ISSN: 2319-5967
ISO 9001:2008 Certified
International Journal of Engineering Science and Innovative Technology (IJESIT)
Volume 4, Issue 4, July 2015

Correlation between process control and emissivity of jacketing materials in steam pipes

Osore E. A. E[1], Ahmed S.M[2], Rotich P.K[3]

Abstract— Process control is a critical design consideration in many industrial environments to maintain the plant operational parameters. The variation in process control is as a result of thermal heat losses from the pipe interior to the surroundings, and failure to maintain constant process control leads to elevated temperature change between the surface temperature and the ambient temperature resulting to affected process parameters. Therefore, any undue loss of heat can seriously affect process performance hence poor product quality and consequently wastage of resources (manpower, time and energy). However, research shows that minimal efforts to highlight the importance of process control have been done but surprisingly these temperature changes prevail when pipe insulations are covered with jacketing materials with an aim of protection against external interference and aesthetic purposes. On the surface of the pipes, 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. But due to the 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 minimizing the temperature changes in processes and categorise them in terms of their performance index. 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 process control 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 temperature change hence being optimum for maintaining constant process. Also, as a design factor, emissivity was found to be inversely proportional to process control by having negatively strong correlations to temperature change.

Index Terms— **Emissivity, Jacketing materials, process control, Temperature change, thermal insulation, steam pipes.**

I. INTRODUCTION

Process temperatures arise from the process heaters that radiate heat into the fluid, this subsequently elevated the process temperature and the excess dissipated through the pipe thickness to the surrounding. There are as many uses for process heaters as there are designs. The basic configuration consists of a shell (outer casing), tubes (where the process fluid flows) and a heat source.

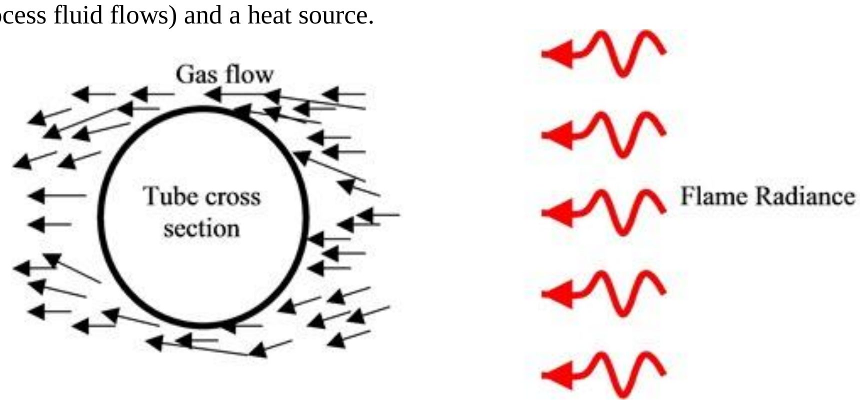

Fig 1: Radiation in process heaters (Orlove, 2012)

Fig 1 illustrates convective gas flow, which is turbulent and radiant heat from the flame, refractory and other tube (Orlove, 2012). In most cases, emissivity can help maintain process temperature to a pre-determined value or within a predetermined range by reducing heat loss or gain. Process control is usually a critical design consideration in many industrial environments and can be relevant with both hot and cold piping (NMIC, 2012).
As a rule of thumb, for a quick check of the performance of insulation on this basis, the temperature change, ΔT between the surface temperature of insulation and ambient air should be less than the values indicated in ***table 1***:

ISSN: 2319-5967
ISO 9001:2008 Certified
International Journal of Engineering Science and Innovative Technology (IJESIT)
Volume 4, Issue 4, July 2015

Table 1: Recommended temperature change for respective process temperatures ranges

Operating Temperature (^{0}C)	$\Delta T\,(T_s - T_a)$ (^{0}C)
≤ 200	7
>200 and ≤ 400	10
>400 and ≤ 600	15
> 600	20-25

Source: U.S. Department of Energy, 1995

These values ensure a tolerable insulation system surface temperature, the heat losses are within limits and workspace temperature around insulated system is comfortable. With insulation systems, the surface finish or emissivity and the surface resistance of the cladding or jacketing over the insulation are the two outstanding thermal barriers that must be considered (U.K Department of Environment, 1992). Considering hot water or steam supply at rated temperatures and pressures could be a stringent process requirement for many industrial processes. Certain processes require uniform temperature in narrow tolerances to achieve proper chemical reaction; too much or not enough heat can completely nullify the chemical reaction or can result in liquid crystallization and the batch loss. For example, in the transport of liquid sulphur, if the temperature drops below its freezing point, the liquid becomes solid. The time and energy required transforming the sulphur back into a liquid and flowing state is more expensive than the cost of replacing the transport system altogether (UK: Department of environment, 1992)

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.

