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PROPER SELECTION OF INSULATION MATERIAL IS AN ART (C. Sethuraman, CSIO)

This paper deals “**How to select insulation material and on what basis a decision is made concerning material selection and costs**” by giving brief writeup about Major insulation materials, Steps involved for economic selection, Properties, Applications, Economic thickness of insulation, Location, Design life, Economics of insulation, Case Study and Conclusion.

Insulation is defined as those materials or combinations of materials which retard the flow of heat energy. Insulation materials fall into two broad categories: organic foams; and inorganic materials. The organic foams include polystyrene, polyurethane, phenolic foam, polyethylene foam etc. The inorganic material include mineral wool, calcium silicate, cellular glass, microporous silica, magnesia, ceramic fibre, vermiculite and perlite.

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. Conduction loss in insulation is negligible.

MAJOR INSULATION MATERIALS

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

1. 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.

2. GLASS

a. Fibrous: Available as flexible blanket, rigid board, pipe insulation and other pre-molded 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.

3. 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.

4. EXPANDED SILICA, OR PERLITE

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

5. 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.

6. FOAMED PLASTIC

Insulation produced from foaming plastic resins create predominately closed-cellular rigid materials. "K" values decline after initial use as the gas trapped within the cellular 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.

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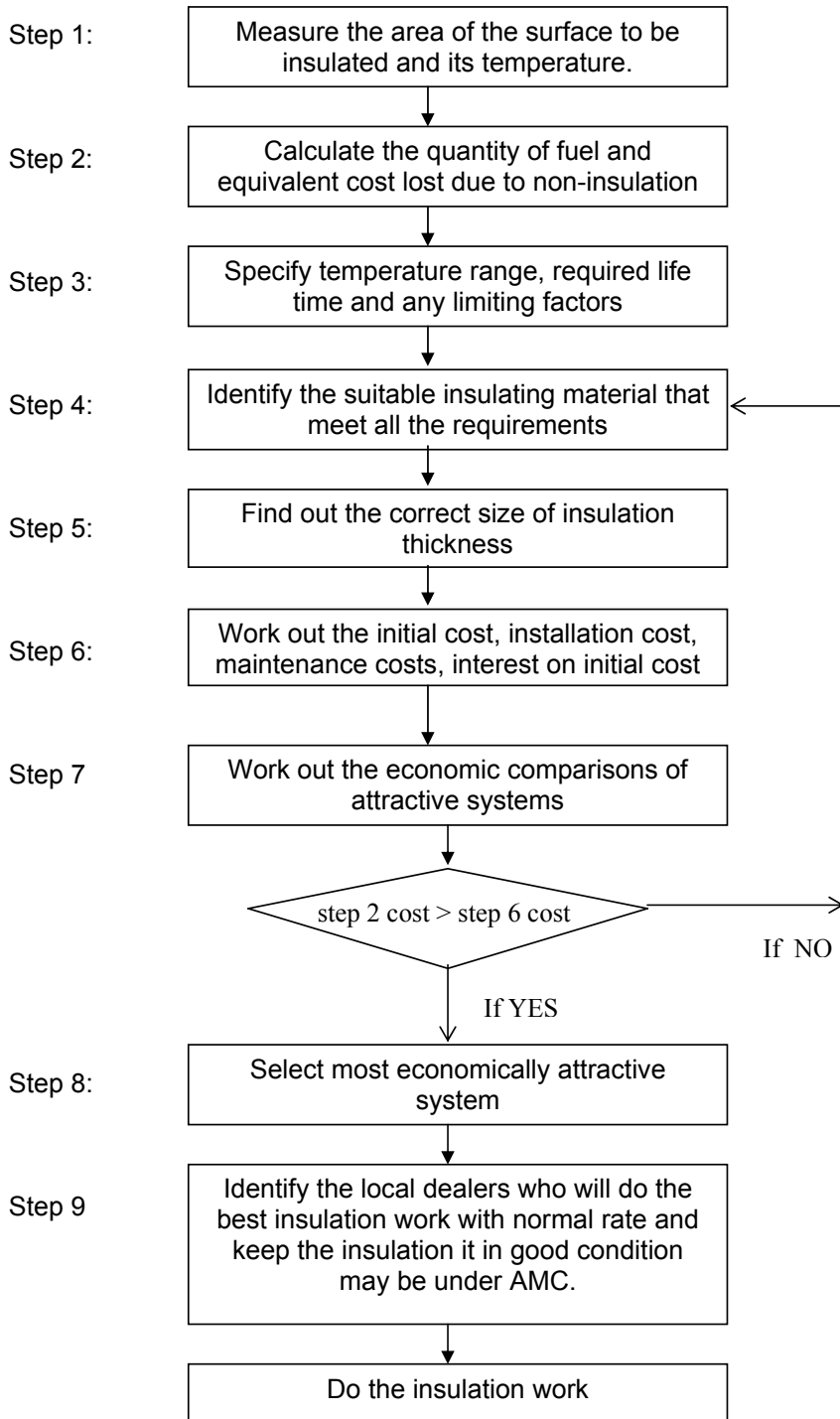
7. REFRACTORY FIBER

