Thermo Economic Analysis and Optimization of Thermal Insulations

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Abstract

Thermo-economic mathematical modeling of thermal insulation has been carried to find out 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 for a cylindrical surfaces and flat surfaces. It was observed that cellular plastic gives better properties of insulation than other materials.

1. Introduction

Global warming is the increase in the average temperature of the Earth's near-surface like air and oceans most of the observed increase in global averaged temperature, since the mid-twentieth century is very likely due to the observed increase in Anthropogenic (man-made) greenhouse gas concentrations via an enhanced greenhouse effect. Greenhouse gases are the gases present in the atmosphere which reduce the loss of heat into space and therefore contribute to global temperatures through the greenhouse effect. The Greenhouse concept is simply that the composition of the gases that make up the atmosphere enveloping the earth is crucial to the existence of life, by acting as an insulator. This is because a precise gaseous composition allows heat which is radiated from the sun to be trapped in by the earth. Furthermore it allows the specific temperature range for life to flourish, as it allows the right amount of heat loss as well as heat retention to keep the balance of life stable

2. Role Of Thermal Insulation

The popular use of insulation is governed by economic considerations in terms of critical economic thickness. The methods to find economic thickness of insulation have progressed significantly. Many researchers have laid down different methods of tackling thickness of insulation..Several investigators have calculated heat losses and developed thermal models which can be used for determining thickness of insulation. They have not considered if economic factors are not known so that heat losses considered without the fact that actual variable market conditions. The lot of work has been done for calculated thickness of insulation as a function of pipe size, fuel costs, pipe temperature based on wind speed of 12 km/hr with 287.16 K ambient temperature. The effect of insulating materials on solar cooker thermal performance experimentally investigated for calculating the economic thickness theoretically by modifying running and inertial cost equations. There is no comparison available for different materials for optimizing thermal and economic performance parameters The presentation mainly deals with the simple economic analysis has been carried out for five insulating materials such as cellular plastic, pearlite, corrugated asbestos, polyurethane 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. 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

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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 five insulating materials such as cellular plastic, pearlite, corrugated asbestos, polyurethane rubber, styro-foam 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. It was observed that the most efficient and economic material comes to be cellular plastic of 0.031(W/mK) thermal conductivity. 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. Numerical computations was carried out for sixteen different insulation materials for a given pipe internal radius of 0.05m to find out most economic insulating materials.

3. Analysis Of Thermal Economic Optimization Of Thermal Insulation

Considering flat surfaces, the heat losses per square meter per year is given by the following expression:

$Q = (T_1-T_a) *Y / ((L/K) + R)$ watt/year. (1)

Where T_1 = Temperature of surface without insulation (^{0}C), T_a=Ambient Temperature (^{0}C), L=Thickness of insulation (m,cm), K = Thermal conductivity of insulation material(W/mK),R=Thermal resistance of outer surface of insulation (m^2 K/W), h_0=Heat Transfer coefficient of outer surface of insulation(W/m^2 K), Y=Hours of operation per year

Assuming M is the cost of heat losses(rupees per million watts), therefore, the cost of heat losses per year per meter is expressed by the following equation:

m=Q*M/1000000 (Rs) (2).

Substituting equation 1 in equation 2, one gets following eq.

$m=(T_1-T_a)$ & Y*M / (1000000)(R+(L/K)) (Rs)….(3)

The cost of insulation can be expressed as

n=100B*L+C... (4).

Where, C=Installation Cost which is fixed (in Rs) and B=Cost of installed insulation per square m per cm length of insulation per year. Therefore, the total cost of insulation can be given by adding eq (3) and eq (4) respectively i.e. Therefore Total cost of insulation (Ct) can be expressed as

C_t= (m+n) (5).

Substituting the value of (m) and (n) in equation one gets following equation

C_t= (m+n) = $(T_1$-Ta)*Y*M/(1000000)(R+(L/K)) + 100*B*L + C ..(6).

Assuming A=y*$(T_1$-Ta)*M/1000000.

Therefore, total cost of insulation can be expressed as

$_{Ct}$=A*K/(L+(K*R)) + 100*B*L + C..(7)

To get minimum value of above expression, one can differentiate equation (7) with respect to thickness. i.e. dCt/dL = 0 and solving, one can get following expression: dCt/dL = AK/((L+RK)(L+RK)) + 100B = 0.

One gets, AK=100B ((L+RK)(L+RK) ..(8).

Rearranging eq. (8), one can get quadratic equation in terms of L as follows $L^2=2LRK+R^2K^2K$– AK/100B = 0... (9)

Solving eq. (9), the economic thickness of insulation for flat surface becomes

L = $(AK)^{1/2}$ / $(100B)^{1/2}$ – RK..(10).

