PROPER SELECTION OF THERMAL INSULATION MATERIALS

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Abstract:

Thermal insulation plays a key role in the overall energy management picture. It is interesting to consider that by using the insulation, the entire energy requirements of a system are reduced. Since, the main function of insulation is to reduce the heat transfer, the insulation material must have the appropriate characteristic to retard the transport of heat occurred by conduction, convection and radiation. The proper selection and application of various insulation materials are very important in the domain of heat transfer. This paper discusses how to select thermal insulation material and on what basis a decision is made for application, concerning material selection and costs, through brief discussion about major insulation materials, properties, steps for economic selection, applications, economics of insulation and thickness, location, case study and conclusion.

Keywords: *thermal insulation, insulation material, economic selection.*

1. Major insulation materials

Table1 shows the major insulations materials used in commercial and industrial installations and its description (1, 2, 3, 4), such as calcium silicate, glass (Fiber glass and cellular glass), mineral fiber / rock wool, expanded perlite, elastomeric foam, plastic foams, refractory and insulating cement.

2. Selection process of insulation material

The most appropriate insulation material is to be selected based on, application requirements, properties of the insulation material, economic thickness of insulation, design life and economics of insulation selection.

2.1. Application requirements

There are two items that must always be considered to determine which insulations are suitable for service. These are range of operating temperature and location or ambient environment. The operating temperature range is classified into the following categories as shows in Table 2.

Table 1. Major insulations materials and its description.

Type of insulation material	Description of insulation material
Calcium silicate	The products, based on this, are formed from a mixture of lime and silica, reinforced with organic and inorganic fibers and moulded into rigid forms. It is suitable for temperatures from 250°F to 1000°F.
Glass (Fiber glass and cellular glass)	Fiber glass, service temperature ranges from -14.4°F up to 1200°F, 1000°F, and 850°F for glass fiber blankets, glass fiber boards and glass fiber piping covering. While cellular glass is used in temperature range -450°F to 900°F.
Mineral fiber / rock wool	The products are distinguished from glass fiber in that the fiber is formed from molten rock or slag rather than silica. Upper temperature limit can reach 1900°F.
Expanded perlite	Perlite is noncombustible and operates in the intermediate and high temperature ranges.
Elastomeric foam	Elastomeric insulations possess good cutting characteristics. The upper temperature limit is 250°F.
Plastic foams	Available in pre-formed shapes and boards, service temperature range -297°F to 300°F.
Refractory	Insulating refractory consist primarily of two types, fiber and brick. The products are used in high temperature applications.
Insulating cement	Cements may be applied to high temperature surfaces.

2.2. Properties of insulation material

There are many different types of insulation materials for piping applications. The insulation type's properties are temperatures range, thermal conductivity, compression strength, fire hazard classification and cell structure as in Table 3.

2.3. Economic thickness of insulation

Fig. 1 shows the economic thickness of insulation (5, 6), where the total cost is quite high when insufficient insulation thickness is used. The cost drops to a minimum when the optimum thickness is used, then rises again when an uneconomical increased thickness is chosen. Fig. 2 shows the economic steps for selecting an insulation material

3. Case study

This is a case study for energy saving through cooperation between Egyptian Petroleum Research Institute and one of the Egyptian refineries located in Cairo. The Boiler Feed Water Tank (BFWT) in which hot condensate is being collected along with makes up water is fully un-insulated. The condensate line is also not insulated. Heat loss by radiation and convection is considered while conduction loss is negligible.

Table 2. Shows operating temperature range is classified into the following categories.

Temperature ranges	Field of application	Suitable type of insulator
Cryogenic (from -455 to -150 °F)	Cryogenic service conditions are very critical and require a well designed insulation system.	Closed-cell foamed glass (cellular glass), fiber glass, and some plastic foam.
Low temp. (from -150 to 212 °F)	Refrigeration systems used in some industries.	Glass fiber, plastic foams, phenolic foams, elastomeric materials, and cellular glass.
Intermediate temp. (from 212 to 1000 °F)	Refineries, power plants and chemical plants.	Calcium silicate, glass fiber, mineral wool, and expanded perlite.
High temp. (from 1000 to 1600 °F)	Superheated steam, boiler exhaust ducting, and some process operations.	Calcium silicate, mineral wool, and expanded perlite.
Refractory (from 1600 to 3600 °F)	Furnaces and kilns in steel mill, heat treating and forging shops.	Ceramic fibers are used, with alumina-silica fibers firebrick.

