Influence of Emissivity of Jacketing Materials on Energy Conservation in Insulated Steam Pipes

E. A. Osore, C. K. Ndiema, H. B Masinde, D.S. Ndugi

***Abstract*— Research has shown that, with steam pipes insulated, substantial quantities of heat energy are still wasted daily in industrial plants nationwide because of thermal radiation which is subsequent to the emissivity factor of the radiant source's surface. These thermal heat losses cause high energy consumption and this, affects process operations and product quality. Insulated pipes are usually jacketed to protect the insulation from external attack and for aesthetic purposes. But due to a difference in the thermal properties and characteristics of jacketing materials, it was necessary to assess if they can be utilized for improving the effectiveness of the insulation by preventing a substantial heat loss and characterizing them in the order of their performance..Therefore, this experiment involved measurement of surface temperatures of three different jacketing materials namely aluminium, galvanised steel and cloth each at different operating temperatures. Then the heat losses were calculated for each jacketing material used and the results analysed by Excel™computer software. It was deduced that, the presence of jacketing materials improved the effectiveness of energy conservation by a range of 4.9% to 5.5% depending on the emissivity of jacketing material used. Aluminium (ϵ = 0.04) recorded the lowest heat loss thus being optimum for energy conservation. Also, as a design factor, emissivity was found to be directly proportional to energy conservation.**

***Index Terms*— Heat conservation, thermal insulation, Jacketing materials, emissivity.**

I. Introduction

The need to conserve energy is more crucial in Kenya due to relative high costs of fuel oil prices and high power consumption trends which render the country's product uncompetitive in the international market (Andrew, 2006). According to statistics, energy remains a primary input in most production processes and accounts for 20-50% of production cost, and in some cases up to 70%, despite the presence of insulations (Oyuke, 2006). A national survey of Kenya industries indicates that wastage of energy ranges between 10-30% of primary energy inputs, yet insulation exist (Wakaba, 2004). This challenge seriously affects process operations and product quality.It can therefore be observed that, the need to further improve the effectiveness of insulation which is the ability of the insulation to best meet the objective for which it was designed for (design criteria) is essential. This is achieved by improving the performance indicators of the respective design criteria, which is heat loss for the case of energy conservation. Thus, the need to assess the effects of emissivity of the jacketing materials, which are primarily used for protecting the insulation, on the pipe insulation designs with regard to heat conservation. The research aimed to assess the performance of jacketing materials in reducing the rate of heat loss, establish the relationship of emissivity of jacketing to the effectiveness of energy conservation, and to determine the optimum emissivity of the jacketing material for energy conservation designs.

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Calculations of exterior heat loss

The amount of radiation emitted is a function of the emissivity factor of the source's surface. Emissivity is the rate at which radiation (emission) is given off (Innovative Insulation Inc., 2013).Hot surfaces lose heat to the surroundings via convection and radiation. The equation for heat loss, Q, to the surroundings at ambient temperature Ta, from a hot surface at T_{os}, with area A is given by ASHRAE Fundamentals (1989) as:

$$Q_{Total} = Q_{Conv} + Q_{Rad} \quad 1$$

$$Q_{total} = h\,A(T_{os} - T_a) + \sigma\,A\,\epsilon\,(T_{os}^4 - T_a^4) \quad 2$$

For warm surfaces, the value of the convection coefficient h is about 8.5 W/m2-K. For hot surfaces, the value of the convection coefficient should be calculated as a function of the orientation of the surface and the temperature difference between the surface and the surrounding air. First verify if the flow is laminar or turbulent. Flow is (ASHRAE Fundamentals, 1989):

$$\text{Laminar if: } D^3\,\Delta T < 63; \ \text{Turbulent if: } D^3\,\Delta T > 633$$

An empirical relation of convection coefficient (h) is then calculated as follows:

Horizontal Pipes and Cylinders:

$$h_{Lam} = 0.27 \times \left(\frac{\Delta T}{D}\right)^{0.25}; \ h_{Tur} = 0.18 \times (\Delta T)^{0.335} \quad 4$$

In these relations, L and D are the characteristic length and diameter respectively (ft.), ΔT is temperature difference between the surface and the surrounding air (K), h is the convection coefficient in W/m^2 K.

