International Journal of Advancements in Research & Technology, Volume 2, Issue 1, January-2013
ISSN 2278-7763

Evaluation of a Passive Flat-Plate Solar Collector

Dara J.E/MIAENG, Ikebudu K.O/MIAENG, Ubani N.O/MIAENG, Chinwuko C.E/MIAENG. Ubachukwu O. A/MIAENG.

1(Jude Ezechi Dara) is the Safety Officer, Petronella Nigeria Limited, Port Harcourt, Nigeria. Mobile: 234-803-772-8188. E-mail: dezechi4@yahoo.com.

2(Ikebudu, Kingsley Okechukwu) is an academic Staff in the Department of Mechanical
Engineering, Anambra State University, Uli Campus, Anambra State, Nigeria. Mobile: 234-803-774-0820. E-mail: ikbuduk@yahoo.com

3(Ubani Nelson Obinna) is a lecturer in the Department of Mechanical Engineering, Michael Opkara University of Agriculture, Umudike, Abia State, Nigeria. Mobile : 234-806-262-4421. E-mail: grantnelson2007@yahoo.com

4(Chuka E. Chinwuko) is a lecture in the Department of Industrial Production Engineering, Nnamdi Azikiwe Universty, Awka. Anambra State, Mobile: 234-803-781-5808. E-mail: chinwukoemmanuelc@yahoo.com

5(Obiekwe A. Ubachukwu) is a lecturer in the Department of Civil Engineering Michael Okpara University of Agriculture Umudike
Abia State, Nigeria Mobile: 234-803-501-4452 E-mail: obiekweuba@yahoo.com

ABSTRACT

Conventional energy resources are exhaustive and there is a need for renewable energy resources for sustainable development. Solar energy promises to be a potentially alternative energy resource for world growing economy. Solar energy can be harnessed through photochemical, photovoltaic and photothermal processes. In any of these processes, the electromagnetic radiation of the solar energy is put in a useful form as energy being vital to economic and human development. This paper presented the evaluation of the performance of a passive flat-plate solar collector. The research investigated the variations of top loss heat transfer coefficient with absorber plate emittance; and air gap spacing between the absorber plate and the cover plate. The effects of these parameters on the performance of the solar collector were also investigated. Results of data obtained from the thermosyphon flat plate solar water heater developed by the National Centre for Energy Research and Development (NCERD), Nsukka, Nigeria were used in the analysis. The procedure for the evaluation of the top loss heat transfer coefficient and the efficiency of the collector plate is iterative in nature; hence computer program written in Visual Basic was used to simplify the solution.

Keywords: passive solar collector, collector plate emittance and heat transfer coefficient.

1 INTRODUCTION

THE Conventional energy resources are not only limited in supply but are exhaustive in nature. Many studies of world energy supply and demand and of projected national and regional energy requirements suggest that there will be an increasing strain on convectional petroleum and natural gas supplies to the point where substitution for these fuels on a large scale will become necessary towards the end of the century, if not before [1]. In view of the foregoing, it calls for an alternative source of energy. The two most significant permanent sources of energy are nuclear and solar energy. Nuclear energy is associated with changes in the structure and composition of the nucleus of matter. Nuclear energy requires advanced technology and costly means for its safe and reliable utilization and may have undesirable side effects [2]. Although, the engineering design and analysis of solar processes present unique problems, the utilization of solar energy shows promise of becoming a dependable energy source.

The direct and indirect uses of solar energy by mankind have been in existence for centuries. Man had used solar energy for drying, heating, cooling with absorption chillers. The various uses of the solar energy can be categorized into three broad classes: photochemical processes, photovoltaic processes and photothermal processes. Photothermal processes involve the use of solar plate collectors. Solar collectors are designed to collect heat by absorbing Sunlight. Solar collector is either concentrating collector or non-concentrating collector.

Concentrating collector, although has a higher energy flux, does not use diffuse component of the radiation since diffuse component cannot be reflected and requires costly orienting system to enable it track the Sun[3].

Non-concentrating collectors can be designed for applications requiring energy delivery at moderate temperatures, up to perhaps 100°C above ambient temperature. They have the advantages of using beam and diffuse solar radiation, not requiring orientation towards the sun, and requiring little maintenance [4]. In tropic countries, average daily collector efficiency of 0.658 and a mean system temperature of 81°C are achievable [5]. The performance of non-concentrating solar collector depends very much on both the flow rate of the working fluid through the collector and the incident solar radiation [6].

