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ORIGINAL ARTICLE

Thermo economic optimization of thermal insulations

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Abstract

Thermo-economic optimization of sixteen thermal insulations have been carried to find the effect of various parameters such as payback period, rate of interest, heat transfer co-efficient and temperature differences in the cost of insulation, cost of heat losses and the total cost of Insulation for a cylindrical surface. It was observed that optimal cost of insulation is Rs.497.5 for 105.1 mm thick plywood along with optimum thickness of insulation was 60.4 mm for polystyrene foam which gives the total optimum cost Rs.1939.60 than other materials. With increase in thermal conductivity the cost of insulation decreases and cost of heat losses increases and hence total cost also increases. Increases in interest rate leads to increases in total cost, and for increase in heat transfer co-efficient, the total cost first increases rapidly and stabilizes for higher values of heat transfer co-efficient.

1. Introduction

Insulations are very important in industrial applications & domestic use because it reduces heat losses to atmosphere or heat gain in cryogenic applications for conserving Energy in terms of money saving by reducing burden on energy resources & environment. The popular use of insulation is governed by economic considerations in terms of critical economic thickness. In this paper, simple economic analysis has been carried out for sixteen insulating materials such as cork, cellotex, plastic, fibre glass, mineral fibre, wood felt, PVC, polystyrene foam, cement, paper wood, silica aerogel, kapok magnesia, rubber, Styrofoam and rock-wool with the objective in terms of most economic thickness. The various costs of insulations have been computed using explicit expressions & effect of various parameters i.e. thickness, heat transfer coefficients, temperature difference, payback period, interest rate for cylindrical geometry of pipes on the costs have been explained in terms of variation of cost of insulation, cost of heat losses and total cost. M Mc Chesney [1] has calculated heat losses and developed simple model for economic model which was used for determining thickness of insulation. They have not considered without the fact that actual variable under market conditions. Ulrich [2] observed that the thickness of insulation on a cold / hot surface is increased, the rate of heat losses is reduced which also effect the reduction of cost of energy. Mishra [3,4] had studied the effect of rural insulating materials on the solar cooker thermal performance experimentally and found significant effect on techno-economic performances. Peters Timmerhaus [5] considered the two opposing factors for determining the thickness of insulation because thicker insulation saves more heat energy at the cost of higher investment on insulation .Mishra [6] carried out techno-economic studied of six insulating materials and calculated the effect of economic thickness of insulation theoretically by modifying running and inertial cost of insulation but not considered the cost of steam per ton Several investigators [7,8] have calculated thickness of insulation as a

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function of pipe size, fuel costs, pipe temperature based on different wind speed with different ambient temperature conditions . We considered fixed cost of insulation and variable cost of insulation by considering the cost of steam in terms of maintenance cost, cost of heat energy loss, service life of insulation, depreciation, taxes etc for determining optimum insulation thickness

1.1 Thermo Economic Analysis and optimization of thermal insulation

Following methodology is based on minimization of total present cost by consideration of interest rate for the case of an insulated pipe carrying a steam (e.g. hot fluid). The various terms and quantities are involved which was useful for cost estimation and economic analysis as length of pipe section (L, metre), outer radius of the insulation (ro , metre) , inner radius of the insulation (ri, metre), thermal conductivity of insulation (K_c, W/m K), inner surface convective heat transfer co-efficient (h_i , W/m^2 K,)outer heat transfer co-efficient (ho W/m^2 K), pipe wall temperature which is equal to the temperature of the inner surface of the insulation (T_i, ºC), ambient temperature (T_o, ºC), cost of insulation C' (Rs/m^3), insulation life (n, years) interest rate (I, Rs/year. We also assumed that inside convective heat transfer coefficient is large. The overall heat transfer coefficient is based on the inner radius of insulation is expressed by following expression.

$$U_i = 1./((1/h_i) + ((r_i/k) * \log(r_o/r_i)) + (r_i./(r_o * h_o))) \qquad (1)$$

The rate of heat loss per year is calculated as

$$Q = (2 * p_i * ri * l * k_1 * k_2 * t_d * U \qquad (2)$$

$$k_1 = 24 * 300 \qquad (3)$$

Where are the number of working hours in a year and K_2 is evaluated for For 18% rate of interest & 5years service life of the insulation.

$$k_2 = 3.127 \qquad (4)$$

The cost of heat loss becomes Q_{Ch} (Rs/year). The total present value of heat loss (P_1) over the service life of the insulation (n years) is expressed in terms of fractional annual compound interest rate (annually compounded) is (P_i).
The volume of insulation applicable in the present investigation is

$$v = (pi * l) * ((r_o * r_o) - ri^{\wedge 2}) \text{ i.e.} 3.14 * L\,(r_o^2 - r_i^2)\ (m^3) \qquad (5)$$

The present value of the insulation is (P_2) becomes C'*V

$$\text{i.e. } P_2 = V * C_2 \qquad (6)$$

The total present value in terms of cost becomes as

$$(P_T = P_1 + P_2) \qquad \mathbf{(7)}$$

The optimum insulation thickness is obtained by putting (dP_t/dr_o) =0

i.e. The above expression for (r_o) for which optimum thickness (r_o-r_i) is based on the expression for total cost.