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.

8. 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.



The most appropriate insulation material is to be selected based on I) Temperature application, II) Properties of the insulation material III) Economic Thickness of Insulation (ETI) IV) Location V) Design Life and VI) Economics of Insulation selection.

I. TEMPERATURE APPLICATION

The temperature range within which the term "thermal insulation" will apply, is from -73.3°C to 815.6°C. All applications below -73.3°C are termed "cryogenic," and those above 815.6°C are termed "refractory."

Thermal insulation is further divided into three general application temperature ranges as follows:

A. Low Temperature Thermal Insulation

1. 15.6°C through 0°C (60°F through 32°F) -- i.e. Cold or chilled water.
2. -0.6°C through -39.4°C (31°F through -39°F) -- i.e. Refrigeration or glycol.
3. -40.0°C through -73.3°C (-40°F through -100°F) -- i. e. Refrigeration or brine.
4. -73.9°C through -267.8°C (-101°F through -450°F) -- i. e. cryogenic.

B. Intermediate Temperature Thermal Insulation

1. 16.1°C through 99.4°C (61°F through 211°F) -- i.e. Hot water and steam condensate.
2. 100.0°C through 315.6°C (212°F through 600°F) -- i.e. Steam, high temperature hot water.

C. High Temperature Thermal Insulation

1. 316.1°C through 815.6°C (601°F through 1500°F) -- i.e. Turbines, breechings, stacks, exhausts, incinerators, boilers.

The following table illustrate the name of the insulation material and its temperature application.

Sl. No.	Type	Name of Insulation Material	Temperature	Areas of application	Remarks
1	Organic foam	Polystyrene foam	Upto and not more than +75°C	Roofing, cold storage, refrigerated transport	Non-toxic & non-irritant. Resistant to water penetration, low cost (i.e. lower than mineral wools)
2	Organic foam	PUR (mixture of agents and additives)	-185°C to +110°C		Very low thermal conductivity. Slightly more expensive but installation costs are much lower

3	Organic foam	PIR	-185°C to +140°C	petrochemical equipment, buildings, refrigerated vehicles, tankers and ducting	More expensive, better fire performance
4	Organic foam	Phenolic foam	-180°C to +120°C	Air conditioning ducting, dry lining, sandwich panels insulation	Very low thermal conductivity. Does not melt when exposed to flame.
5	Organic foam	ENR	limit around +150°C	Industrial H&V, domestic heating and plumbing.	More expensive than mineral wools but is normally used in thinner layer
6	Organic foam	Polyethylene foam	Limit around +100°C	Domestic heating and plumbing	Unsuitable for process plant
7	Inorganic material	Calcium silicate	37.8°C to 648.9°C	Back up insulation in the refractory industry, boilers, ducting and process pipe work	More expensive than mineral wool
8	Inorganic material	Cellular glass	-267.8°C to 482.2°C	Process plant application and wide range of building application.	Resistant to water vapor, high compressive strength and good chemical resistance. Non combustible. High production cost.
9	Inorganic material	Microporous silica	+400°C to +1000°C	Refractory industry, aerospace and process plant	Its structure can be designed to prevent the passage of infra-red radiation. Low thermal conductivity. Higher cost than mineral wool.