Similarly, heat losses per meter length of insulating cylinder can be expressed as

Q= 2*3.14(T1-Ta)/ ((1/K)*(ln (r_2/r_1)) + $(1/h_0r_2)$) Watt/m... (11).

Where r_1=Radius of inner surface of insulation (m), r_2=radius of outer surface of insulation (m). The cost of heat losses per year per meter can be expressed by the following expression

m = [2*3.14$(T_1$-Ta)/((1/K)*(ln (r_2/r_1)) + $(1/h_0r_2)$)] *Y*M/10^6 (Rs/year) (12)

Where R=1/h_0, m= 2*3.14(r_2*A*K)/($r_2$ln(r_2/r_1) + RK) (13)

and A= y*$(T_1$-Ta)*M/1000000.

The cost of insulation per liner metre per year can be expressed as (n)

n= 2*3.14*(r_2^2-r_1r_2)*B + C(14)

and m=2*3.14*r_2*1] (r_2-r1)*B + C. Therefore, total cost per metre per year can be expressed as C_t=m+n = 2*3.14*AK / ((r_2 ln(r_2/r_1) + RK) + 2*3.14(r_2^2-r_1r_2)*B + C ..(15). To get optimum value of r_2, we differentiate eq. (15) with respect to r_2 because inner diameter of a cylinder is constant. Differentiating eq. (15) one gets following expression:

dCt/dr_2 = [2*3.14*(r_2 ln(r_2/r_1) +RK)AK – r_2AK(1+ln(r_2/r_1))]/($r_2$ln(r_2/r_1)+RK)^2 + (2r_2-r_1)B*2*3.14 = 0 ..(16).

Rearranging equation (14), one gets following expression:

$[(2*3.14*(r_2 \ln(r_2/r_1) + RK)AK))/B] - [(r_2AK (1+\ln (r_2/r_1)))/B] + (2r_2-r_1)*(r_2\ln (r_2/r_1)) + RK)^2 = 0$... (17)

Solving eq. (17) and rearranging, one can get following transcendial equation which was solved by trial and error method to obtain optimum radius of pipe (r_2).

$(r_2 \ln(r_2/r_1) + RK)*(2r_2-(r_1/r_2)-RK)^{1/2} = (Y(T_1-Ta)BMK/1000000)^{1/2}$ ..(18).

The economic thickness of insulation is obtained by ($r_2$opt – r_1)

4. Numerical Computation

In this paper we considered following values of 6 insulating materials such as Cellular plastic (K=0.031 W/m oC), Perlite (K=0.06 W/m C), Corrugated Asbestos (K=0.1 W/m oC), Polyurethane rubber (k=0.15 W/m oC), Polystyrene Styrofoam (K=0.263 W/m oC), Rock Wool (K=0.4 W/moC). Length of pipe = 1m, Temperature of inner surface = 172oC, Ambient temperature = 20 oC. Heat transfer Coefficient 10.32 (W/m2 oC), Cost of insulation 5540(Rs/m2), Payback period = 5 Years (variable), cost of hetr generation 0.001437 Rs/KJ. The variation of total cost of insulations with rate of interest has been presented in the tables. It was observed that increasing the rate of interest, the total cost of insulation decreases significantly. For all insulating materials increasing heat transfer coefficient, the cost also increases. Similarly, payback period also increases with the total cost. Similarly, by decreasing temperature differences, the total cost of insulation also decreases significantly for a insulating materials. The thickness of insulation increases, the total cost of insulation decreases, and optimum value of thickness of insulation has been obtained.

5. Results And Discussions

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 five insulating materials such as cellular plastic, pearlite, corrugated asbestos, polyurethane 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. It was observed that the most efficient and economic material comes to be cellular plastic of 0.031(W/m oC) thermal conductivity.. 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

Materials	Thermal Conductivity	Economic thickness (m)	Total cost (Rs.)
Cellular Plastics	0.031	0.060	16949.56
Pearlite	0.06	0.095	2330.85
Corrugated Asbestos	0.1	0.120	3252.6
Polyurethane Rubber	0.015	0.145	4261.48
Styrofoam	0.263	0.19	6177.9
Rockwool	0.4	0.25	7958.93