2. Results and Discussion

The following numerical values have been considered for calculating the variation of total cost with effect of inner heat transfer coefficient for different insulating materials. The saturated temperature of steam at pressure of 8.2 bar =172 (ºC), ambient temperature =20 (ºC), length of insulation in meter (*l*=1) , inner radius in meter (r_i=.084) , outer radius in meter (r_o=(r_i+t)), thickness of insulation in meter (t), temperature difference (t_d=150) ,inner heat transfer co-efficient in W/m^2 K (hi=20), outer heat transfer co-efficient in W/m^2 K (h_o=5), latent heat in Kcal/kg (lh=487), cost of steam (c_1=700) ,cost of insulation (c_2=15000) ,c_3=c1/(1000*487), thermal conductivity of material in W/m K (variable for sixteen materials), number of working hours in a year (k_1=24*300), Assuming interest rate (i) = 18% rate of interest & for five years' service life(k_2=3.127), the cost of steam (c_3)=c_1/(1000*487); where 487 is the latent heat (Kcal/kg) ,cost of steam per ton is c1=700 (Rs.), cost of insulation (c_2= Rs.15000), thermal conductivity of material in W/m K (is variable), The variation of total cost , cost of heat losses and cost of insulation have been plotted with variation in the thickness of insulation are shown in Fig-1a to 16a respectively and it was observed that the economic material comes to be plywood of thermal conductivity 0.120 (W/m K) and optimum thickness was found 60.4 mm for polystyrene foam of thermal conductivity 0.025 W/mK) .For increasing the thermal conductivity, the total cost also increases as same value of temperature difference. For increase in payback period, the total cost also increases linearly. Increase in the heat transfer co-efficient the total cost of insulation first increases rapidly and stabiles for higher value of heat transfer co-efficient are shown in figs (1b to 16b) respectively. Similarly, the optimum economic insulation thickness for different insulating materials with total cost is shown in table-1 respectively.

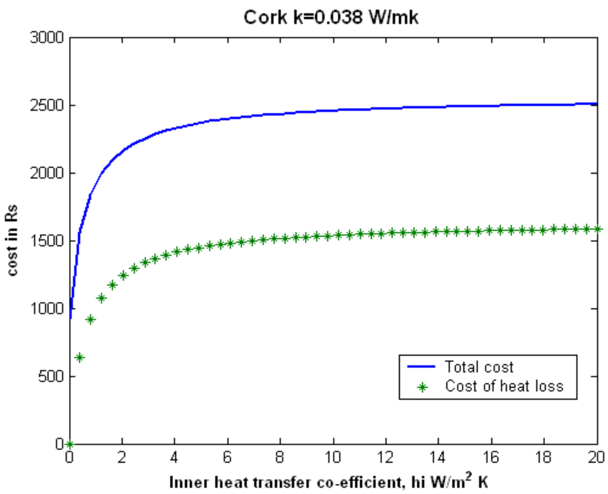

Figure 1(a): Variation of total cost, cost of heat loss with inner heat transfer coefficient for cork material

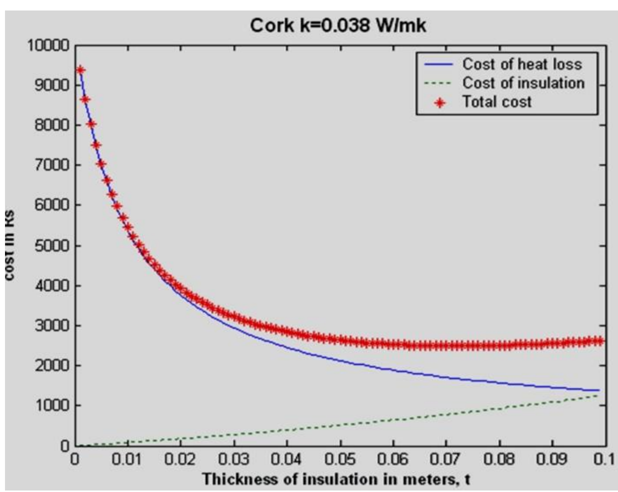

Figure 1b: Variation of total cost, cost of heat loss and cost of insulation with thickness of insulation for cork material

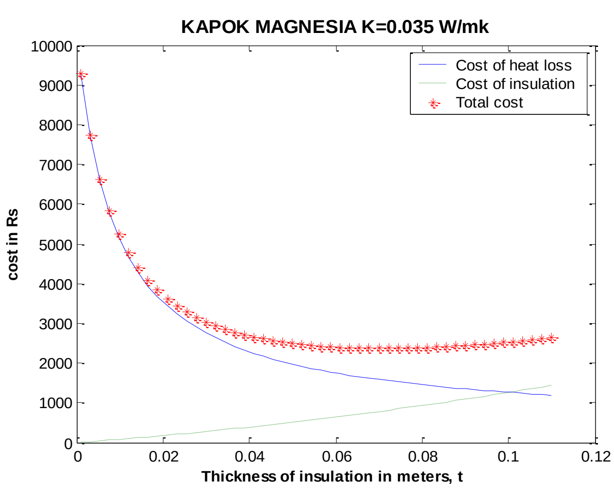

Figure 2a: Variation of total cost, cost of heat loss and cost of insulation with thickness of insulation for kapok magnesia material