Thermal insulation is commonly used to reduce the rate of unwanted heat loss from mechanical systems and equipment. Identifying the rate of thermal energy (heat) loss from an uninsulated surface is the starting point for understanding the incentive for installing thermal insulation (U.S Department of energy, 1995)

Jacketing materials

Insulation systems are usually (but not always) jacketed to protect the insulation or for aesthetic purposes. Jacketing is generally categorized by the type of protection required (e.g. weather barriers, vapour retarders, mechanical abuse coverings, or appearance coverings). Some insulation products utilize factory-applied coverings which may combine the finish and securement functions. Installation of these products should be per the manufacturer's recommendations. In other cases, the finish is installed in the field. Metal jacketing may be aluminium, stainless steel, or coated steel (NMIC, 2012).

II. MATERIALS AND METHODS

Experimental design

The experiment was carried out at Mumias Sugar company limited in the Kakamega county of Kenya. The experiment was a 1- factor completely randomized design with a comparative objective.The jacketing materials selected comprised of high emissive cloth (ϵ= 0.90), moderate emissive galvanized steel (ϵ=0.28) and low emissive aluminium (ϵ=0.04) to check for a significant change in the performance of thermal insulation parameters of energy conservation for the above different emissivities. Hence, the design termed as a randomized with a comparative objective.

Instruments

The instrumentation used to make the necessary measurements included:

a) NiCr-Ni alloy digital thermometer (0^0C – 1960^0C) for temperature indication.
b) Surface contact and point contact type thermocouple probes compatible with the temperature indicator.
c) Mercury thermometers (0-100^0C and 0-360^0C) for temperature verification.
d) Vernier callipers and meter rule for measuring pipe diameter and span length.
e) Aluminium, galvanised steel and cloth jacketing materials of emissivity 0.04, 0.28 and 0.90 respectively (read from manufacturers' tables for the material).
f) Hot water and steam pipes made of steel and insulated with glass fibre, each of Ø100mm at process temperatures of 100, 150, 220, 300, 350 and 500^0C where the jacketing materials were wrapped on the surface interchangeably.

Experimental set up

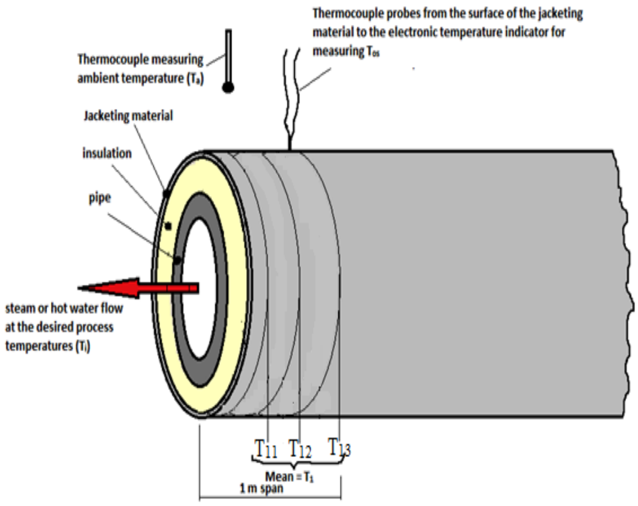

Figure 1: Experimental arrangement for data collection.

Surface temperatures were measured by physical contact between the thermocouple sensor and the surface of the jacketing materials as shown in Figure 1.For each jacketing material wrapped interchangeably, the measurements were taken on a chosen steam pipe over sixrandom spans of 1 m each and in each span further sub readings were taken at intervals of 300mm. The average of the sub readings represented the surface temperature reading over the respective span. Subsequently, the average of the six span readings represented the outside surface temperature for the respective jacketing material at that particular process condition. The ambient temperature was measured by holding the thermocouple probe in the air at a meter distance from the insulation system surface. This temperature was measured separately against each reading of the insulation system surface temperature. For consistency and comparative purposes, it was aimed at having all readings in still air withindoor environment at wind speed of 0.3 m/s, (Baldwin P.E.J and Maynard A.D 1998).This was to ensure that the temperature readings were recorded at a particular wind speed, since wind speed (nuisance factor) affects T_{os}. The following process temperatures adopted by the experiment were found in the respective locations in the company (All outer nominal pipe diameters are 100 mm).

