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DETERMINATION OF OPTIMUM INSULATION THICKNESS OF STEEL PIPES USED IN HEAT TREATMENT FURNACE BETWEEN BLOWER TO FURNACE BOX (A CASE STUDY)

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Abstract
This paper is greatly valued over the determination of econmic insulation thickness mounted over the steel pipes. The insulation is done by calcium silicate which has the ability to absorb high heating temperature nearly about 950^0C.This insulation is provided on the steel pipes which is connected with the input blower(combustion chamber) to the heating chamber of the furnace box .Due to the higher temperature the heat loss occurs at the pipes thereby reducing the productivity . By providing insulation and saving the heat loss may not bring productivity also, as the investment may rise so there is a need for determining economic thickness of insulation of steel pipes. The economic thickness is evaluated with the help of determining the total cost of heat energy loss costs and the insulation cost for various insulation thickness like 2”,2.5” and 3.1” values and finally calculated for calcium silicate as an insulating material the economic thickness is 3.1" for 168.3 mm Bare steel pipe diameter and length of 50 meter.
Keywords: Net present value, Thermal conductivity, Surface emmisivity and Heat energy loss.

Introduction
There is always a need for preventing heat transfer from the steel pipes where the heat is supplied to carry out heat treatment to the furnace,so proper insulation is desired which is utilized to mount over it.As the insulation is having low thermal conductivity so it can counteract the heat from getting transfer through the pipes to the surrounding medium.The thermal insulation has several benefits
(1) Energy usage is minimum
(2) Balances the process temperature inside the furnace
(3) Eliminates the corrosion on the steel pipes.
(4) Acts as an fire extinguisher of the furnace, as pipes can get heated and starts phase transformation.
(5) Due to low loss of heat ,the temperature calibration is maintained inside the furnace.

Insulation material:- Insulation materials is grouped into two types(a) organic type.(b) Inorganic typeIn organic type there are hydrocarbon polymers which can be expanded to obtain high void structure like thermocol (expanded polystyrene) and poly Urethane form (puf).In Inorganic polymers the hydrocarbons is based on siliceous /Aluminuous/Calcium materials in fibrous,granular or powder form.Example mineral wool,calcium silicate etc.

Properties of common Insulating material are as under:-

1) Calcium silicate- It is used in engineering industry where it is to be utilized in furnace,boiler etc.The temperature range is $(400 – 950)^0$celcius.
2) Glass – mineral wool –It is available in flexible form which is quite rigid slabs and preformed pipe work sections.It finds wide application in good thermal and acoustics insulation and chilling systems pipelines and can withstand temperature in the range of $(50\text{-}500)^0$ celcius.
3) Thermocol –It is mainly used as cold insulation for piping and cold storage construction.They can withstand very low temperature.

Thermal conductivity of a typical hot insulating material is shown in table for calcium silicate for various temperature

Mean temperature in degree celcius	Values of calcium silicate
100	**0.07**

200	**0.08**
300	**0.081**
400	**0.09**
700	**0.10**
1000	**0.11**

Economic Thickness of Insulation – Any thing which is adding advantage to the engineering industry will incur a certain additional cost which is an capital expenditure .To control the over use or wastage or due elimination of one item introduced, leads to the loss of existing item may incur additional cost causing adverse effect in the system is to be planned and that is said to be Economics.The parameters which influence optimality of insulation thickness is the furnace efficiency and different fuel cost.To determine the economic insulation thickness we have to determine least heat loss and least depreciation cost and the optimum value will be obtained where this two factors are evaluated simultaneously and get the final result.

Literature survey

AL-Sanea 2005 has investigated the thermal insulation of building using moulded polystyrene as an insulating material and evaluated the effects of electricity tariff on optimum insulation thickness.[1] Ozturk 2006 has investigated four technologies to determine optimum pipe diameter and insulation thickness like minimization of heat loss with or without cost minimization, applying law of thermodynamics, maximizing energy efficiencies with and without cost minimization.[2] Ucar 2010 has determined experimentally the optimum thickness of insulation by using condensed vapourin external walls calculated by exergoeconomic analysis.[3] Buyukalaca 2004 has investigated new outdoor design conditions for heating and cooling according to (ASHRAE) for different base temperatures in nine provinces by south eastern Anatolia project[4]. Bahadori 2010 has analysed and adopted simple method for determining the thickness of thermal insulation for flat surfaces upto 250mm and duct and pipes upto 2400mmwith an accuracy of 3.25%.[5]. Dombayci 2006 has determined the optimum insulation thickness of the external wall basedon life cycle cost using coal and expanded polystyrene as insulating material [6]. Yu Jinghua 2009 has investigated the best life cycle cost saving and lowest pay back period of the expanded polystyrene out of many materials for insulation in the wall of the buildings.[7]. Omar kaynakli 2011 has investigated the various control factors for determining optimum insulation thickness like heating and cooling energy ,lifetime of the insulation ,inflation rate ,energy costs ,thermal conductivity of insulation and finally calculated total life cost and payback period of building walls[8]. Mahlia 2010 has investigated the optimum thickness of insulation of building walls by introducing air gap and calculated the optimum width of air gap and also determined cost energy savings for its use.[9]. Li Y F and Chow 2005 had applied thermoeconomic optimization techniques to maintain reliable tube wall temperature of the piping system with least value. Thus evaluated life cycle cost analysis for it.[10]. Ozkan 2011 has optimized the insulation thickness for glazing areas for different insulation thickness and fuel on fuel consumption and determined emissions reduction for effectiveness.[11]. Daouas 2011 has predicted the life cycle cost analysis over a building and shown that south orientation of building is most effective for energy savings and payback period for optimum insulation thickness. [12]. Sisman,Nuri 2007 has investigated the optimum thickness of insulationfor external walls ,roofs for different degree day regions in turkey.[13]. Hasan Afif 1999has investigated life cycle cost analysis and payback period period of rockwool and polystyrene insulation and payback period are less depending on wall surface.[14]. Ucar 2010 has optimized the life cycle cost analysis for different insulation materials and found out the maximum payback period is obtained for natural gas and least for liquid petroleum gas.[15]. Sahin 2005 has analysed deviation of insulation thickness of a pipe where high temperature fluid flows and determined a very close to linear variation exist which is very easy to implement in practical work[16].

