Performance Efficiency of Jacketing Materials in Relation to Emissivity on Environmental Conservation in Insulated Steam Pipes

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***Abstract*— Emissivity is the focus of this study because it is only on the surface of the pipes that, in addition to convection, heat is emitted and dissipated to the atmosphere by radiation. 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 pose great challenges which include high fuel consumption and consequently environmental pollution. Therefore, any undue loss of heat can seriously affect the environment at large. Insulated pipes are usually jacketed to protect the insulation and/or for aesthetic purposes. But due to a difference in the thermal properties and characteristics of these jacketing materials, it is necessary to assess if they can be utilized for improving the effectiveness of the insulation and curb the said challenges. 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 loss and pollutant emissions were calculated for each material used and the results analysed by Excel™ computer software. It was deduced that, the presence of jacketing materials improved the effectiveness of pollution control by 4.9% to 5.5% depending on the emissivity of the jacketing material used. Low emissive aluminium ($\epsilon = 0.04$) recorded the lowest pollutant emissions than the high emissive cloth ($\epsilon = 0.90$), thus being optimum for improved environmental conservation. Also, as a design factor, emissivity was found to be directly proportional to environmental conservation by having positively strong correlations to pollutant emission.**

Keywords*— Emissivity, environmental conservation, Jacketing materials, pollutant emission, thermal insulation, steam pipes.

I. INTRODUCTION

Thermal insulation is a major provision which assists a designer in fulfilling the vital economic need of preventing loss of available heat energy. According to Robert and Collins (2007), insulation is defined as a material or combination of materials, which retard the flow of heat. Mechanical insulation is primarily used for energy conservation. There are three primary reasons to conserve energy: Energy (minimizing the use of scarce natural resources), Economics (maximizing return on investment and minimizing the life cycle cost), and Environment (minimizing the emissions associated with energy usage). In conjunction with the benefits associated with conserving energy resources, insulation contributes to the reduction in emissions associated with using those energy resources. Since fossil fuels are the primary source of energy in developed countries, a reduction in energy usage will translate into a reduction in emissions from the burning of fossil fuels. The primary products of combustion of fossil fuel are CO_2 and water vapour. Both are considered greenhouse gases (NMIC, 2012).

Table 1: The weight concentration of the significant atmospheric pollutants in (ppm) for solid fuels like coal, bagasse, wood and charcoal

Chemical formulae	Weight concentration in parts per million
	kg/m/10^6 W
CO_2	309.97
NO_x	0.83
CE	84.46

(Source: ASTM C585, 1994)

For CO_2: 309.97kg of CO_2 is produced in every 10^6 W of heat per year;
For NO_x: 0.83kg of NO_x is produced in every 10^6 W of heat per year;
For CE: 84.46kg of CE is produced in every 10^6 W of heat per year

Calorific value of bagasse = 4942.75 W/kg (Hugot, 1986)

$$\text{The excess bagasse} = \frac{\text{Rate of heat loss, } Q}{\text{Calorific value}} \quad (1)$$

Table 2: Excess bagasse burnt due heat loss per year per meter of pipe

	Control experiment		Aluminium E=0.04		Galvanised steel E=0.28		Cloth E=0.90	
Ti	Q/hr (W/m)	bagasse kg/yr/m	Q/hr (W/m)	bagasse kg/yr/m	Q/hr (W/m)	bagasse kg/yr/m	Q/hr (W/m)	bagasse kg/yr/m
100	826849.8	167.3	136263.5	27.6	229365.6	46.4	233824.0	47.3
150	1176113.0	237.9	204513.3	41.4	371791.5	75.2	428856.4	86.8
220	1795524.0	363.3	365524.4	74.0	587675.8	118.9	673307.0	136.2
300	2666483.7	539.5	538563.1	109.0	931144.2	188.4	1053365.1	213.1
350	3229140.2	653.3	662867.4	134.1	1130463.8	228.7	1306781.3	264.4
500	4943977.3	1000.2	1081590.8	218.8	1736487.7	351.3	1991102.3	402.8

II. MATERIAL 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. The experiment was a 1- factor completely randomized design 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 ^{0}C 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 ^{0}C where the jacketing materials were wrapped on the surface interchangeably.