Instruments

The instrumentation used to make the necessary measurements included:

a) NiCr-Ni alloy digital thermometer (0 ^{0}C – 1960 ^{0}C) 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 ^{0}C) for temperature verification.
d) Vernier callipers and meter rule for measuring pipe diameter and span length.
e) Aluminium, galvanized 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

Surface temperatures were measured by physical contact between the thermocouple sensor and the surface of the jacketing materials as shown in ***fig 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.

ISSN: 2319-5967
ISO 9001:2008 Certified
International Journal of Engineering Science and Innovative Technology (IJESIT)
Volume 4, Issue 4, July 2015

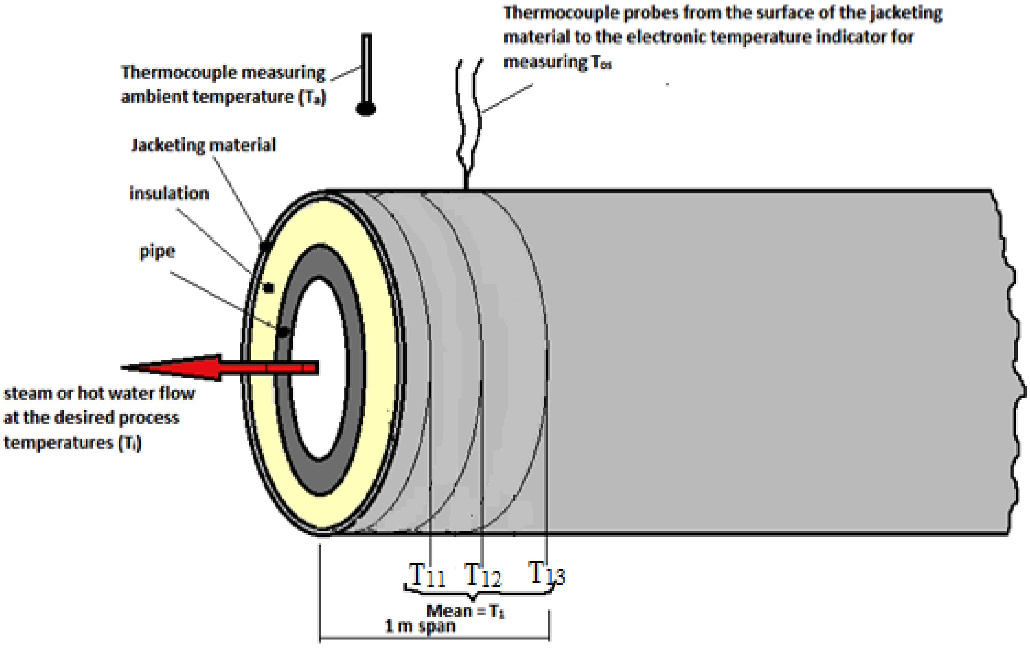

Fig 2: Experimental arrangement for data collection

Table 2: 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 effectiveness of insulation to provide process control is indicated by the temperature difference, ΔT between the observed surface temperature, T_{os} and the ambient temperature, T_a i.e. The lower the ΔT, the better the performance of the jacketing materials and consequently the more effective it is in providing process control and vice versa. ΔT are also recommended to be within the limits shown in *Error! Reference source not found.*. For the experiment conducted, the summary of the calculated and recorded ΔT for the respective emissivity's is shown in ***Table 3***.

Table 3: Level of process control determined by the difference in temperature between the surface and the ambient atmosphere i.e. ΔT (T_{os}-T_a)

operating temp T_i	Bare pipe ΔT(T_s-T_a)	Control experiment ΔT(T_{os}-T_a)	Aluminium ϵ =0.04 ΔT(T_{os}-T_a)	Galvanised steel ϵ =0.28 ΔT (T_{os}-T_a)	Cloth ϵ =0.90 ΔT (T_{os}-T_a)	**Pearson's Correlation (R) of ϵ with ΔT**
100.00	69.9	5.30	4.38	3.03	1.56	**-0.9745**
150.00	119.8	7.45	6.35	4.84	2.85	**-0.9852**

ISSN: 2319-5967
ISO 9001:2008 Certified
International Journal of Engineering Science and Innovative Technology (IJESIT)
Volume 4, Issue 4, July 2015

220.00	189.6	11.16	10.61	7.49	4.43	**-0.9674**
300.00	269.2	16.14	14.69	11.50	6.85	**-0.9898**
350.00	318.8	19.24	17.39	13.73	8.42	**-0.9895**
500.00	467.0	23.11	21.47	16.52	10.17	**-0.9841**
Mean	**239.05**	**13.73**	**12.48**	**9.52**	**5.71**	
Effectiveness		**0.943**	**0.948**	**0.960**	**0.976**	

Also, the graph of the ΔT against T_i for each of the jacketing material in the above table is plotted in ***fig 3*** below.

