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Characterisation of Emissivity of Jacketing Materials on Personnel Safety 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 which is subsequent to the emissivity factor of the radiant source's surface. These thermal heat losses elevate the temperature intensity leading to skin burns and equipment malfunctioning, hence personnel and equipment safety hazard. Therefore, any undue loss of heat can seriously affect workforce performance hence poor product quality. Insulated pipes are usually jacketed to protect the insulation from external interference and/or 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 performance of insulation by reducing the temperature intensity exposed to workers 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 and the results analysed by Excel™ computer software. It was deduced that, the presence of jacketing materials improved the effectiveness of personnel safety by a range of 0.5% to 3.3%, depending on the emissivity of jacketing material used. High emissive cloth (ϵ = 0.90) recorded the lowest surface temperatures hence being optimum for improved personnel safety and Also, as a design factor, emissivity was found to be inversely proportional to personnel safety by having negatively strong correlations to surface temperatures.**

Index Terms— **Surface temperatures, thermal insulation, Jacketing materials and emissivity.**

I. INTRODUCTION

Mechanical insulation is primarily used to limit heat gain or loss from surfaces operating at temperatures above or below ambient temperatures (Bhatia, 2012), but it also satisfies personnel protection by controlling surface temperatures to avoid contact burns (Robert and Collins, 2007).With industrial steam pipes insulated, there is still evidence that the pipe surfaces attains temperatures above 58°C, thus workers suffer burns resulting from skin contact with surfaces of hot piping and equipment(U.S Department Of Energy, 1995). These challenges seriously affect workforce and subsequently product quality. Thus, the need to assess how emissivity of the jacketing materials, primarily used for protecting the insulation, affects personnel safety. The research aimed to assess the performance of jacketing materials in reducing surface temperatures, establish the relationship of emissivity of jacketing to the effectiveness of safety, and to determine the optimum emissivity of the jacketing material for safety designs.

A material's surface emissivity is a measure of the energy emitted from the surface. Effective emissivity is affected by several variables, the most important of which are the geometric shape of the blackbody, the uniformity of the blackbody temperature, the surface emissivity and wavelength dependence (Chang-Da and Mudawar, 2002). All objects radiate infrared rays from their surfaces in all directions, in a straight line, until they are reflected or absorbed by another object. Traveling at the speed of light, these rays are invisible, and they have no temperature, only energy. Heating an object excites the surface molecules, causing them to give off infrared radiation. When these infrared rays strike the surface of another object, they are absorbed and only then is heat produced in the object. This heat spreads throughout the mass by conduction. The heated object then transmits infrared rays from exposed surfaces by radiation if these surfaces are exposed directly to an air space (Innovative Insulation Inc, 2013).

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(Holland, 2013).When designing an insulation system for personnel protection, the surface temperature becomes critical. The surface temperature can increase both from outside solar heat gain and from within as heat radiates outward from a hot pipe (Bhatia, 2012).To consider, is the ambient conditions that will create the hottest surface temperature, such as summer weather with no wind and a metal jacketing material. According to Orlove (2012), if an object has a higher temperature than its environment, then increasing its emissivity will certainly lower its temperature.

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 personnel protection for the above different emissivities. Hence, the design termed as a randomized with a comparative objective.

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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) Infrared camera for viewing heat intensities on respective jacketing materials.
d) Mercury thermometers (0-100^0C and 0-360^0C) for temperature verification.
e) Vernier callipers and meter rule for measuring pipe diameter and span length.
f) Aluminium, galvanised steel and cloth jacketing materials of emissivity 0.04, 0.28 and 0.90 respectively (read from manufacturers' tables for the material).
g) 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

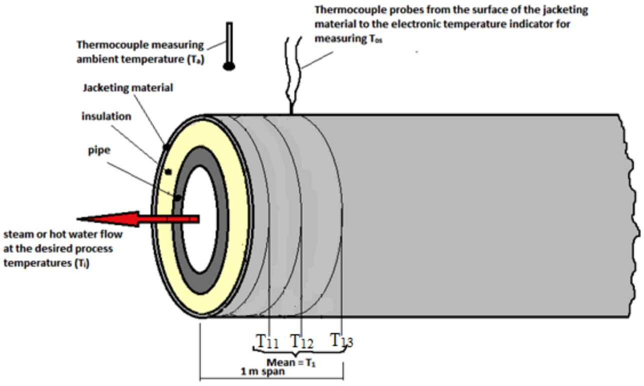

Figure 1: Experimental arrangement for data collection (see plate 3-10).