Table 3. Shows properties of insulation types.

Insulation type and form	Temp. range (°F)	Thermal conductivity Btu-in/hr.ft².oF at T_{mean} (75 oF)	Thermal conductivity Btu-in/hr.ft².°F at T_{mean} (200 °F)	Cell structure (Permeability and moisture absorption)
Calcium silicate blocks, shapes and P/C	to 1500	0.37	0.41	Open cell
Glass fiber blankets	to 1200	0.24 - 0.31	0.32 - 0.49	Open cell
Glass fiber boards	to 1000	0.22	0.28	Open cell
Glass fiber pipe covering	to 850	0.23	0.3	Open cell
Mineral fiber blocks and P/C	to 1900	0.23- 0.34	0.28-0.39	Open cell
Cellular glass blocks and P/C	-450 to 900	0.38	0.45	Closed cell
Expanded perlite blocks, shapes, P/C	to 1500	_	0.46	Open cell
Urethane foam blocks and P/C	(-100 to -450) to 225	0.16 0.18	_	95% Closed cell
Isocyanurate foam blocks and P/C	to 350	0.15	_	93% Closed cell
Phenolic foam P/C	-40 to 250	0.23	_	Open cell
Elastomeric closed cell sheets and P/C	-40 to 250	0.25 0.27	_	Closed cell
MIN-K blocks and blankets	to 1800	0.19 0.21	0.20-0.23	Open cell
Ceramic fiber blankets	to 2600	_	_	Open cell

P/C means pipe covering.

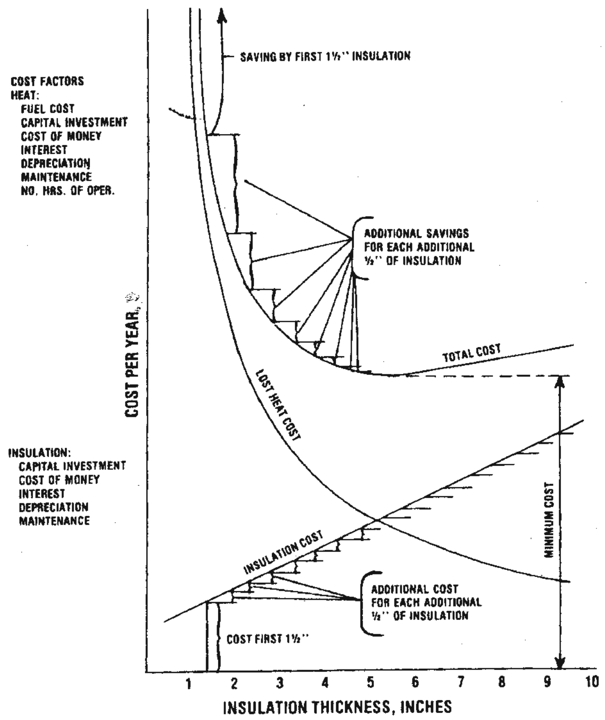

Fig. 1. Economic thickness of insulation.

3.1. Heat loss calculation for BFWT

The Boiler Feed Water Tank (BFWT) is fully uninsulated and with the following conditions.

Average surface temperature of the bfwt, T1 = 55°C = 131°F = 590.6°R.

Ambient Temperature, T2 = 30°C = 86°F = 545.6°R.

No. of sides exposed to the atmosphere = 5 (i.e., except bottom),

(Length = 7.546 ft; Width = 7.546 ft &Height=6.561 ft),

$A = (2 \times 7.546 \times 6.561)) + (2 \times 7.874 \times 6.561) +$
$+ (7.546 \times 7.874) = 261.755$ ft².