Experimental set up

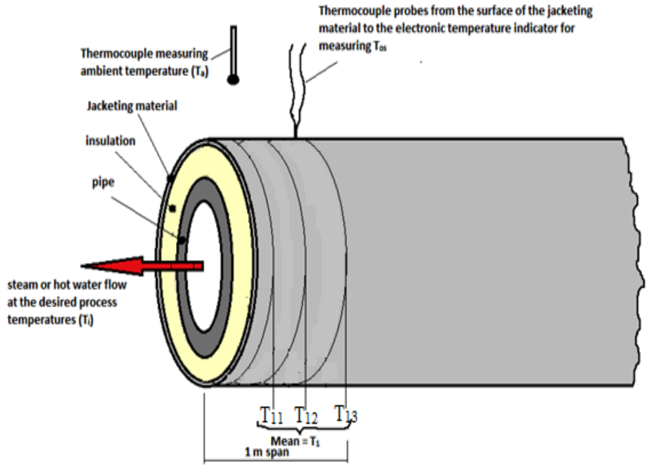

Fig 1: Experimental arrangement for data collection

Surface temperatures were measured by physical contact between the thermocouple sensor and the surface of the jacketing materials as shown in ***fig1***. For each jacketing material wrapped interchangeably, the measurements were taken on a chosen steam pipe over six random 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 (indoor environment at wind speed of 0.3 m/s). 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.

III. RESULTS AND DISCUSSION

From *Error! Reference source not found.* the effectiveness of insulation to provide environmental conservation is indicated by the rate of pollutant emitted to the atmosphere as a result of the excess fuel used to compensate for the heat lost in the system so as to maintain the process. The lower the rate of gaseous emission, the better the performance of the jacketing materials and consequently the more effective it is in conserving the environment and fuel usage. The three main gases considered to be associated with greenhouse effect were CO_2, NO_x and CE and the total rate of gaseous emission was calculated in accordance to ASTM C585 where the weight concentration of the various greenhouse gases are given for solid fuels. ***Table 3*** shows the summary of the gaseous pollutant emissions for the respective jacketing materials.

Table 3: Summary of the total greenhouse pollutants emitted to the atmosphere per year due to excess bagasse used in the furnace to compensate for the heat lost when various jacketing materials are incorporated in insulation

T_i		Total pollutants emitted (kg/m/yr)				Pearson's Correlation (R) of ϵ with pollutants
	Bare pipe	Control exp	Aluminium ϵ =0.04	Galvanised steel ϵ =0.28	Cloth ϵ = 0.90	
100	934.53	182.44	42.18	46.10	47.34	0.7432
150	1932.78	264.51	66.60	78.66	89.70	0.8647
220	3838.34	412.82	125.03	130.07	144.44	0.8774
300	6913.14	624.68	186.86	214.28	231.78	0.8556
350	9432.72	762.66	230.19	263.74	291.01	0.8751
500	20627.87	1145.69	343.22	383.78	440.88	0.8782
Mean	7279.88	565.47	165.68	186.11	207.53	
Effectiveness		0.922	0.977	0.974	0.971	

Also, the graph of the pollutant emissions against T_i for each of the jacketing material in the above table is plotted in ***fig 2***.