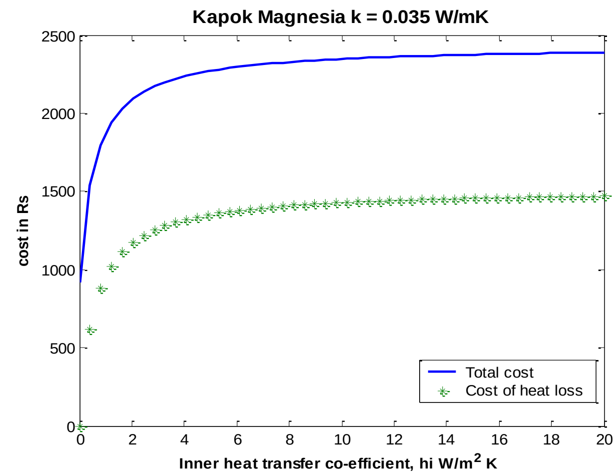

Figure 2b: Variation of total cost, cost of heat loss with inner heat transfer coefficient for kapok magnesia material

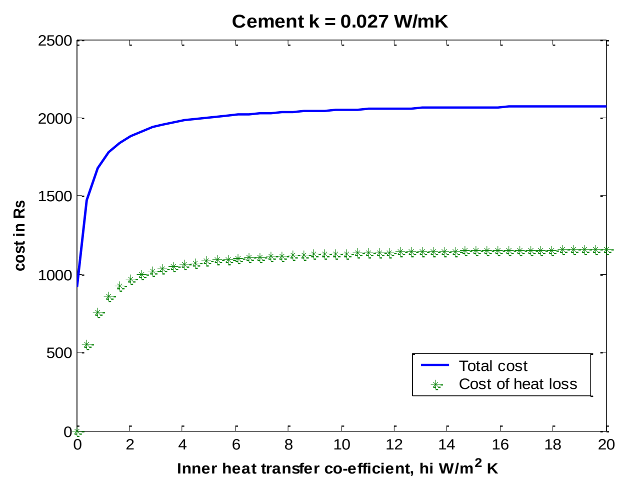

Figure 3a: Variation of total cost, cost of heat loss and cost of insulation with inner heat transfer coefficient for cement material

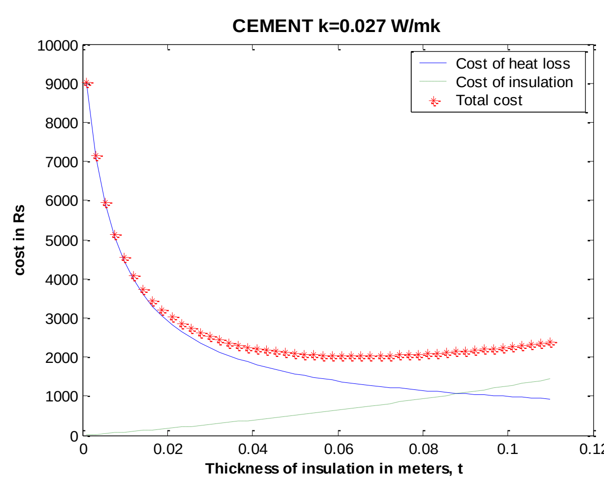

Figure 3b: Variation of total cost, cost of heat loss and cost of insulation with thickness of insulation for cement material

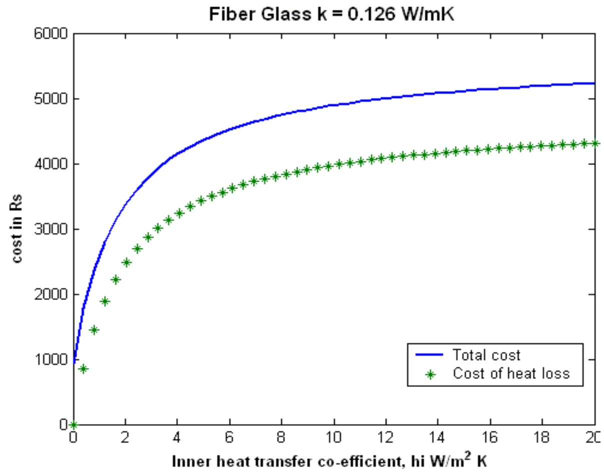

Figure -4a: Variation of total cost, cost of heat loss with inner heat transfer coefficient for fibre glass material

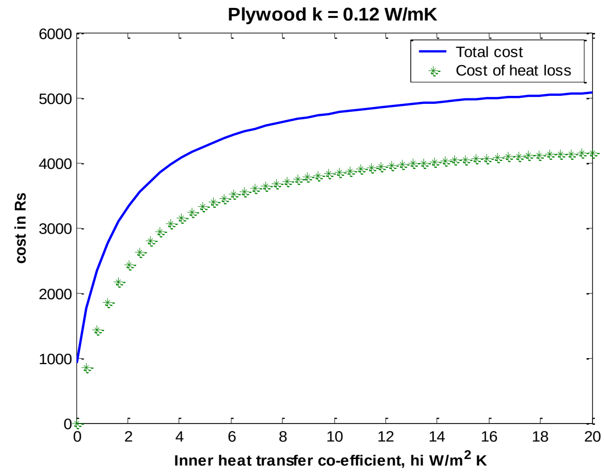

Figure -5b: Variation of total cost, cost of heat loss with inner heat transfer coefficient for plywood material

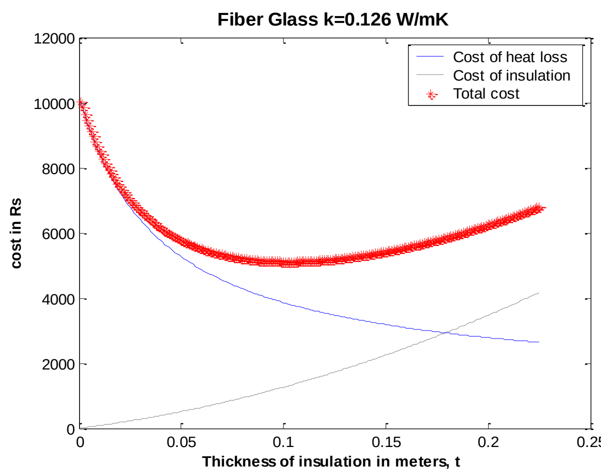

Figure 4b: Variation of total cost, cost of heat loss and cost of insulation with thickness of insulation for fibre glass material