To achieve optimum results from solar collector systems, design parameters should be investigated in a view to determining the appropriate design range. This paper investigates the effects of absorber plate emittance and the air spacing between the absorber plate and the cover plate on the top loss coefficient and consequently on the performance of the collector.

2 METHOD OF SOLUTION

The procedure for evaluating the top loss heat transfer coefficient is necessarily an iterative process. The procedure is to guess a cover plate temperature and an absorber plate mean temperature. These guessed values are used to evaluate the radiative heat transfer coefficient from the cover to the sky, radiative heat transfer coefficient between the absorber plate and the cover plate, and the convective heat transfer coefficient between the absorber plate and cover plate. With these heat transfer coefficients and convective heat transfer coefficient for wind, the top loss heat transfer coefficient is calculated. These results are then used to evaluate the actual cover plate temperature and the absorber plate mean temperature. If these actual temperature values are close to the guessed values, no further calculations are necessary; otherwise, the newly calculated temperature values are used and the processes are repeated.

This iteration process could be tedious and time consuming; therefore, solution program is developed in visual basic which is used in simplifying and solving these problems in this context.

2.1 Evaluation of Top-Loss Coefficient

The loss heat transfer coefficient for the top surface is the result of convection and radiation, between parallel plates. The energy transfer between the plate at the mean plate temperature and the first cover glass at cover temperature is exactly the same as between any other two adjacent glass plates and is also equal to the energy lost to the surroundings from the top cover glass.

There are four heat lost coefficients associated with top-loss coefficient. They are convective heat transfer coefficient for wind, radiative coefficient from the cover to the sky, convective heat transfer coefficient between the plate and the cover and radiative heat transfer coefficient between the plate and the cover.

The convective heat transfer coefficient for wind is [7]

$$h_w = 5.7 + 3.8v \tag{1}$$

where ν is the local wind speed in m/s.

The radiative heat transfer coefficient from the cover to the sky is given as [2]

$$h_{rs} = \varepsilon_g \sigma (T_g + T_s)(T_g^2 + T_s^2) \tag{2}$$

The convective heat transfer coefficient between the plate and cover is given as [8]

$$h_{cp} = \frac{Nuk}{L} \tag{3}$$

The radiative heat transfer coefficient between the plate and cover is given as [9]

$$h_{rg} = \frac{\sigma (T_p + T_g)(T_p^2 + T_g^2)}{\left(\frac{1}{\varepsilon_p} + \frac{1}{\varepsilon_g}\right)^{-1}} \tag{4}$$

The top loss coefficient for a single glass cover system is [4]

.

$$U_T = \left(\frac{1}{h_{cp} + h_{rg}} + \frac{1}{h_w + h_{rs}}\right)^{-1} \qquad (5)$$

2.2 Thermal Losses and Efficiency of flat Plate Collector

As the collector absorbs heat its temperature gets higher than that of the surrounding and heat loss depends on the collector overall heat loss coefficient and the collector temperature [10].

$$Q_o = U_L A\left(T_p - T_a\right) \qquad (6)$$

Thus, the rate of useful energy gained by the collector is the energy absorbed by the collector, less the amount lost by the collector to its surroundings.

$$Q_u = Q_i - Q_o \qquad (6a)$$

$$Q_u = A\left[IR(\tau\alpha)_e - U_L\left(T_p - T_a\right)\right] \qquad (6b)$$

Collector efficiency is a measure of flat-plate collector performance. It is the ratio of the useful energy gain over any time period to the incident solar energy over the same time period [2]. The maximum possible useful energy gain in a solar collector occurs when the whole collector is at the inlet fluid temperature. Hottel Whillier-Bless equation relates the actual useful energy gain with the inlet temperature as [11]

$$Q_u = F_R A[IR(\tau\alpha)_e - U_L(T_i - T_a)] \qquad (7)$$

To assist in obtaining detailed information about the performance of collector and to prevent the necessity of determining some average surface temperature, it has been convenient to introduce collector efficiency factor [2] into equation (7) to give