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 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, (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. 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 (°C)	**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

The performance of insulation to provide personnel safety is indicated by the intensity of the outside surface temperatures. The lower the outside surface temperatures exhibited, the better the performance of the jacketing materials and consequently the more effective it is in providing personnel safety against burns and vice versa. For the experiment conducted, the summary of the measured and recorded outside surfaces temperatures (T_{os}) for the respective emissivities is shown in Table 1. Also, the image of the surface heat intensity as depicted by the infrared camera when galvanised steel and cloth jackets were installed on an insulated steam pipe with a process temperature of 350^o C is shown in plates 1.

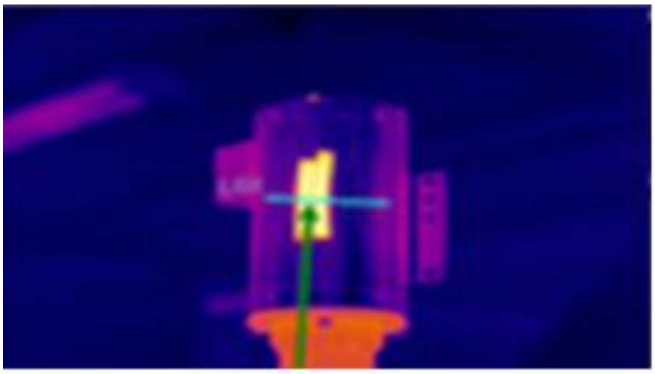

Plate 1: Surface heat intensity on galvanized steel($\epsilon = 0.28$) at the process temperatures of 350 °C ($T_{os} = 43.7^o$C.

Table 2: Location of 100 mm outer nominal diameter pipes

Operating temp (T_i)	Insulation thickness	Surface temperatures, T_{os} (°C)					Pearson'sCorrelation (R) of ϵ with T_{os}
	(t)	Bare pipe T_s	Control experiment	Aluminium ϵ= 0.04	Galvanised steel	Cloth	
					ϵ = 0.28	ϵ=0.90	
100	150	99.9	35.3	34.4	33	31.6	**-0.9745**
150	150	149.8	37.5	36.4	34.8	32.8	**-0.9852**
220	150	219.6	41.2	40.6	37.5	34.4	**-0.9674**
300	150	299.2	46.1	44.7	41.5	36.8	**-0.9898**
350	150	348.8	49.2	47.4	43.7	38.4	**-0.9895**
500	200	497	53.1	51.5	46.5	40.2	**-0.9841**
	Mean	**269.05**	**43.73**	**42.48**	**39.52**	**35.71**	
Effectiveness			**0.837**	**0.842**	**0.853**	**0.867**	

Also, the graph of T_{os} against T_i for each of the jacketing material in the above table is plotted below.

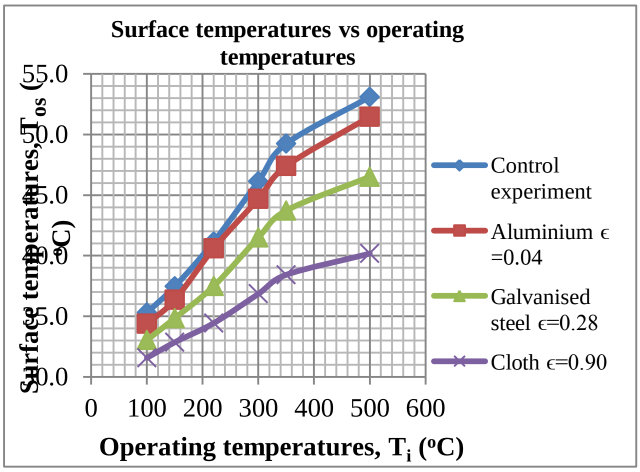

Figure 2: Graphs of T_{os} vs. T_i for the jacketing materials.

Discussion

From **plate s1** and **2**, For galvanised steel jacket (ϵ = 0.28), the measured steady state temperature is 43.7°C. The rate of radiation is low due to low emissivity compared to convection hence high surface temperature intensity. However, the rate of heat generation by the steam in the pipe has to be exactly balanced by the rate of heat loss on the surface of the jacket. Hence, jacketing with cloth(ϵ=0.90), the heat transfer will change. The rate of radiation will increase then the huge increase in the radiation loss will reduce the surface temperature to 38.4°C hence low surface temperature intensity

