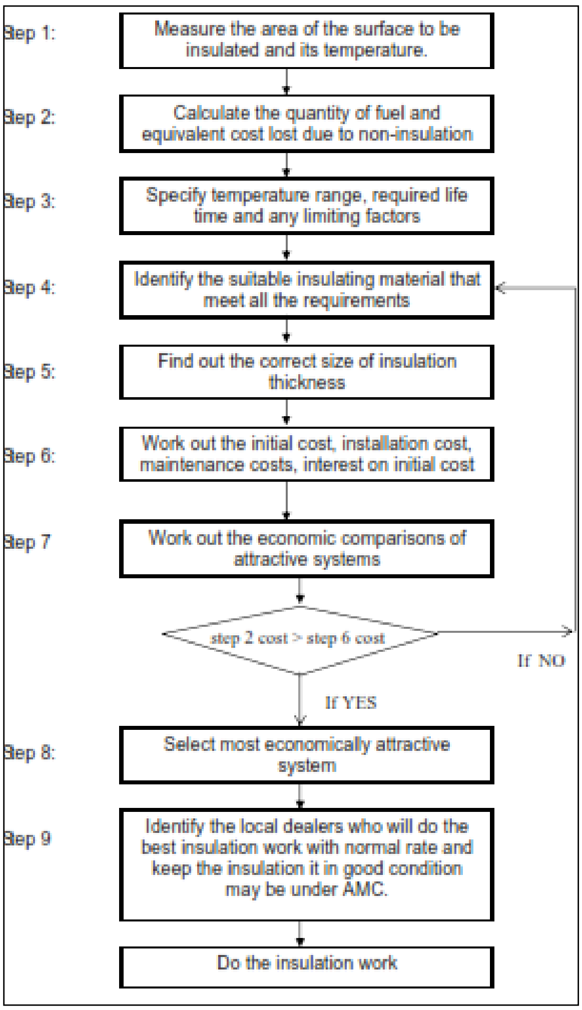
o Refractory Fiber

Refractory fiber insulations are mineral or ceramic fibers, including alumina and silica, bound with extremely high temperature binders. The material is manufactured in blanket or rigid form. Temperature limits reach 1648.9°C. The material is noncombustible.

o Insulating Cement

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.

The following figure-1 shows the steps involved for economically selecting an insulation material.



3. Functions of Insulation:

- o Increase operating efficiency of heating/ventilation/cooling, plumbing, steam, process and power systems.
- o Prevent or reduce damage to equipment from exposure to fire or corrosive atmospheres.
- o Reduce heat loss or heat gain to achieve energy conservation.
- o Protect the environment through the reduction of CO_2 , NO_x and greenhouse gases.
- o Control the temperature of commercial and industrial processes.
- o Prevent or reduce condensation on surfaces.
- o Reduce noise from mechanical systems.
- o Control surface temperatures for personnel and equipment protection.

4. Criteria for insulation material selection:

The most appropriate insulation material is to be selected based on

A. Temperature application
B. Properties of the insulation material
C. Economic Thickness of Insulation (ETI)
D. Economics of Insulation selection.
E. Design Life

A. Temperature application

- **Low Temperature Thermal Insulation**
- o . 15.6°C through 0°C (60°F through 32°F) -- i.e. Cold or chilled water.
- o -0.6°C through -39.4°C (31°F through -39°F) -- i.e. Refrigeration or glycol.
- o -40.0°C through -73.3°C (-40°F through -100°F) -- i. e. Refrigeration or brine.
- o . -73.9°C through -267.8°C (-101°F through -450°F) -- i. e. cryogenic.

- **Intermediate Temperature Thermal Insulation**
- o 16.1°C through 99.4°C (61°F through 211°F) -- i.e. Hot water and steam condensate.
- o 100.0°C through 315.6°C (212°F through 600°F) -- i.e. Steam, high temperature hot Water.

- **High Temperature Thermal Insulation**
- o 316.1°C through 815.6°C (601°F through 1500°F) -- i.e. Turbines, breechings, stacks,
- o Exhausts, incinerators, boilers.

B. Properties of the insulation material

Insulations have different properties and limitations depending upon the service, location, and required longevity of the application. These are taken into account by engineers when considering the insulation needs of an industrial or commercial application.