Table 1: Location of 100 mm outer nominal diameter pipes

Process temperature, T_i(^oC)	Fluid transported	Location
100	Hot imbibition water	Sugar milling plant
150	Steam from heat exchanger	Ethanol plant
220	Steam to evaporator tanks	Sugar milling plant
300	Steam to the heater tanks	Ethanol plant
350	Steam from turbines to condensates	Co-generation plant
500	Steam from steam header to turbines	Co-generation plant

Control experiment

The same experiment was conducted without the jacketing materials in place, but only the insulating material (fibre glass). This was to enable the assessment of the performance of jacketing materials relative to when it is not installed. The fibre glass had an emissivity of 0.95 as per the manufacturer's recommendation.

III. RESULTS AND DISCUSSION

Energy conservation

The effectiveness of insulation to provide energy conservation is indicated by the rate of heat loss, Q. The lower the rate of heat loss exhibited, the better the performance of the jacketing materials and consequently the more effective it is in conserving energy and vice versa. Q was calculated using equations by ASHRAE fundamentals. The summary of the calculated Q for the respective emissivities is shown in table below.

Table 2: The summary of the heat loss from the surfaces to the surroundings.

Operating temperature	Bare pipe	Control experiment	Aluminium ϵ =0.04	Galvanised steel ϵ =0.28	Cloth ϵ =0.90	Pearson's Correlation (R) of ϵ with Q
T_i		Q/hr (W/m)	Q/hr (W/m)	Q/hr (W/m)	Q/hr (W/m)	
100	284.17	55.48	12.83	14.02	14.4	0.7432
150	587.72	80.43	20.25	23.92	27.28	0.8647
220	1167.14	125.53	38.02	39.55	43.92	0.8774
300	2102.16	189.95	56.82	65.16	70.48	0.8556
350	2868.32	231.91	70	80.2	88.49	0.8751
500	6272.55	348.38	104.37	116.7	134.06	0.8782
Mean	2213.68	171.95	50.38	56.59	63.1	
Effectiveness		0.922	0.977	0.974	0.971	

The graph of Q vs. T_i for each jacketing materialin table 3 is plotted in figure 2.

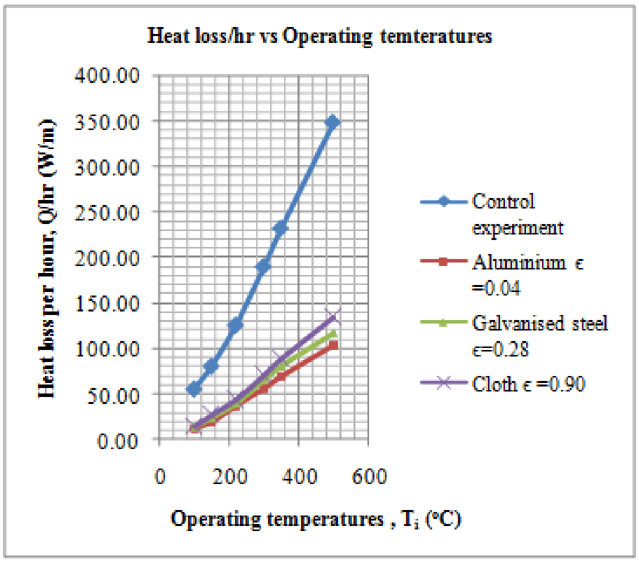

Figure 2: Graphs of heat loss per hour vs. T_i for the jacketing materials.

IV. DISCUSSION

The trend shows that, the higher the operating temperature the higher the rate of heat loss, this is because more heat is dissipated at higher process temperatures.From the above table, the mean Q for the control experiment, Aluminium, galvanized steel and cloth jacketing are 171.95, 50.38, 56.59 and 63.10 W/m. respectively. Their corresponding performance effectiveness, calculated with respect to the mean Q of the bare pipe as $\frac{Q_{bare\ pipe} - Q_{jacketing}}{Q_{bare\ pipe}}$ are 92.2, 97.7, 97.4 and 97.1% respectively. For the three jacketing, Aluminium of lowest emissivity(ϵ = 0.04) exhibited the least Q of 50.38 W/m, which is equivalent to the highest effectiveness of 97.7%. While cloth of highest emissivity (ϵ = 0.90) exhibited the highest Q of 63.10 W/m which is equivalent to the lowest effectiveness of 97.1%. Therefore, aluminium jacketing proves to be the best of the three when energy conservation is the design criteria of the insulation. When a control experiment was conducted, the mean Q was the highest of all with 171.95 W/m which equivalents to the least effectiveness of 92.2%. The presence of jacketing contributed to energy conservation by approximately 4.9% (97.1 – 92.2%) to 5.5% (97.7 – 92.2%) for high and low emissive jacketing respectively. This is well illustrated by the above graph of Q vs. $T_i$which depicts that Aluminium with low emissivity ϵ = 0.04 allows less heat loss to the surrounding compared to Galvanized steel and Cloth of emissivity of 0.28 and 0.90 respectively for all the operating temperatures.