Problem indentification:

After surveying the investigations by several authors it is being investigated that there was massive analysis done on insulation material over the buildings ,there walls and roofs and determined the life cyclecosts and payback period of best insulation material, but no one have studied or analysed till about the insulation of steel pipes which is used in the attachment between the heater and the heat treatment furnace where very high temperature is developed and the heat loss from the pipe is very significant and that loss can be protected by mounting insulation of suitable thickness .Now we have to consider an important factor that is economic thickness of insulation. The insulation which we are providing must not cause an increase in depreciation due to increased thickness of insulation so that economical value will be determined out of different thickness being selected .

Methodology and Results Discussions

To determine the Economical thickness of insulation material there are several factors which need to be considered like duration of operating hours ,volumetric efficiency of the fuel, value of heating energy in the fuel, furnace efficiency,operating surface temperature ,pipe diameter/thickness of the insulating surface ,Estimated cost of insulation and average ambient temperature.

To carry out the operation we have to follow various steps (1) Note the reading of the bare pipe surface temperature. (2) Note the dimension of the pipeline like diameter ,length and surface area. (3) Assume an average ambient temperature =20^0celcius. (4) Determine the surface temperature after insulation which will be done by trial method. (5) Calculate the surface heat transfer coefficient of bare and insulated surface .(6) Select r_2 such that the equivalent thickness of insulation of pipe = insulation thickness.(7) Adjust the desired surface temperature values so that thickness is close to standard values.(8) Estimate the surface area of the pipe with different insulation thickness calculate total heat loss from surfaces using heat transfer coefficient and temperature difference between pipe surface and ambient .(9) Estimate the cost of energy losses in all the three cases. Calculate the net present value for five years for the future of energy cost of the insulation life.(11) Find the total cost of putting insulation for the three cases including material and labour cost.(12) Calculate the total cost of energy cost and insulation for the three cases.(13) Insulation thickness corresponding to **the lowest total cost** will be **Economic thickness of insulation.**

Selection of Dimension for Steel pipes for covering Insulation:

Material of steel pipe =Stainless steel.

Grade of SS pipe= TP314S or TP310S

Length of the pipe=50 meters

Bare pipe outer diameter=168.3mm

Ambient temperature =20^0 C

Heat treatment furnace temperature =900 ^{0} C

Bare pipe temperature= 700 ^{0}C

Insulating material =**Calcium Silicate.**

Selected Insulation thickness for optimization =**2", 2.5" and 3.1".**

Calculation:

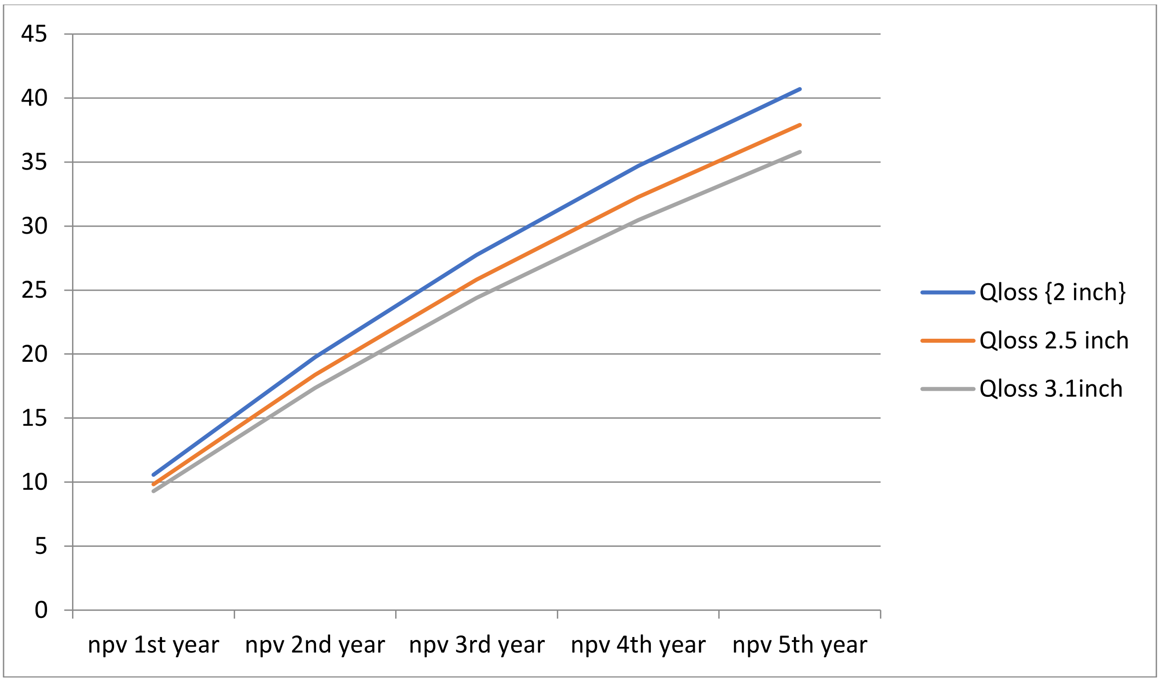
Description	Formula(if any)	Unit	Insulation thickness 2"	Insulation thickness 2.5"	Insulation thickness 3.1"
Length of pipe	selected	meters	50	50	50
Base pipe outer diameter D_1	selected	millimeter	168.3	168.3	168.3