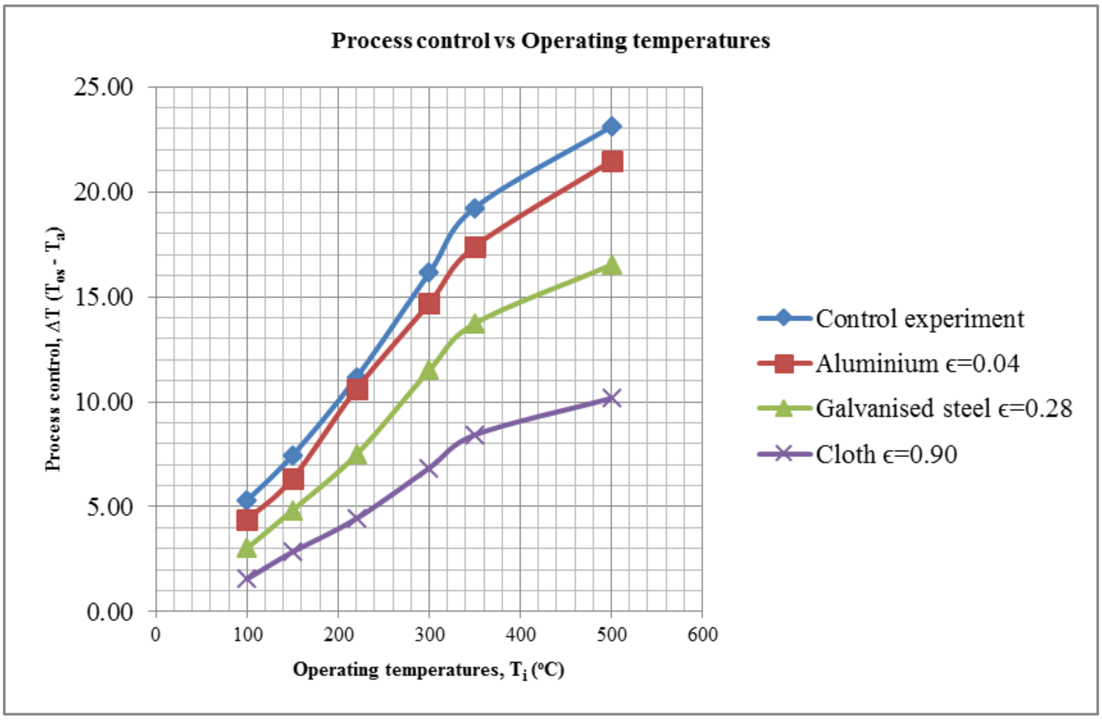

Fig 3: Graphs of ΔT vs Ti for the jacketing materials

Discussion

From ***table 3***, the mean ΔT for the control experiment, Aluminum, galvanized steel and cloth jacketing are 13.73, 12.48 , 9.52 and 5.71 °C respectively. Their corresponding performance effectiveness, calculated with respect to the mean ΔT of the bare pipe i.e. 239.05°C as $\frac{\Delta T_s - \Delta T_{os}}{\Delta T_s}$ are 94.3, 94.8, 96.0 and 97.6 % respectively. For the three jacketing, Cloth (ϵ = 0.90) recorded the lowest ΔT of 5.71°C equivalent to the highest effectiveness of 97.6%, while Aluminum (ϵ = 0.04) recorded the highest ΔT of 12.48 °C which is equivalent to the lowest effectiveness of 94.8%. Therefore, cloth jacketing proves to be the best of the three when process control is the design criteria of the insulation. When a control experiment was conducted, the mean ΔT was the highest of all with 13.73 °C equivalent to the least effectiveness of 94.3%. This shows that the presence of jacketing contributed to process control by approximately 0.5 % (94.8 – 94.3 %) to 3.3% (97.6 – 94.3%) 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) ΔT compared to Aluminum and galvanized steel of 0.28 and 0.04 respectively for all the operating temperatures.
According to the US Department of energy on *Error! Reference source not found.*, the stated limits must be achieved for there to be desirable process parameters or maintained process temperatures. This will also ensure tolerable surface temperatures and heat losses. In this experiment, it is found that a cloth jacketing of 0.9 gave a mean ΔT of 5.71°C compared to aluminum jacketing of 0.04 which gave a mean ΔT of 12.48°C. It is therefore

evident that, the higher the emissivity of the jacketing the lower the ΔT and the better the process control. Hence, high emissivity is the optimum for process control design.