Similarly, this being the observed trend in this experiment, it is therefore evident that jacketing materials can influence the Q in that, the lower the emissivity the lesser the rate of heat loss from the system and the better the performance of the insulation. Hence, low emissivity is the optimum for energy conservation design.

V. ANALYSIS OF VARIANCE

The only factor being investigated is the emissivity of jacketing. There were 6 replicates for each treatment. The replicates are the calculated Qat T_i = 100,150,220,300,350 and 500°C. The treatment levels are the three emissivities of the jacketing. The ANOVA table for a single factor at a significance level of 5% was generated.

Table 3: ANOVA: Single Factor with replications for energy conservation

Groups	*Count*	*Sum*	*Average*	*Variance*
Ti = 100 oC	3	72.05	24.02	43.83
Ti = 150 Oc	3	120.81	40.27	196.39
Ti = 220 Oc	3	195.49	65.16	364.56
Ti = 300 oC	3	303.25	101.08	1045.13
Ti = 350 Oc	3	372.61	124.2	1599.58
Ti = 500 Oc	3	578.03	192.68	3180.4

ANOVA

Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	57808.28	5	11561.66	10.79	0	3.11
Within Groups	12859.79	12	1071.65			
Total	70668.07	17				

** 0.05 significance level

For relationship analysis(Box, George E.P. et. al, 2007), let:

H_o: There is no linear relationship between any of the ϵ, under consideration, and Q. (All the population means for the various treatments are equal) H_1: There exists a functional relationship between Q and ϵ. True if $F_{calc} > F_{crit}$. **From the ANOVA table:**

The calculated value of F (F_{calc}) = MSE/MSR = 11561.66/1071.65 = 10.79 Since $F_{calc} > F_{crit}$, H_o is rejected and it is concluded that at 95% confidence level, there is sufficient evidence that there exist a relationship between Q and ϵ. By the comparison of two sample variance technique, in hypothesis testing using F-test, Q and hence energy conservation is directly proportional to ϵ of jacketing. This is also illustrated by the positively high correlation coefficients (R) in Table 3 and the positively sloped correlation curves in figure 3.

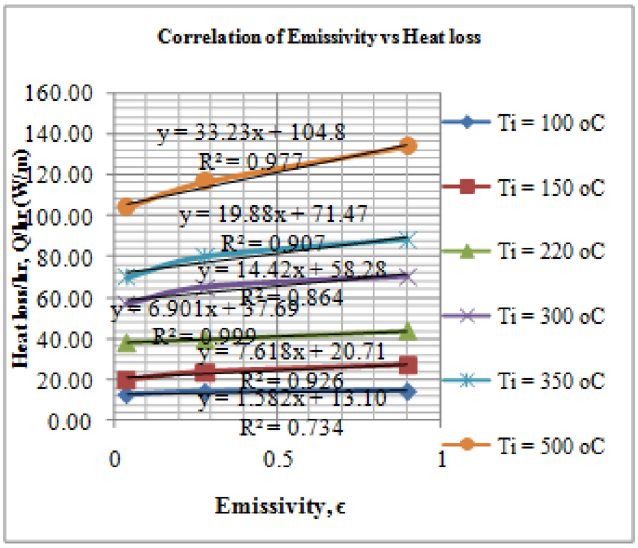

Figure 3: Correlation graphs of Q vs. ϵ

VI. CONCLUSION

Proper selection of Jacketing materials should be incorporated in the design of insulation because it improves the overall performance of insulation rather than being used for protection and aesthetic use only.The presence of jacketing materials does improve the overall performance of insulation designs. When control experiments were conducted the mean values of heat loss were the highest compared to the mean values recorded when the jacketing materials were in place as shown in Table 3with an effectiveness range of 4.9% through 5.5%.

In the selection of the jacketing materials, the lower the emissivity of jacketing materials the better the performance in energy conservation. Aluminium with the lowest emissivity of 0.04 recorded the least mean heat loss compared to Cloth with the highest emissivity of 0.90 which recorded the highest mean heat loss.Hence, jacketing materials with low emissivity allows less heat to radiate from the system and are the optimum.

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