- o Apparent Thermal Conductivity (ka) (Btu in./h ft2 F)
- o Thermal Resistance (R) (F ft2 h/Btu)
- o Thermal Conductivity (k) (Btu in./h ft2 F)
- o Density (lb/f3) (kg/m3)
- o Surface Burning Characteristics
- o Cleanability
- o Thermal Expansion/Contraction and Dimensional Stability
- o Water Vapor Permeability
- o Compressive Resistance
- o Temperature Resistance
- o Weather Resistance
- o Abuse Resistance
- o Ambient Temperature
- o Corrosion Resistance
- o Fire Resistance/Endurance
- o Fungal Growth Resistance

C. Economic Thickness of Insulation (ETI)

- o The most basic model for insulation on a pipe is shown below. R1 and R2 show the inside and outside radius of the pipe respectively. R3 shows the radius of the insulation. Typically when dealing with insulations, engineers must be concerned with linear heat loss or heat loss per unit length

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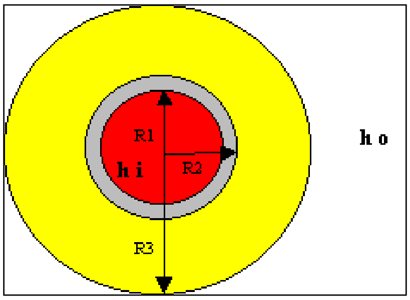


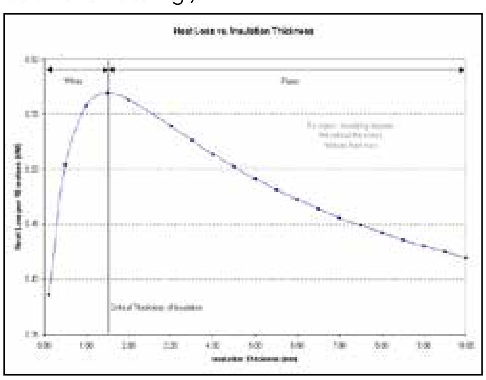
$$U = \frac{1}{\frac{R3}{R1\,hi} + \frac{R2\,LN(R2/R1)}{k_{pipe}} + \frac{R3\,LN(R3/R2)}{k_{insulation}} + \frac{1}{ho}} \quad (1)$$

Generally, the heat transfer coefficient of ambient air is 40 W/m^2 K. This coefficient can of course increase with wind velocity if the pipe is outside. A good estimate for an outdoor air coefficient in warm climates with wind speeds under 15 mph is around 50 W/ m^2 K. The total heat loss per unit length can then be calculated by:

$$\frac{Q}{L} = 2\pi R3\,U\,\Delta T$$

$$\text{where } \Delta T = T_{insidepipe} - T_{ambient} \quad (2)$$

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. Since the critical thickness is almost always a few millimeters, it is seldom (if ever) an issue for piping. Critical thickness is a concern however in insulating wires. Figure shows the heat loss vs. insulation thickness for a typical insulation. It's easy to see why wire insulation is kept to a minimum as adding insulation would increase the heat transfer. (heat loss vs. insulation thickness Fig).



D. Economics of Insulation selection.

The investment on insulation can be justified, if the cost of insulation can be recouped by a reduction in total energy cost.

- Insulation costs: The insulation cost should include material cost, maintenance cost and labor cost. All of these may vary location to location and for different type of insulation.
- Lost Heat Costs: The energy cost must include the raw fuel cost, modified by the conversion efficiency of the equipment. The cost of the heat generation plant should also be included in the analysis. The use of this factor accounts for a reduction in required plant capacity by a well insulated system.
- Other Costs: As the economic calculations become more sophisticated, other costs must be included in the analysis. The major additions are the cost of money and the tax effect of the project.

E. Design Life

The cost of an insulation material relates to its temperature capability. Hence, insulation and refractory systems are designed to include several layers of different materials that offer optimum economic performance. Selecting the most economical system requires consideration of its cost compared to potential savings from reduction of heat losses. In some cases, the most economical thickness may not meet regulatory requirements for the safety of personnel and property. In such cases, appropriate design and materials should be used. In other cases, thickness may be reduced when there is a danger of exceeding the limiting refractory or insulating temperature.

A number of tools and design methods are available for selecting the most economical or appropriate refractories or 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.

5. CASE STUDY

It has been observed in a Chemical Plant that Boiler Feed Water Tank (BFWT) in which hot condensate is being collected along with make up water is fully un-insulated. The condensate line is also not insulated. The heat loss from the surface of the hot tank and condensate line is worked out and the same can be seen below:

Heat Loss Calculation for BFWT
Average surface temperature of the bfwt,
T1 = 60°C (333K)
Ambient Temperature, T2 = 33°C (306K)

No. of sides exposed to the atmosphere = 5 (i.e., except bottom)
Total area of the tank, A
(length=2.2m; breath=2.2 m & Height = 2.1m) = (4x2.2x2.1)+(1x2.2x2.2)
= (18.48 + 4.84) m2
= 23.32 m^2

Total heat loss per m2 area
Q/A = 1.24(T1-T2)1.33 + 5.669 x ∊ {(T1/100)4-(T2/100)4)