Analysis of variance

The experiment was a randomized one whereby only one factor (emissivity of jacketing) was being investigated. There were 6 replicates for each treatment. These replicates are the recorded ΔT at T_i = 100,150,220,300,350 and 500° C. The treatment levels are the three emissivity's of the jacketing. Using Excel™, the following ANOVA table at a significance level of 5% was generated

Table 4: ANOVA for the level of process control

Groups	*Count*	*Sum*	*Average*	*Variance*
Ti = 100 °C	3	8.97	2.99	1.98
Ti = 150 °C	3	14.04	4.68	3.09
Ti = 220 °C	3	22.52	7.51	9.52
Ti = 300 °C	3	33.03	11.01	15.57
Ti = 350 °C	3	39.54	13.18	20.35
Ti = 500 °C	3	48.16	16.05	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 (Box, George E.P. et. al, 2007), let:

Ho: There is no linear relationship between any of the ϵ, under consideration, and ΔT. (All the population means for the various treatments are equal)

H1: There exists a functional relationship between ΔT and ϵ. True if Fcalc > Fcrit.

From the ANOVA table:

The calculated value of F (F_{calc}) = MSE/MSR = 76.77/13.77 = 5.58

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 temperature change, ΔT and emissivity, ϵ.

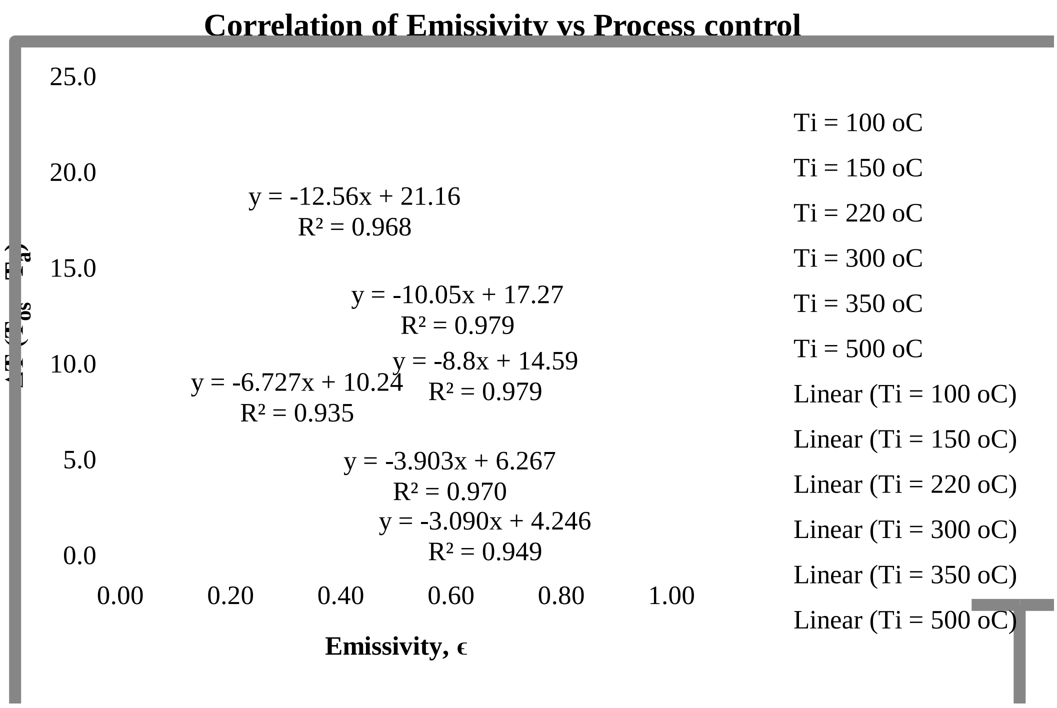

Fig 4: Correlation graphs of ΔT (Tos - Ta) vs ϵ

ISSN: 2319-5967
ISO 9001:2008 Certified
International Journal of Engineering Science and Innovative Technology (IJESIT)
Volume 4, Issue 4, July 2015

By the comparison of two sample variance technique, in hypothesis testing using F-test, temperature change, ΔT and hence process control is inversely proportional to emissivity, ϵ of jacketing material. This is also illustrated by the negatively high correlation coefficients (R) in Error! Reference source not found. and the negatively sloped correlation curves in **fig 4**.