Total heat loss per ft² area can be calculated from the following equation (1):

$$\frac{Q}{A} = 0.2969(T_s - T_a)^{5/4} + 0.174\varepsilon\left[\left(\frac{T_s}{100}\right)^4 - \left(\frac{T_a}{100}\right)^4\right]$$

Where

Q = rate of heat loss,

A = surface area of the tank, (A=261,755 ft²),

T_s = average temperature of pipe surface, 55 °C = 131°F = 590.6 °R,

T_a = average temperature of the surroundings (air), 30 °C = 86°F = 545.6 °R,

ε = surface emittance, 0.9.

Hence, Q/A = 86.259 Btu/ hr.ft².

Total heat loss, Q = 86.259 ×261.755 = 22578.74 Btu/hr.

The BFWT is work as 350 day/year (15 days to maintenance).

Then the annual equivalent energy loss through BFWT = 22578.74 × 24 × 350 = 189661416 Btu.

Changing the annual equivalent energy loss through BFWT to equivalent furnace oil as following;

Equivalent furnace oil = (189661416×0.252) / (9650 x 0.75) = 6603.75 kgs/year = (6603.75 / 0.92) = 7177.99 Liters/year.

Annual cost equivalent at 3.4 L.E. (Egyptian Pound) per liter = 7177.99 × 3.4 = 24405.18 L.E.

3.2. Heat loss calculation for condensate line

In this section we calculate the annual equivalent energy loss through un-insulated pipes, hence the annual cost. The length and surface area of the condensate pipe is given in the Table 4, these data collected from one of the Egyptian refineries located in Cairo.

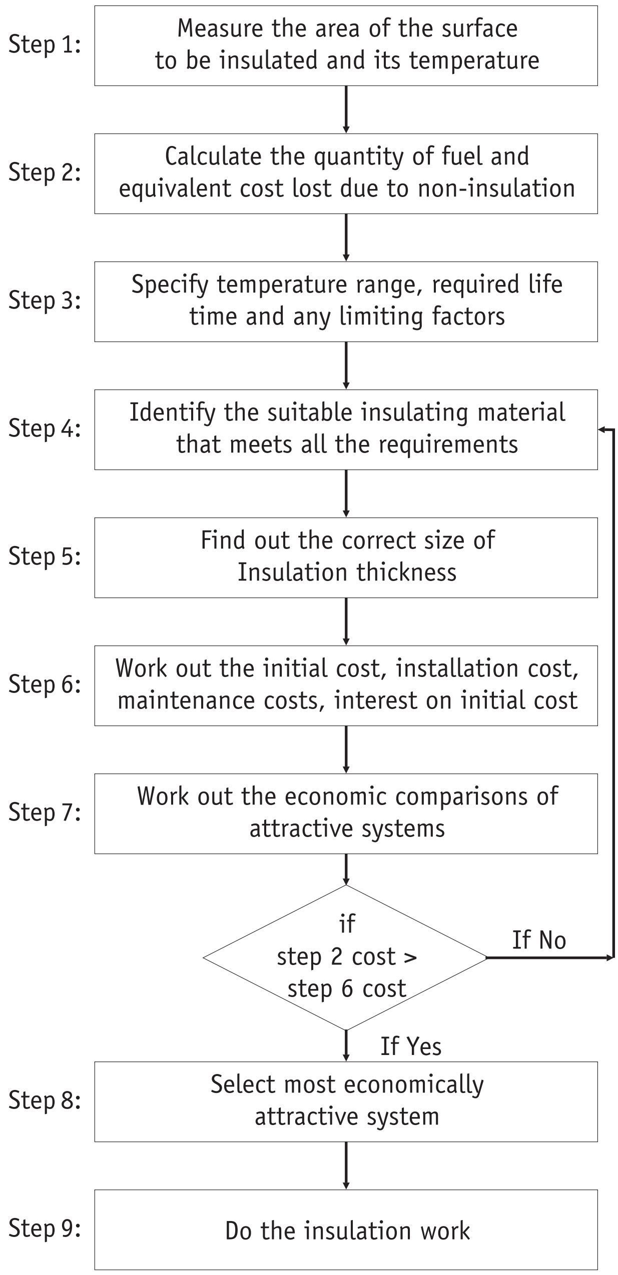

Fig. 2. Economic steps for selecting an insulation material.