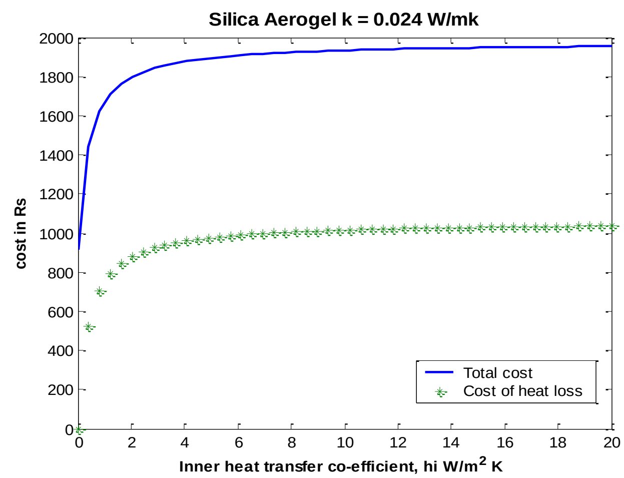

Figure 6 a: Variation of total cost, cost of heat loss with inner heat transfer coefficient for silica aerogel material

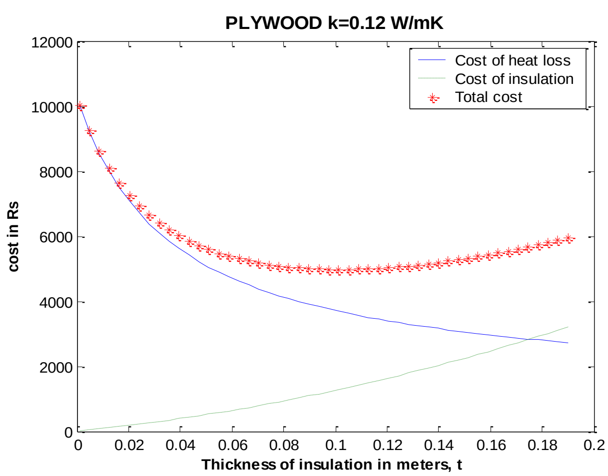

Figure 5a: Variation of total cost, cost of heat loss and cost of insulation with thickness of insulation for plywood material

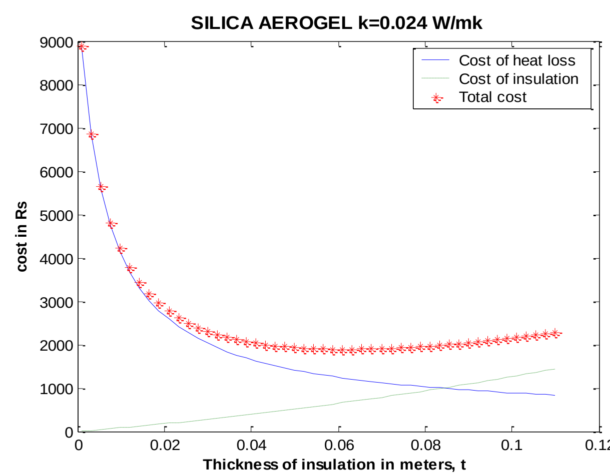

Figure -6b: Variation of total cost, cost of heat loss and cost of insulation with thickness of insulation with thickness of insulation for silica aerogel material

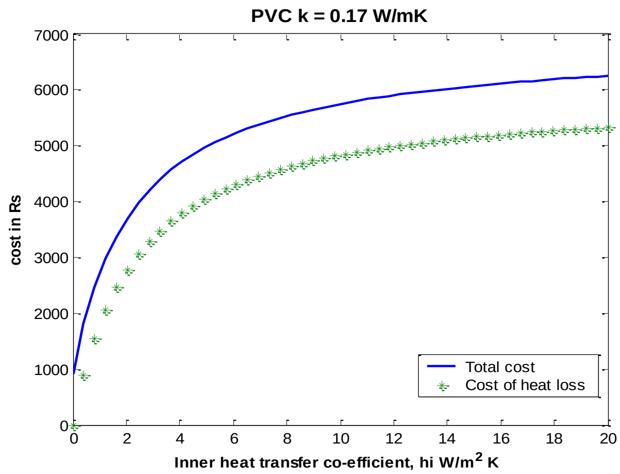

Figure 7a: Variation of total cost, cost of heat loss with inner heat transfer coefficient for PVC material

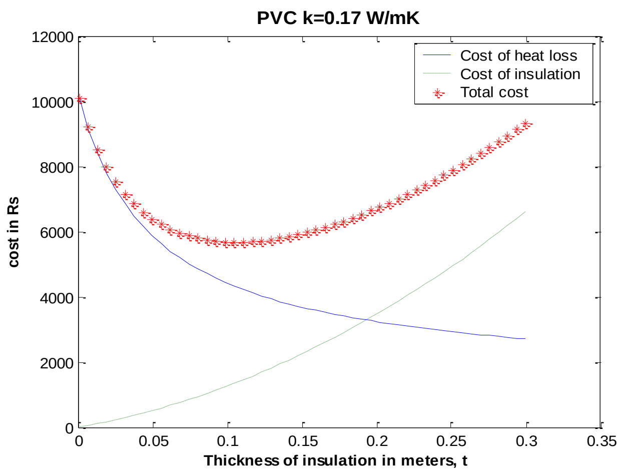

Figure -7b: Variation of total cost, cost of heat loss and cost of insulation with thickness of insulation for PVC material