$$Q_u = F'A\left[IR(\tau\alpha)_e - U_L(T_m - T_a)\right] \qquad (8)$$

The efficiency of the passive flat-plate solar collector is then given as

$$\eta = F'(\tau\alpha)_e - F'U_L\left(\frac{T_m - T_a}{I}\right) \qquad (9)$$

2.3 Determination of Heat Transfer Coefficients

Equation (1) gave the convective heat transfer coefficient for wind. The radiation heat transfer coefficient from the cover to the sky is given by equation (2) with T_s as [7]

$$T_s = 0.0552(T_a)^{1.5} \qquad (10)$$

Equation (3) gave the convective heat transfer coefficient between the absorber plate and the cover plate with Nu as Nusselt number. Nusselt number is obtained using the equation given by [9] as

$$Nu = 1 + 1.44\left(1 - \frac{1708}{RaCos\beta}\right)\left(1 - \frac{1708Sin(1.8\beta)^{1.6}}{RaCos\beta}\right) + \left[\left(\frac{RaCos\beta}{5830}\right)^{1/3} - 1\right] \qquad (11)$$

$$Ra = \frac{g\Delta T L^3 \rho^2 c_p}{\mu K T} \qquad (12)$$

Equation (4) gave the radiative heat transfer coefficient between the plate and the cover.

2.4 Determination of Cover Plate Temperature

As The processes involved are iterative. The iterations are among equations (1), (2), (3), (4) and (5). The procedure is to guess a cover temperature and a mean plate temperature from which h_{rs}, h_{cp} and h_{rg} are calculated. With these heat transfer coefficients and h_w, the top loss coefficient is calculated using equation (5). These results are then used to evaluate T_g using the relation [4].

$$T_g = Tp - \frac{U_T\left(T_p - T_a\right)}{hcp + hrg} \qquad (13)$$

If T_g is close to the initial guess, no further calculations are unnecessary. Otherwise the newly calculated T_g is used and the process is repeated.

2.5 Determination of the Mean Plate Temperature

To determine the mean plate temperature, the overall heat loss coefficient is needed. The overall heat loss coefficient is a function of the mean plate temperature; hence, iterative approach becomes necessary in order to determine the mean plate temperature. The mean plate temperature is evaluated by [9].

$$T_p = T_{f,m} + \frac{Q_u}{h_f \pi D_{in} L_p} \qquad (14)$$

Where

$$T_{f,m} = T_i + \frac{Q_u}{U_L F_R A}\left[1 - \frac{F_R}{F'}\right] \qquad (15)$$

2.6 Result and Discussion

The average values of the air gap spacing,top loss heat transfer coefficient and efficiency were plotted in fig.1 and fig.2.

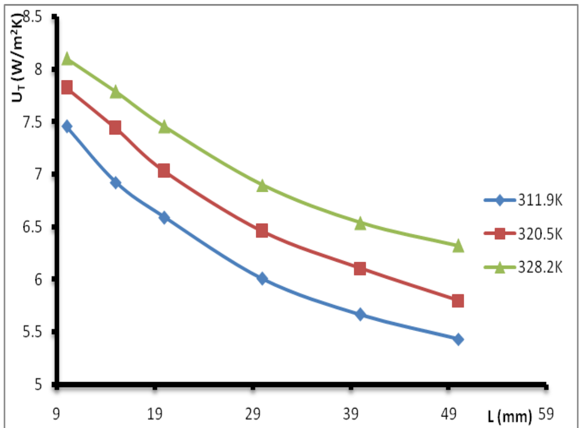

Figure 1. Variation of top heat loss coefficient with air gap spacing

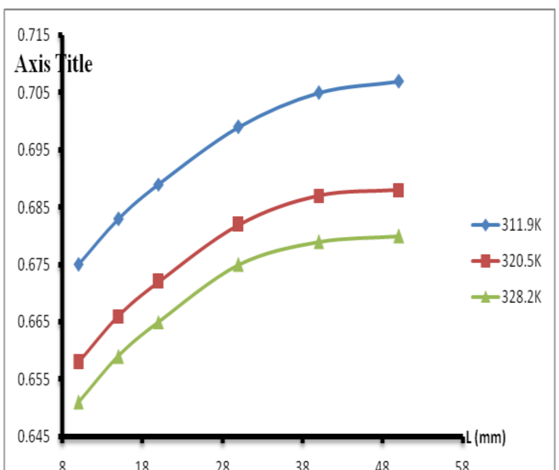

Figure 2. Variation the collector efficiency with air gap spacing

Fig.1 shows the variation of top heat transfer coefficient with air gap spacing between the absorber plate and the cover. It can be seen that increase in the air gap spacing resulted to decrease in the top loss heat transfer coefficient, but the effect of air gap spacing becomes less significant with air gap spacing of above 33mm. Equation(12) showed that air gap spacing is proportional to Rayleigh number. Also equation (11) showed that Rayleigh number is proportional to Nusselt number. From equation (3), it is observed that convective heat transfer coefficient between the plate and cover is proportional to the Nusselt number and inversely propositional to the air gap spacing.