10	Inorganic material	Ceramic fibre	Upto 1600°C	It can be used in application where rapid heating is followed by immediately by rapid cooling. Refractory industries	Low density and good resistance to thermal shock. Its cost is considerably higher than that of mineral wool.
11	Inorganic material	Expanded vermiculate	Upto 1000°C	Cementitious binders to produce sprays or boards as a fire production product	Naturally occurring material, light weight, granular material, inert and high melting point.
12	Inorganic material	Perlite	Upto 650°C	It is often used as a form of loose fill insulation	Naturally occurring material, Cheaper than mineral wool

II. PROPERTIES OF INSULATION MATERIAL

There are many insulation materials on the market claiming to be the most efficient. How to decide which material is best requires an understanding of five key properties.

The first property is **compression strength** (unit: psi), which is the maximum force required to deform a material prior to reaching its yield point. The importance of this property is for maintaining press alignments. Typically, compression strength of most insulation materials decreases as temperature increases. In fact, a small increase in temperature can result in a significant decrease in compression strength in some insulating grades. Manufacturers can provide this data through their technical bulletins.

The second key property for selecting mold insulation is service **temperature** (unit: °C), which is the highest temperature at which a material can perform reliably in long-term application ("long term" being inconsistently defined by the manufacturers). Depending on the product, most platens operate between 135°C and 232°C. It is recommended to select insulation 25 percent above operating temperature of mold.

The third and most important key property is **thermal conductivity** (lambda, measured in watts per meter per degrees Kelvin, W/mK) of a material represents the quantity of heat that passes through a metre thickness per square metre per time unit with one degree difference in temperature between the faces. Thermal conductivity (K Factor) is important in determining a material's ability to resist the flow of heat. The lower the K Factor, the higher the material's insulating power, and thus lower overall heat transfer and operating costs. The value of thermal conductivity is used for three purposes. First, it is used as a benchmark of a material's performance during operation. Second, it is

used to determine a utility's savings (e.g., steam or oil). Last, it is used to measure the return on investment. Understanding these three purposes for thermal conductivity aids in making a good buying decision of insulation material.

In general, K increases with temperature. The following figure-2 shows the effect of temperature on thermal conductivity for several low to intermediate range materials.

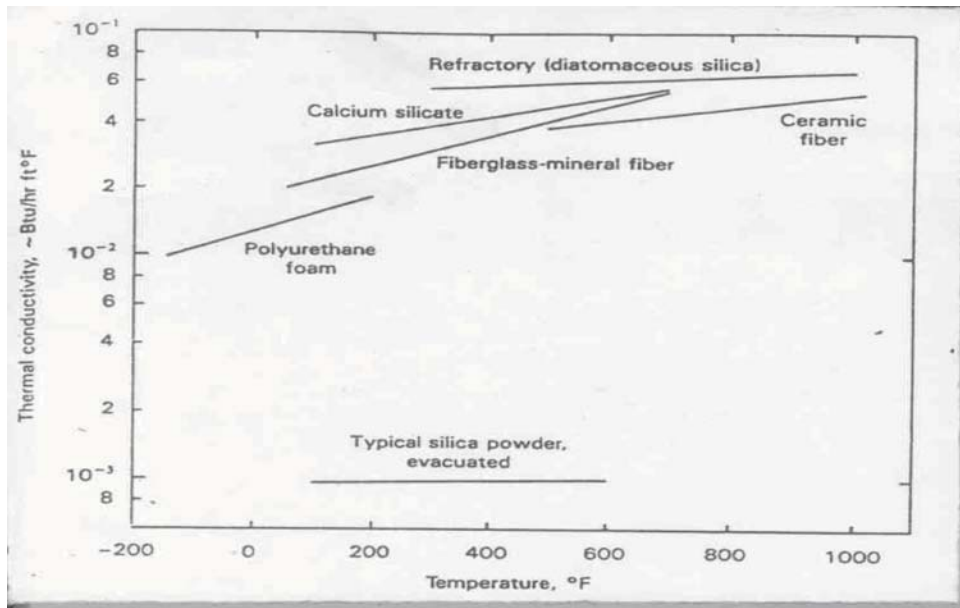


Figure-2: Effect of temperature on thermal conductivity for different insulation materials.