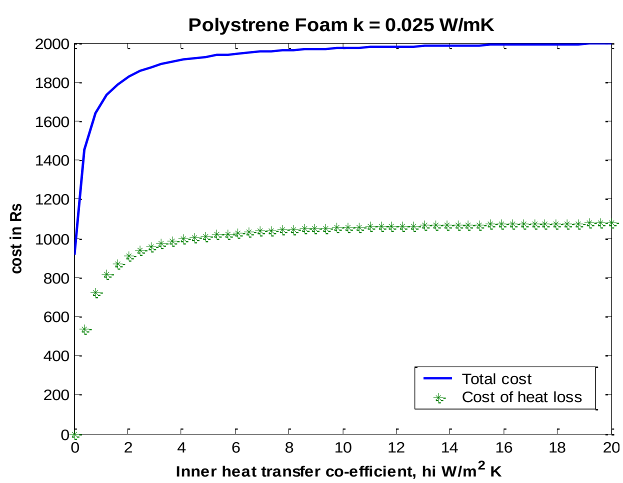

Figure 8a: Variation of total cost, cost of heat loss with inner heat transfer coefficient for polystrene material

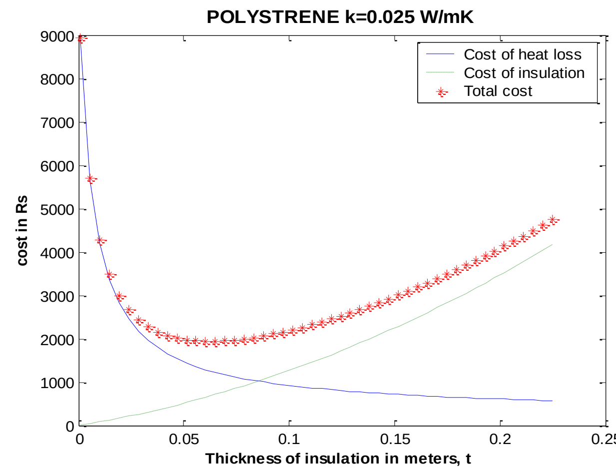

Figure 8b: Variation of total cost, cost of heat loss and cost of insulation with thickness of insulation for polystrene material

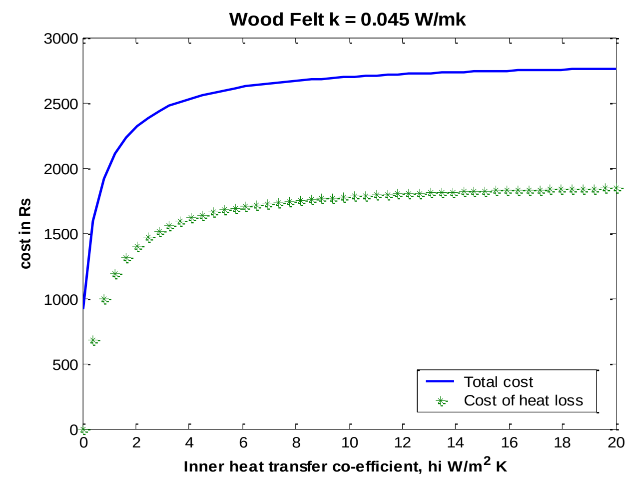

Figure 9(a): Variation of total cost, cost of heat loss with inner heat transfer coefficient for wood felt material

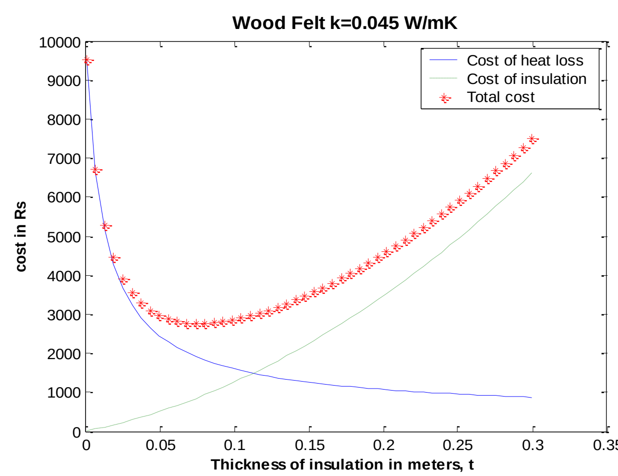

Figure 9b: Variation of total cost, cost of heat loss and cost of insulation with thickness of insulation for wood felt material

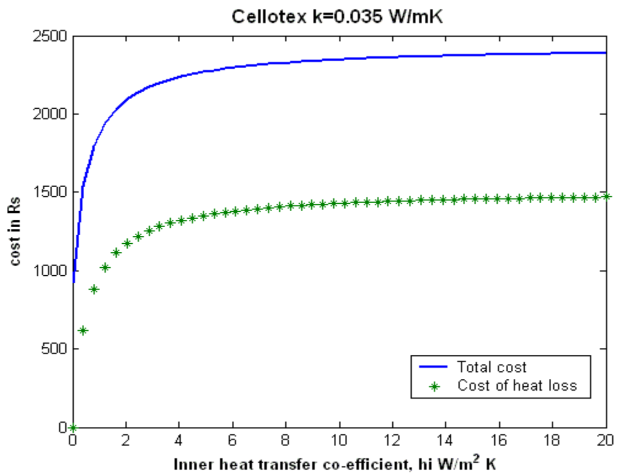

Figure 10a: Variation of total cost, cost of heat loss with inner heat transfer coefficient for cellotex material