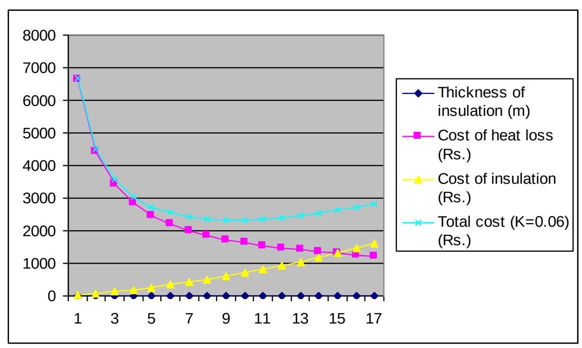

Fig: 1. Variation of cost with thickness of Rock wool insulation

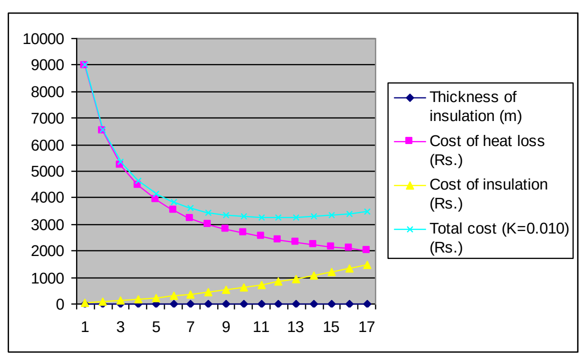

Fig: 2. Variation of cost with thickness of Pearlite insulation

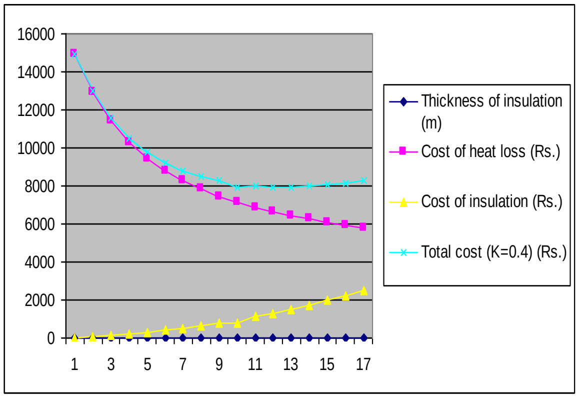

Fig: 3. Variation of cost with thickness of Corrugated Asbestos insulation

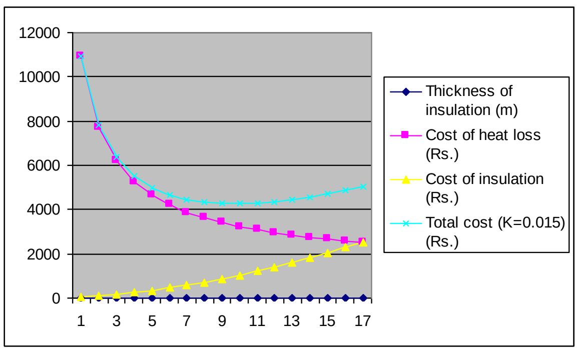

Fig: 4. Variation of cost with thickness of Polyurethane Rubber insulation (K=0.015)

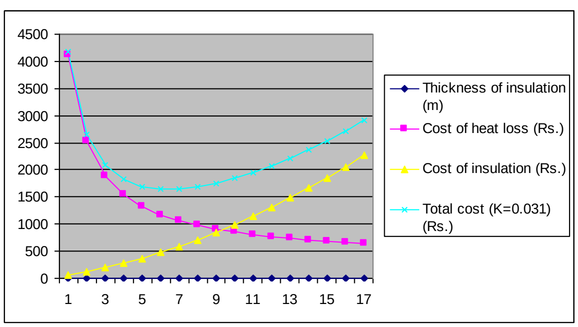

Fig: 5. Variation of cost with thickness of Cellular Plastic insulation (K=0.031)

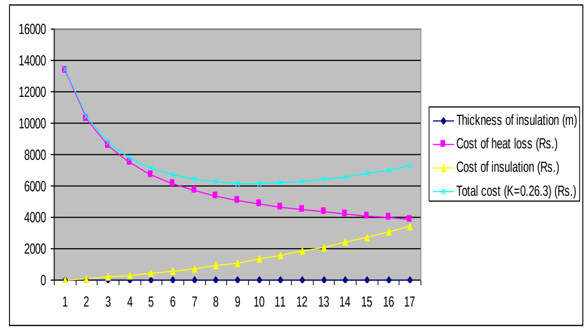

Fig: 6. Variation of cost with thickness of Styrofoam insulation (K=0.263)

6. Recommendation

The thermal analysis was done for the materials for 6 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:

1. The most efficient economic material comes out to be cellular plastic.
2. With increase in thermal conductivity the cost of insulation decreases and cost of heat losses increases and hence total cost also increases.
3. Increases in interest rate leads to increases in total cost.
4. For increase in heat transfer co-efficient, the total cost first increases rapidly and stabilizes for higher values of heat transfer co-efficient.
5. For increases in temperature differences the total cost increase linearly.
6. For increase in thermal conductivity the total cost also increases for same value of temperature differences.
7. For increase in payback period the total cost of insulation also increases linearly.

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