IV. 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 temperature changes, ΔT 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 higher the emissivity of jacketing materials the better the performance in process control. Aluminum with the lowest emissivity of 0.04 recorded the highest mean temperature change compared to Cloth with the highest emissivity of 0.90 which recorded the lowest mean temperature change. Hence, jacketing materials with high emissivity allows less change in process parameters (temperature) from the system and are the optimum.

ACKNOWLEDGEMENT

Sincere gratitude goes to the almighty God for the **gift** of life. Secondly, I thank the entire staff of the Mechanical and Industrial Engineering, Chemistry and Physics departments of Masinde Muliro University of Science and Technology, for the knowledge, equipment and financial (scholarship grant) support.

Appreciations to the University library fraternity for its effort towards equipping the facility with useful and up to date online access to research and data review resource materials.

Thanks to the entire management of Mumias Sugar Company Ltd for the permission granted to conduct the data collection exercise and their technical support they offered on the ground.

Lastly, thanks to the National Council for Science, Technology and Innovation (NACOSTI) for their research grant offered to facilitate the project.

REFERENCES

[1] Baldwin P.E.J and Maynard A.D (1998): A survey of wind speeds in indoor workplaces. The Annals of Occupational hygiene. Vol 42: 303-313

[2] Bhatia A. (2012): Process Plant Insulation and Fuel Efficiency, A PDH online Course M156 (4 PDH). (www.pdhonline.org/courses/m156/m156content.pdf). Accessed on 16.08.2012

[3] Box, George E.P. et. Al (2007): Statistics for Engineers: An Introduction to Design, Data Analysis, and Model Building. New York: John Wiley & Sons.

[4] Calvert, J.B (2009): Atmospheric Radiation (http://mysite.du.edu~ etuttle/weather/atmrad.html) accessed on 02.10.2013

[5] Chang-Da and Issam Mudawar (2002): Experimental Investigation of Emissivity of Aluminum Alloys and Temperature Determinations using Multispectral Radiation Thermometry (MRT) Algorithms. JMEPEG VOL 11:551-562. ASM International

[6] Cook, Gary D. (1985): Insulation- Selection and Installation, a fact sheet (EES-25) published by the Florida Energy Extension Service and IFAS.

[7] Federal Energy Administration, (August 1976): Economic Thickness for Industrial Insulation, Conservation Paper Number 46.

[8] Feijt A. J, Kohsiek W.(1995): The effect of emissivity variation on surface temperature determined by infrared radiometry,Volume72, Issue3, pp323-327 (http://link.springer.com/article/10.1007%2FBF00836339 http://link.springer.com/journal/10546/72/3/page/1) accessed on 01.10.2013

ISSN: 2319-5967
ISO 9001:2008 Certified
International Journal of Engineering Science and Innovative Technology (IJESIT)
Volume 4, Issue 4, July 2015

[9] Finley Daniel (2003) thermal radiation: blackbody radiation; the Stefan-Boltzmann Law, and the Planck's formulae for Spectral Radiancy (http://panda.unm.edu/courses/finley/p262/thermalrad/node1.html) access on 03.10.2013

[10] Harold, J.S. (1958), Criteria of Good Research, Phi Delta Kappan, Vol. 39.

[11] Holland, S. (2012): Emissivity Effects on Thermal Surveys (www.thermographic consultancy.com/effects-of-emissivity/) accessed on 01.10.2013.

[12] NIST (2003): Engineering Statistics Handbook http://www.itl.nist.gov/div898/handbook/ (accessed on 01.10.2012)

[13] Optotherm: (http://www.optotherm.com/emiss-physics.htm) accessed on 01.10.2013

[14] Orlove, Gary (2012): Thermo graphic measurement techniques-measuring emissivity, infrared training centre (http://irinformir.blogspot.com/2012/02/thermographic-measurement-techniques.html#more)

AUTHOR BIOGRAPHY

Osore E. A. E, Department of Mechanical and Industrial Engineering, Masinde Muliro University of Science and Technology, Kakamega Kenya.

Swaleh M.A, A registered Engineer in the Department of Mechanical and Production Engineering, University of Eldoret, Eldoret - Kenya.

Rotich P.K Department of Mechanical and Industrial Engineering, Masinde Muliro University of Science and Technology, Kakamega Kenya.