Base pipe surface area A_1	$3.14*D_1*L$	Meter^2	26.42	26.42	26.42
Ambient temperature T_a	selected	^{0}C	20	20	20
Bare pipe wall temperature T_h	known	^{0}C	700	700	700
Desired insulated wall temperature T_c	Safe value	^{0}C	150	140	130
Mean temperature of insulationT_m	**$T_m= (T_h + T_c)/2$**	^{0}C	425	420	415
Specific conductivity of insulation	From data table	W/m^{0}C	0.09	0.10	0.11
Surface emisivity of bare pipe	From data table		0.95	0.95	0.95
Surface emissivity of insulation cladding	From data table		0.85	0.90	0.92
Surface heat transfer coefficient of hot bare surface h	$h=[0.85+0.005(T_h-T_c)]*10$	W/m^2 ^{0}C	42.5	42.5	42.5
Surface heat transfer after insulation h'	$h'=[0.31+0.005(T_c-T_a)]*10$	W/m^2 ^{0}C	9.6	9.1	8.6
Thermal resistance R_{th}	$R_{th}= (T_h-T_c)/[h'(T_c-T_a)]$	^{0}C-m^2/W	0.55	0.62	0.72
Thickness of insulation t	$t =k*R_{th}$	mm	49.5	62	79.2
Outer radius r_1		mm	84.15	84.15	84.15
Equivalent thickness T_{eq}	$T_{eq}= r_2 \ln(r_2/r_1)$	mm	50.2	62.1	80.3
After insulation outer radius r_2		mm	126	134	146

Thickness of insulation	calculated	mm	50.2	62.1	80.0
Insulated pipe area A_2	A_2=3.14*D_2L	m^2	39.56	42.06	45.84
Total loss from bare surface Q	Q=h*A_1*(T_h-T_a)	KW	763.53	763.53	763.53
Total loss from insulated surface Q'	Q'=h'*A_2*(T_c-T_a)	KW	49.37	45.92	43.36
Power saved P	P=Q-Q'	kW	714.16	717.61	720.17
Annual working hours n	Known for a concern	Hrs/ year	8000	8000	8000
Energy saving after providing insulation E	E=P*n	KWh/year	5713280	5740880	5761360
Fuel cost	From data	Rs/kg	21	21	21
Heat energy cost p'	From data	Rs/kwh	3.08	3.08	3.08
Annual monetary saving S	S=E*p'	Rs	17596902.4	17681910.4	17744988.8
Discount factor for NPV of cost of energy loss i	Allowable	%	15	15	15
Cost of insulation (mat+labour)	calculated	Rs/m	276	345	433.3
Total cost of insulation	(Cost/m)*L	Rs	13800	17250	21665
Annual cost of Energy loss E'	Q'*n*p	Rs/year	1216476.8	1131468.8	1068390.4
NPV of annual cost of energy loss for 5years	Summation from t=0 to 5 of($E'/(1+i)^t$) where i=discount.t=time period	Rs	4077818.894	3792858.883	3581410.326
Total cost [insulation +NPV of heat loss]	TC+NPV	Rs	4091618.894	3810108.883	3603075.326

Lowest value of total cost = Rs 3603075.326 which shows economic thickness for insulation as 3.1".

Graph: Graph plotted between NPV for a period of 5 years verses total cost due to heat loss for selected insulation thickness



Conclusion

From above calculation we observe that minimum cost incurred for heat loss is for insulation thickness of 3.1".So Economic insulation thickness is 3.1 inch and the graph also represents the minimum value for the cost expense for 3.1 inch.so calcium silicate of 3.1" is suitable for length of SS pipe of 50mm,d_o =168.3 mm ,can able to withstand 700^0celcius and ambient temperature of 20^0celcius.

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