The fourth property for selecting thermal insulation is **water absorption** (unit %), which is defined as the amount of water absorbed by a material when immersed in water for a period of time. The common measure is the percent swell. The disadvantage of water absorption to insulation is that swelling can cause misalignment and cracking. Therefore, the lower the value the better a material is at resisting the absorption of water.

The fifth key property is **thickness tolerance** (unit: inch), which is the material's ability to maintain parallelism across flats. On most press applications, tolerance is extremely important for achieving alignments and product quality. The value of thermal expansion at operating temperatures is so low that operations are unaffected. Parallelism, therefore, is important only during initial purchase of thermal insulation. The last yet least discussed property is a material's resistance to lubricants and hydraulic/thermal oils. When hydraulic fluid leaks through components, the oil runs down the machine and contacts the insulation. Again, this gives rise to potential swelling and cracking.

III. ECONOMICAL THICKNESS OF INSULATION

The economical thickness of insulation (ETI) is defined as the thickness of insulation for which the cost of the next insulation is just balanced by increased energy savings over the life of the project.

It should be noticed from the following figure-3 that 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. The low point of the combined curve i.e., sum of insulation cost and lost heat cost determines the economic thickness of insulation.

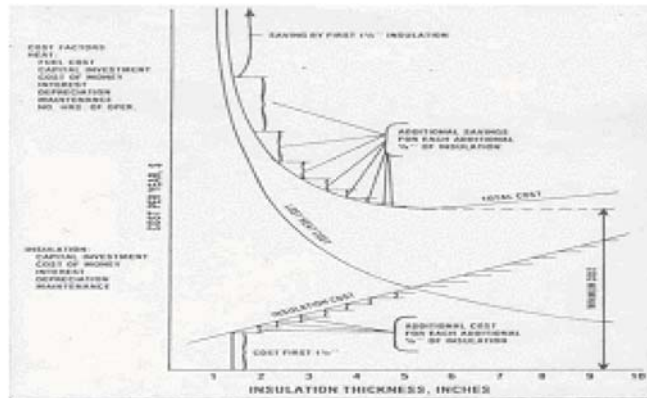


Figure-3: Economic thickness of insulation

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.

In most applications, economics and performance require use of more than one type of insulating material. All major suppliers offer guidelines and help in application and installation of insulation systems. In some cases, special tools and techniques are developed, and personnel must be trained for proper installation work. A number of tools and 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

IV. LOCATION

Location includes many factors that are critical to choosing the most cost-effective product for the life of the application. Material selection based on initial price only

without regard to location can be not only inefficient, but also dangerous under certain conditions.

An outdoor system needs to keep water from entering the insulation. Indoor applications are generally less demanding with regard to weather resistance, but there are washing areas that see a great deal of moisture, chemical fumes will affect the insulation material. There are many applications where vibrations are severe, for this application one has to go for a rigid insulations such as calcium silicate than other fibrous materials. Location in a fire-prone area can affect the insulation selection in two ways. First, the insulation system cannot be allowed to carry the fire to another area; this is fire hazard. Second, the insulation can be selected and designed to help protect the piping or equipment from the fire. For this calcium silicate is probably the best selection. This is due to the water of hydration in the product.

V. DESIGN LIFE

To illustrate this, consider the difference between designing a 40 year power plant and a two year experimental process. Assuming that the insulation in the experimental process will be scrapped at the close of the project, it makes no sense to use a more costly insulation that has lower maintenance requirements, since those future benefits will never be realized. Similarly, utilizing a less costly but maintenance intensive system when the design life is 40 years makes little sense, since the additional front end costs could be regained in only a few years of reduced maintenance costs.

VI. ECONOMICS OF INSULATION

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.

There are four primary methods of evaluating an insulation investment: I) Simple payback II) Discounted payback III) Minimum annual cost using a level annual equivalent; and IV) Present-value cost analysis using discounted cash flows.