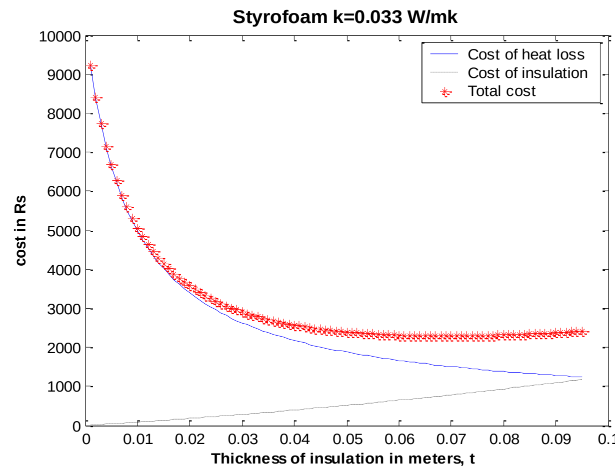

Figure 11b: Variation of total cost, cost of heat loss and cost of insulation with thickness of insulation for Styrofoam material

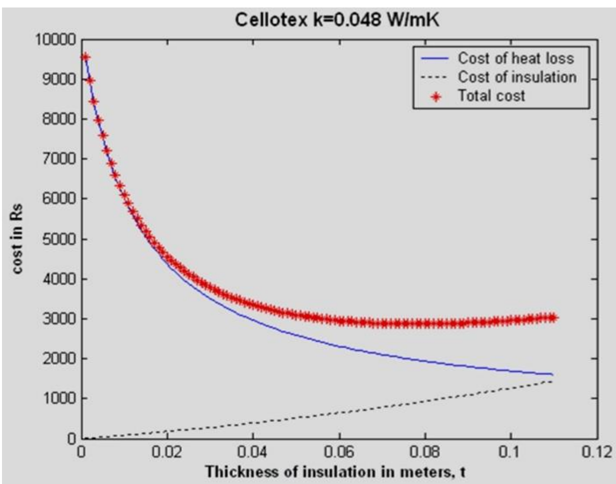

Figure 10b: Variation of total cost, cost of heat loss and cost of insulation with thickness of insulation for cellotex material

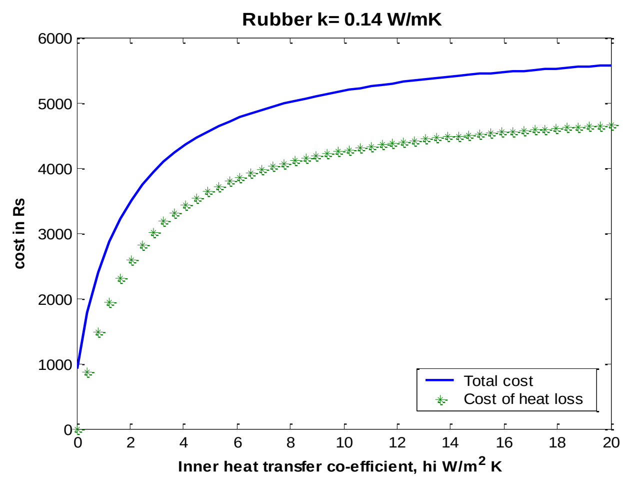

Figure 12a: Variation of total cost, cost of heat loss with inner heat transfer coefficient for rubber material

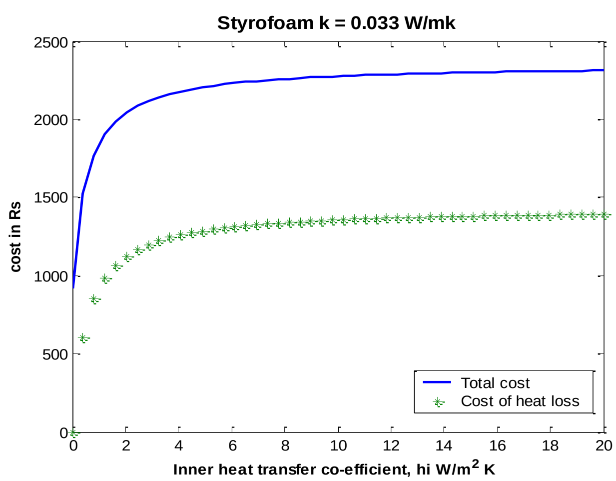

Figure 11a: Variation of total cost, cost of heat loss with inner heat transfer coefficient for Styrofoam material

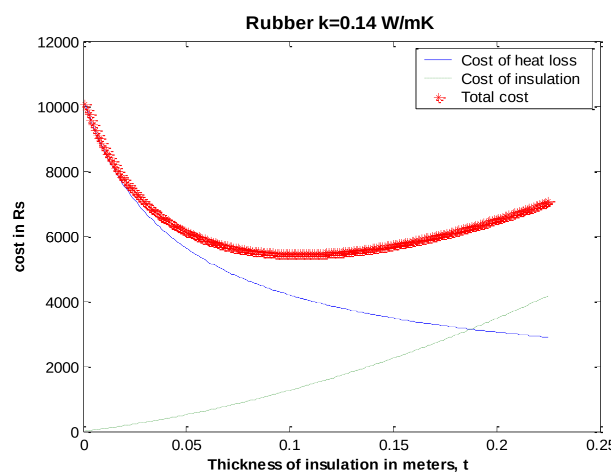

Figure 12b: Variation of total cost, cost of heat loss and cost of insulation with thickness of insulation for rubber material