Where
Q = rate of heat loss, W
A = surface area of the tank, m2
T1 = temperature of the surface, °K
T2 = temperature of the surroundings, °K
∊ = emissivity of the surface, 0.9

Therefore, Q/A = 280 Watts
Total heat loss, Q = 280 x 23.32
= 6530 Watts
= 6.53 kW

Annual equivalent energy loss through BFWT
= 6.53 x 24 x 350
= 54852 Kwh/Year

Equivalent heat loss = 54852 x 860
= 47172720 kcal

Equivalent Furnace Oil
= 47172720/(9650x 0.75)
= 6518 kgs
(i.e., 6518/0.92 = 7085 Ltrs)

Annual cost equivalent @ Rs.18/- per litre
= 7085 x 18
= Rs.1,27,530/-

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Heat Loss Calculation for Condensate Line

The llength and surface area of the condensate pipe is given in the following table

Un-insulated pipe size	Length (m)	Area m^2
T-86 Line		
2"	1.2	0.192
1.5"	16.5	1.97
1"	78	6.2
PGS to FWT		
1.5"	73.5	8.8

Total Un insulated area (A) = 17.16m^2

Average Surface Temperature(Ts) = 70°C
= 343 K
Ambient Temperature (Ta) = 33°C
= 306 K
Heat loss through un-insulated pipe= Radiation Loss + Convection Loss

Radiation Loss = B x E x A x (Ts4-Ta4) x 860/1000

Where,
B = Stefan Boltzmann Constant=5.67 x10-8
E = 0.9, Ts = 343°k, Ta = 306°k &
A = 17.16 m^2

Radiation Loss
= 5.67 x 10-8 x 0.9 x 17.16 x(3434-3064) x 860/1000
= 4443 Kcal/hr

Convection Loss = C x A x (Ts-Ta) 1.25 x 860/1000

Where,

C = 2.3 constant for horizontal cylinder
Convection Loss = 2.3 x 17.16 (343-306)1.25 x 860/1000
= 3097 Kcal/hr

Total heat loss through uninsulated pipe
(4443 + 3097) = 7540 kcal/hr

Equivalent quantity of Furnace Oil
=7540 / (9650 x 0.75 x 0.92)
= 1.132 ltr/hr

Annual equivalent considering 350 days plant operation in a year is
= 1.132 x 24 x350
= 9508 litres

Annual cost equivalent @ Rs.18/- per litre
= 9508 x 18
= 1, 71,144 /- Rs.

Total annual heat lost cost in BFWT and Condensate Pipe
= Rs. 127530 + Rs. 171144
= Rs. 3.0 Lakhs (rounded figure)

Having known the annual heat lost cost, now the procedure of selecting the insulation material as given below:

Temperature rang = 25°C to 100°C required life time = 5 years

Any limiting factor:
Resistant to water vapor, high compressive strength and good chemical resistance. Non combustible and not expensive.

Now, we have to work out the initial cost, installation cost, maintenance costs and interest on initial cost:

Initial and installation cost for
- o Fixing the cellular glass mattress having density of 100 Kg/m^3 25 mm thick with ¾ x 24 G wire netting on one side and fabricating.
- o Fabricating and fixing of Aluminium sheet – 24 SWG by means of S.T Screws.
- o Sealing all joint with sealing compound if the pipelines are exposed outside. is given in the following table:

Sl. No.	Particulars	Unit	Rate per unit	Amount in Rs
1	Boiler Feed Water Tank	22.32m^2	693	15468
2	Condensate pipe 2"	1.2m	349	419
3	Condensate pipe 1.5"	90mm	310	27900
4	Condensate pipe 1"	78 m	291	22698
5	Total on initial and installation cost, Rs (1+2+3+4)			66485
6	Interest on initial and installation cost @ 1%			7978
7	Annual maintenance cost			6000
Total (5+6+7) in Rs				80463

Simple payback period = (80463 / 300000) x 12
= 3.2 Months

Since, we are getting very attractive payback, no need to work out economic comparison with other insulation materials, we can select cellular glass as the insulation material.

6. Conclusion

The appropriate insulation must be selected on the basis of temperature, thermal conductivity and other limiting factors that might limit application. The appropriate thickness must be determined for the particular application. While doing the payback calculation on insulation; one has to consider the cost of capital investment, interest on investment, depreciation period and maintenance cost.

REFERENCE 1) Thermal Insulation Handbook | By: Willam C. Turner and John F. Malloy | 2) Industrial Energy Management and Utilisation By: Larry C. Witte, Philip S. Schmidt and David R. Brown | 3) Energy Management Handbook By: Wayne C. Turner | 4) TNPL AC plant's Tender Documents | 5) Tooling Corner: Using more insulation to reduce costs By: Kurt H. Hartwig | 6) Perry's Chemical Engineers' Handbook |