VII) 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

$$\begin{aligned} \text{Average surface temperature of the bfw, } T_1 &= 60^\circ\text{C (333}^\circ\text{K)} \\ \text{Ambient Temperature, } T_2 &= 33^\circ\text{C (306}^\circ\text{K)} \\ \text{No. of sides exposed to the atmosphere} &= 5 \text{ (i.e., except bottom)} \\ \text{Total area of the tank, } A & \\ (\text{length}=2.2\text{m; breath}=2.2\text{m}\&\text{Height}=2.1\text{m}) &= (4 \times 2.2 \times 2.1) + (1 \times 2.2 \times 2.2) \\ &= (18.48 + 4.84) \text{ m}^2 \\ &= 23.32 \text{ m}^2 \end{aligned}$$

Total heat loss per m² area

$$Q/A = 1.24(T_1 - T_2)^{1.33} + 5.669 \times \epsilon \{ (T_1/100)^4 - (T_2/100)^4 \}$$

Where

$$\begin{aligned} Q &= \text{rate of heat loss, W} \\ A &= \text{surface area of the tank, m}^2 \\ T_1 &= \text{temperature of the surface, } ^\circ\text{K} \\ T_2 &= \text{temperature of the surroundings, } ^\circ\text{K} \\ \epsilon &= \text{emissivity of the surface, 0.9} \end{aligned}$$

$$\begin{aligned} \text{Therefore, } Q/A &= 280 \text{ Watts} \\ \text{Total heat loss, } Q &= 280 \times 23.32 \\ &= 6530 \text{ Watts} \\ &= 6.53 \text{ kW} \end{aligned}$$

Annual equivalent energy loss through BFWT

$$\begin{aligned} &= 6.53 \times 24 \times 350 \\ &= 54852 \text{ Kwh/Year} \end{aligned}$$

Equivalent heat loss

$$\begin{aligned} &= 54852 \times 860 \\ &= 47172720 \text{ kcal} \end{aligned}$$

Equivalent Furnace Oil

$$\begin{aligned} &= 47172720 / (9650 \times 0.75) \\ &= 6518 \text{ kgs (i.e., } 6518/0.92 = 7085 \text{ Ltrs)} \end{aligned}$$

Annual cost equivalent @ Rs.18/- per litre

$$\begin{aligned} &= 7085 \times 18 \\ &= \text{Rs.1,27,530/-} \end{aligned}$$

Heat Loss Calculation for Condensate Line

The length 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 BFWT		
1.5"	73.5	8.8

Total Un insulated area (A) = 17.16m²
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 Boltzman Constant=5.67 x10⁻⁸

E = 0.9, Ts = 343°k, Ta = 306°k & A = 17.16 m²

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 range = 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.

Keeping the above factors in mind, we may select **Cellular Glass** as our insulation material which can be used in the temperature range of -267.8°C to 482.2°C.

Now we have to find out the correct size of insulation thickness. The thickness of insulation material shall be as per the tables given below:

Temperature range in °C	Pipe dia in mm	Insulation thickness in mm
Below (-) 1°C	15 to 80	100
(-) 1.1 to (+) 3.9	100 to 300	125
	15 to 80	75
(+) 4.4 to (+) 12.8	All sizes	50
(+) 13.4 to (+) 15.6	All sizes	40
(+) 16.2 & above	All sizes	25

Since, in our application, the temperature range is more than (+) 16.2°C, we can go for 25mm as insulation thickness.

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

Initial and installation cost for

- Fixing the cellular glass mattress having density of 100 Kg/m³ 25 mm thick with ¾ x 24 G wire netting on one side and fabricating
- Fabricating and fixing of Aluminium sheet – 24 SWG by means of S.T Screws.
- 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	22.32 m ²	693	15468
2	Condensate pipe 2"	1.2 m	349	419
3	Condensate pipe 1.5"	90 m	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 = $(80463 / 300000) \times 12$
= 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.

Local dealer: M/s. Chandy Insulations Pvt. Ltd
Engineers & Contractors
No. 9, Balaji Nagar, Ernavoor, Chennai – 600 057

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
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- 2) Industrial Energy Management and Utilisation
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- 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