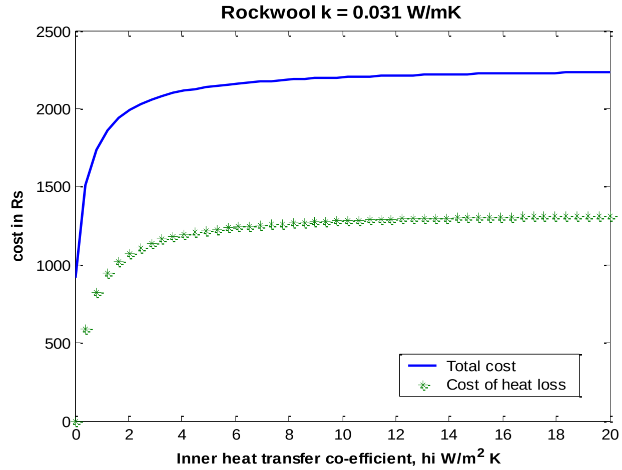

Figure 13a: Variation of total cost, cost of heat loss withinner heat transfer coefficient for rock-wool material (K=0.031(W/mK)

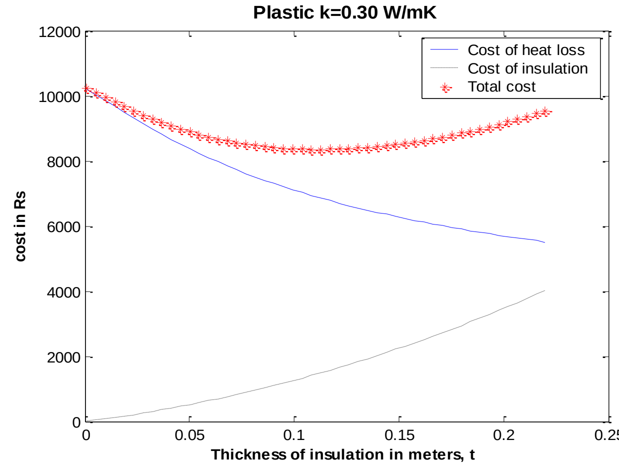

Figure 14b: Variation of total cost, cost of heat loss and cost of insulation with thickness of insulation for plastic material

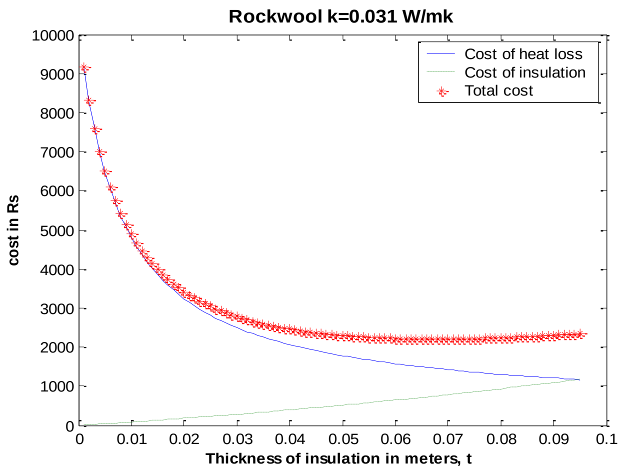

Figure 13b: Variation of total cost, cost of heat loss and cost of insulation with thickness of insulation for rock-wool material

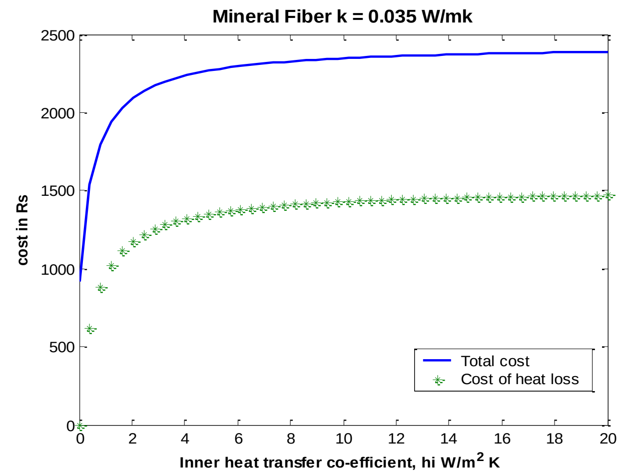

Figure 15a: Variation of total cost, cost of heat loss with inner heat transfer coefficient for mineral fibre material

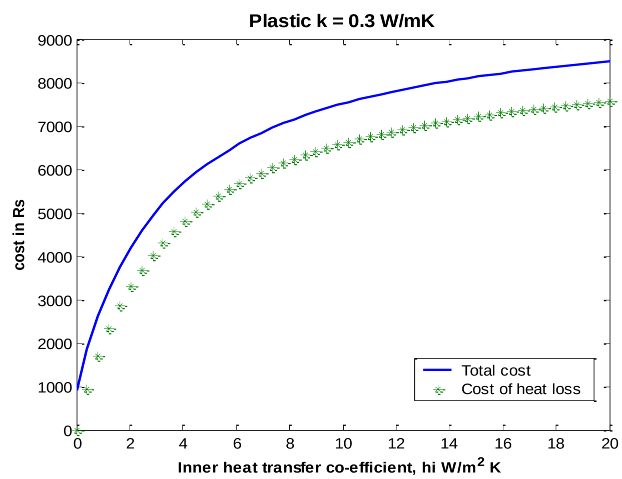

Figure 14a: Variation of total cost, cost of heat loss with inner heat transfer coefficient for plastic material