Table 4. Shows diameters, lengths and surface areas of the condensate pipe.

Size of D, inches	Length L, ft	Area (πDL)
2	4.59	2.403
1.5	56.43	22.16
1.5	267.057	104.873
1	222.11	58.148
Total Area A1		187.584

A = total surface area of the pipes, (A=187.584ft2),

ε = surface emittance, 0.9,

T_s = average temperature of pipe surface, 60 °C = 140°F = 599.6 °R,
T_a = average temperature of the surroundings (air), 30 °C = 86°F = 545.6 °R.

Heat loss through un-insulated pipe = Convection Loss + Radiation Loss.
Hence, Q/A = 79.723 Btu/ hr.ft2.
Total heat loss, Q = 79.723 ×187.584 = 14954.759 Btu/hr.
Annual equivalent energy loss through pipes = 14954.759 × 24 × 350 = 125619977.5 Btu.
Equivalent Furnace Oil = (125619977.5 × 0.252) / (9650 x 0.75) = 4373.918 kgs/year = (4373.918/0.92) = 4754.259 Liters/year.
Annual cost equivalent at 3.4 L.E. (Egyptian Pound) per liter = 4754.259 × 3.4 = 16164.481 L.E.
Total cost = 24405.18 + 16164.481 = 40569.66 L.E.

3.3. Selecting the insulation material and calculationof total cost

Properties of insulation materials should be high compressive strength, resistant to moisture absorption and chemical, non combustible and not expensive.

Temperature range = 30°C to 75°C and required life time = 5 years.

Respecting to above factors, we may select fiber glass as insulation material, which can be used in the temperature range of -14.4°F to 850°F.

From Table 5 we can select the thickness of insulation material as given below.

In this application, the temperature range is more than (+ 16.2°C) 61, 16°F, we can go for 1 inch (25 mm) as insulation thickness.

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

Initial and installation cost for

- Fixing the glass fiber mattress having density of (100 Kg/m^3) 25 mm thick with wire netting and Aluminum jacket.
- Sealing all joints with sealing compound if the pipelines are exposed outside is given in the following Table 6.

Using simple payback method to evaluate insulation investment,

Simple payback period = (10619.03 /40569.66) x 12 = 3.14 Months.

Hence, from the above total insulation cost and annual heat loss cost, we are getting very attractive saving cost. So, we can select glass fiber as the insulation material.

Table 5. Shows thickness of insulation material based on temperature range and diameter.

Temperature ranges in °F	Pipe diameter in inches	Insulation thickness	
		inches	mm
Below (- 30.2)	0.59 to 3.1496	3.397	100
From (-30.02) to (+39.02)	3.937 to 11.811	4.921	125
	0.59 to 3.1496	2.953	75
From (+39.92) to (+55.4)	All sizes	1.968	50
From (+56.12) to (+60.08)	All sizes	1.575	40
From (+61.16) and above	All sizes	0.984	25

Table 6. Shows the total of insulation cost.

Items	Unit	(Price / unit) L.E.	Total price L.E.
Boiler feed water tank	261.755 ft^2	16	4188.08
Condensate pipe 2 inches	4.59	8.5	39.05
Condensate pipe 1.5 inches	323.48	8.3	2684.88
Condensate pipe 1 inch	222.11	7.75	1721.35
Total initial and installation cost			8633.36
Interest at 12%			1036
Annual maintenance at 11%			949.67
Total cost			**10619.03**

4. Conclusions

The appropriate insulation materials must be selected based on 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 capital cost, interest on capital cost, depreciation period and maintenance cost. Comparing the total insulation cost and annual heat loss cost, we are getting very attractive saving cost for the case study. So, we can go for 1 inch (25 mm) as insulation thickness from glass fiber mattress having density of (100 Kg/m^3). The simple payback period to evaluate insulation investment is 3.14 Months.

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