It is noted from **Table 1** that T_{os} increases with an increase in the operating temperature for all the jacketing materials. This is because more heat is dissipated at higher process temperatures. From table 1, the mean T_{os} for the control experiment, aluminium, galvanized steel and cloth jacketing are 43.73, 42.48, 39.52 and 35.71 °C respectively. Their corresponding performance effectiveness, calculated with respect to the mean T_s of the bare pipe as $\frac{T_s - T_{os}}{T_s}$, are 83.7, 84.2, 85.3 and 86.7 % respectively. For the three jacketings, Cloth with the highest emissivity (ϵ = 0.90) recorded the lowest T_{os} of 35.71° C equivalent to the highest efficiency of 86.7%, while aluminium with the lowest emissivity (ϵ = 0.04) recorded the highest T_{os} of 42.48 ° C which is equivalent to the lowest efficiency of 84.2%. Therefore, cloth jacketing proved to be the best of the three, when personnel safety is the design criteria of the insulation. When a control experiment was conducted, the mean $T_{os}$was the highest of all with 43.73 ° C equivalent to the least effectiveness of 83.7%. This shows that the presence of jacketing contributed to personnel safety by approximately 0.5 % (84.2 - 83.7 %) to 3% (86.7 - 83.7%) for low and high emissive jacketing respectively. This is well illustrated by the above graph which depicts that cloth of high emissivity ϵ = 0.9 recorded low (safest) T_{os} compared to Aluminium and galvanized steel of 0.28 and 0.04 respectively for all the operating temperatures.

It is therefore evident that a cloth jacketing of 0.9 gave a mean T_{os} of 35.71° C compared to aluminium jacketing of 0.04 which gave a mean T_{os} of 42.48° C. this ascertains that, the higher the emissivity of the jacketing the lower the T_{os} and the better the personnel safety. Hence, high emissivity is the optimum for personnel safety design.

Analysis of variance

The experiment was a randomised one whereby only one factor (emissivity of jacketing) was being investigated. There were 6 replicates for each separate treatment. These replicates are the recorded T_{os} at T_i = 100,150,220,300,350 and 500° C. The treatment levels are the three emissivities of the jacketing under investigation. Using Excel^{TM}, the following ANOVA table for a single factor at a significance level of 5% was generated.

Table 3:ANOVA: Single Factor with replications for personnel safety

Groups	*Count*	*Sum*	*Average*	*Variance*
T_i = 100 ^oC	3	98.97	32.99	1.98
T_i = 150 ^oC	3	104.04	34.68	3.09
T_i = 220 ^oC	3	112.52	37.51	9.52
T_i = 300 ^oC	3	123.03	41.01	15.57
T_i = 350 ^oC	3	129.54	43.18	20.35
T_i = 500 ^oC	3	138.16	46.05	32.09

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	383.84	5	76.77	5.58	0.01	3.11
Within Groups	165.21	12	13.77			
Total	549.05	17				

** 0.05 significance level

For relationship analysis, let:

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

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 T_{os} and ϵ. the comparison of two sample variance technique, in hypothesis testing using F-test, T_{os} and hence personnel safety is inversely proportional to emissivity of jacketing. This is also illustrated by the negatively high Pearson's correlation coefficients (R) in Table 1and the negatively sloped correlation curves below.

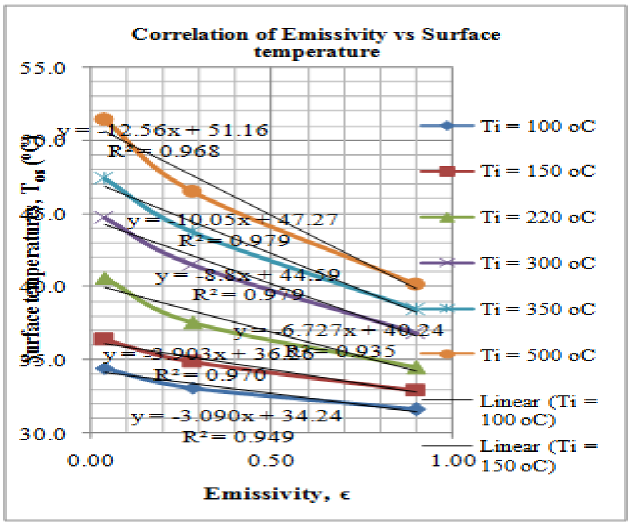

Figure 3: Correlation graphs of T_{os} vs. ϵ.

IV. CONCLUSION

When designing on the basis of safety, jacketing materials should be incorporated in the design because it improves the overall performance of insulation rather than for protection and aesthetic use. The presence of jacketing materials does improve the overall performance of insulation designs. When control experiments were conducted the mean values ofT_{os} recorded were the highest compared to the mean values recorded when the jacketing materials were in place as shown in Table 1 with an effectiveness range of 0.5% through 3.3% for personnel safety. In the selection of the jacketing materials, the higher the emissivity of jacketing materials the lower the surface temperatures experienced, hence the better the performance in personnel safety. Therefore, personnel safety is inversely proportional to the emissivity as shown by the strong negative Pearson's correlation coefficients in Table 1.

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