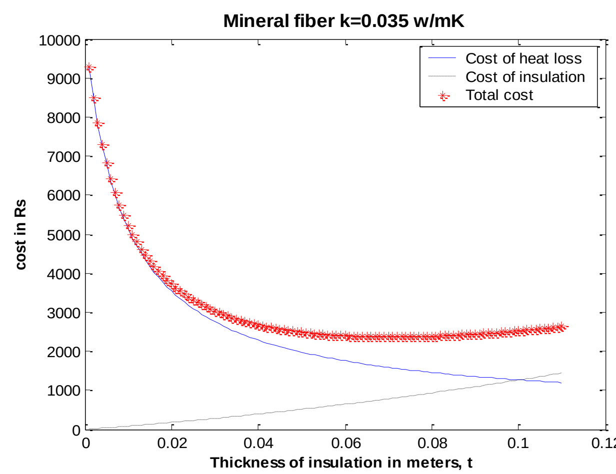

Figure 15b: Variation of total cost, cost of heat loss and cost of insulation with thickness of insulation for mineral fibre material

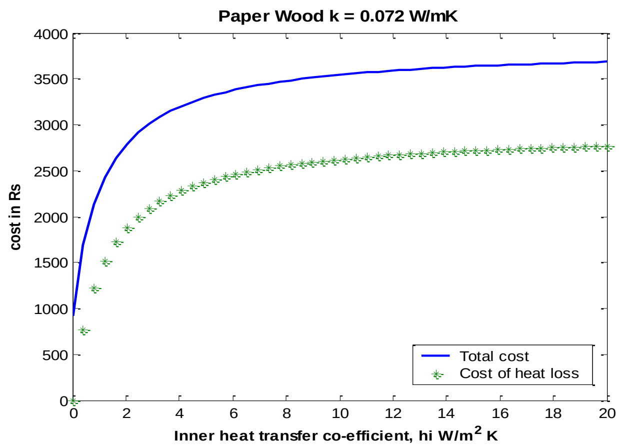

Figure 16a: Variation of total cost, cost of heat loss and cost of insulation with thickness of insulation for paper wood material

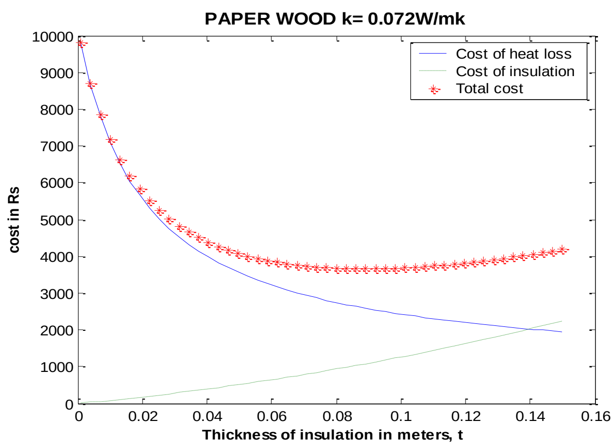

Figure 16b: Variation of total cost, cost of heat loss and cost of insulation with thickness of insulation for paper wood material

Table 1: Optimum economic insulation thickness for different insulating materials with total cost.

Materials	Thermal Conductivity (W/mK)	Economic thickness (mm)	Total cost (Rs.)
Plywood	0.120	105.10	497.5
Fibre glass	0.126	101.6	512
Rubber	0.140	106.1	544.7
PVC	0.0170	104.7	567.1
Plastic	0.30	112.7	834.70
Silica aerogel	0.024	6	1892.0
Polystrene foam	0.025	60.4	1939.6
Cement	0.027	63.3	2030.3
Rookwool	0.031	68	2205.8
Styrofoam	0.033	68.1	2290.2
Kapok Magnisia	0.035	70	2372.6
Mineral Fibre	0.035	70	2372.6
Cork Plastics	0.038	73.0	2493
Wood felt	0.045	74.2	2763.7
Cellotex	0.048	78.9	2870.4
Paper wood	0.072	89.2	3665.80

3. Conclusions

The thermal analysis was done for the materials for sixteen different insulation materials for a given pipe internal radius of 0.05m and numerical computation was carried out to find out most economics materials. The following conclusions have been drawn:

- The economic insulating material comes out to be plywood which has 105.1 mm thick at optimum cost of Rs.497.0 and optimum insulation thickness was observed in polystyrene foam of 60.4 mm thickness with optimum cost of Rs.1939.60 respectively.
- With increase in thermal conductivity the cost of insulation decreases and cost of heat losses increases and hence total cost also increases.
- Increases in interest rate leads to increases in total cost.
- for increase in heat transfer co-efficient, the total cost first increases rapidly and stabilizes for higher values of heat transfer co-efficient.
- For increases in temperature differences the total cost increase linearly.
- For increase in thermal conductivity the total cost also increases for same value of temperature differences. For increase in payback period the total cost of insulation also increases linearly

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