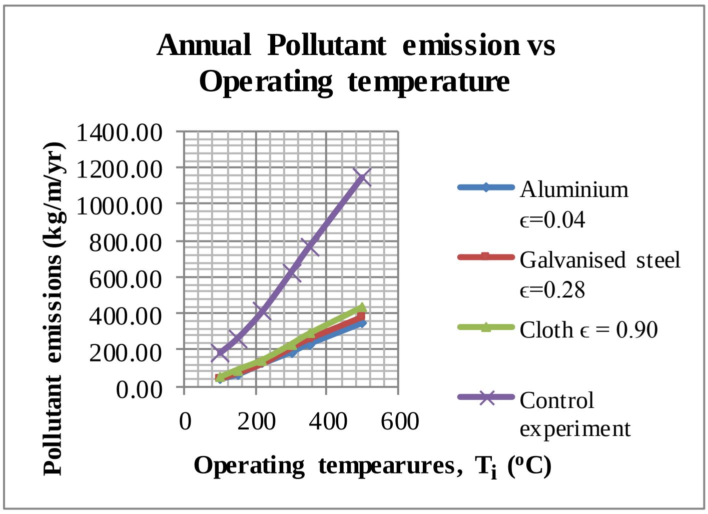

Fig 2: Graphs of annual pollutant emission vs. Ti for the jacketing materials

Discussion

The amount of pollutant emitted depends on the rate of heat loss, and consequently an increase in the operating temperature means an increase in the pollutant emission. From the above table, the mean total pollutants for the control experiment, aluminium, galvanized steel and cloth jacketing are 565.47, 165.68, 186.11 and 207.53 kg/m/yr respectively. These correspond to performance effectiveness, calculated with respect to the mean pollutant emissions of the bare pipe $\frac{P_{pipe}-P_{jacketing}}{P_{pipe}}$ of 92.2, 97.7, 97.4, 97.1% respectively. For the three jacketing, Aluminium of lowest emissivity (ϵ = 0.04) exhibited the least rate of pollutant emission of 165.68 kg/m/yr, which is equivalent to the highest effectiveness of 97.7%. While cloth of highest emissivity (ϵ = 0.90) exhibited the highest rate of pollutant emission of 207.53 kg/m/yr 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 pollutant emission was the highest of all with 565.47 kg/m/yr which equivalents to the least effectiveness of 92.2%. This shows that the presence of jacketing contributed to environmental 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 pollutant emission vs. T_i which depicts that Aluminium with low emissivity **ϵ** = 0.04 allows less gases to the surrounding compared to Galvanized steel and Cloth of emissivity of 0.28 and 0.90 respectively for all the operating temperatures, thereby reducing the extra amount of bagasse burnt to compensate for the lost heat and consequently the amount of the gaseous emissions to the atmosphere. According to NMIC and Calvert, reduction in fuel usage will translate into a reduction in emission from burning the excess fuel. These green- house gases are components of the atmosphere that contribute to green-house effect. Based on the observed results, Aluminium proves to be the best of the three jacketing since it emits the least gases. Hence, low emissive jacketing is the optimum jacketing for environmental conservation designs.

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 pollutant emission at T_i = 100,150,220,300,350 and 500° C. The treatment levels are the three emissivities of the jacketing. Using Excel™, the following ANOVA table for a single factor at a significance level of 5% was generated

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Table 4: ANOVA for pollutant emission

Groups	*Count*	*Sum*	*Average*	*Variance*
Ti = 100 ºC	3	236.9419	78.98062	474.0618
Ti = 150 ºC	3	397.3034	132.4345	2123.945
Ti = 220 ºC	3	642.8988	214.2996	3942.648
Ti = 300 ºC	3	997.2782	332.4261	11302.92
Ti = 350 ºC	3	1225.361	408.4537	17299.16
Ti = 500 ºC	3	1900.893	633.631	34395.5

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*
Between Groups	625186.9	5	125037.4	10.78866
Within Groups	139076.5	12	11589.71	
Total	764263.4	17		

** 0.05 significance level

For relationship analysis, let:

H_o: There is no linear relationship between any of the ϵ, under consideration, and pollutant emissions (population means for the various treatments are equal)

H_1: There exists a functional relationship between pollutant emission and ϵ. True if $F_{calc} > F_{crit}$.

From the ANOVA table:

The critical value of F (F_{crit}) from Excel = F.INV (0.95, 5, 12) = 3.11

The calculated value of F (F_{calc}) = MSE/MSR = 125037.4/11589.71 = 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 a relationship exist between pollutant emission and ϵ.

By the comparison of two sample variance technique, in hypothesis testing using F-test, pollutant emission and hence environmental conservation is directly proportional to emissivity of jacketing. This is also illustrated by the positively high correlation coefficients (R) in ***Error! Reference source not found.*** and the positively sloped correlation curves in ***fig 3***.

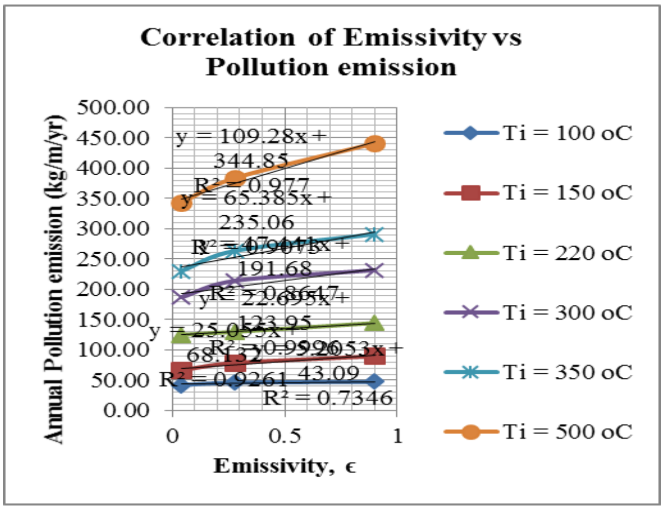

Fig 3: Correlation graphs of pollution emission vs ϵ

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 exterior 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 pollutant emissions were the highest compared to the mean values recorded when the jacketing materials were in place as shown in ***Table 3*** with an effectiveness range of 4.9% through 5.5%.

In the selection of the jacketing materials, the criteria is that the lower the emissivity of jacketing materials the better the performance in environmental consevation. Cloth with the highest emissivity of 0.90 recorded the highest mean poluttant emitted compared to Aluminium with the lowest emissivity of 0.04 which recorded the lowest mean pollutants emission. Hence, jacketing materials with low emissivity allows less pollution in the system and are thus the optimum.

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