Meanwhile, from equation (5), one can observe that increase in the convective heat transfer coefficient between the plate and the cover will lead to increase in top loss heat transfer coefficient. Therefore, increase in air gap spacing between the absorber plate and the cover will lead to decrease in the top loss heat transfer coefficient as observed in fig.1.

The variation of the collector efficiency with air gap spacing between the absorber plate and the cover is shown in fig.2. The efficiency of the collector increases as the air gap spacing increases. Equation (11) accounts for non-linearity of the plot.

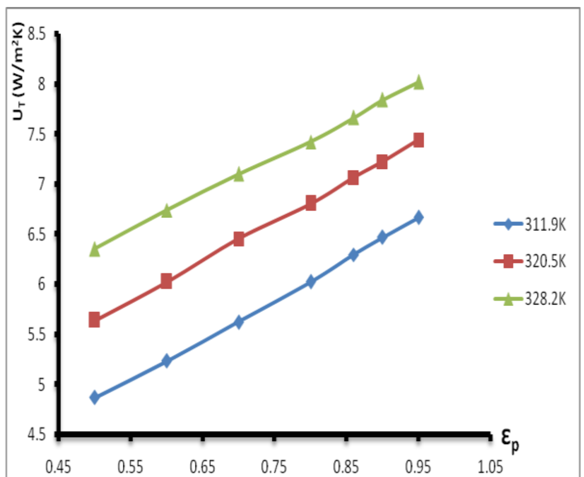

Figure 3. Variation of top heat loss coefficient with absorber plate emittance

International Journal of Advancements in Research & Technology, Volume 2, Issue 1, January-2013
ISSN 2278-7763

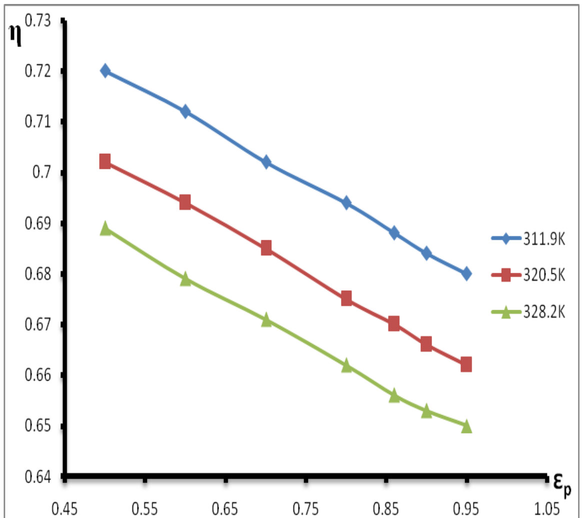

Figure 4. Variation of the collector efficiency with absorber plate emittance

The average values of the plate emittance, top loss coefficient and efficiency of the absorber plate were used to plot fig.3 and fig.4. Fig.3 shows the variation of top loss heat transfer coefficient with absorber plate emittnace. It can be observed that increase in the absorber plate emittance results to increase in the top loss heat transfer coefficient because high plate emittance leads to dissipation of more heat to surroundings.

The relationship between the top loss heat transfer coefficient and plate emittance is given in equations (4) and (5). Equation (4) showed that plate emittance is proportional to radiative heat transfer coefficient between the plate and the cover. From equation (5), one can observe that increase in the radiative heat transfer coefficient between the plate and the cover will lead to increase in the top loss heat transfer coefficient. Therefore, increase in plate emittance will lead to increase in the top loss heat transfer coefficient as indicated in fig.3.

Fig.4 shows the variation of efficiency of the collector with absorber plate emittance. High dissipation of energy associated with high plate emittance will result to reduction in collector efficiency. Therefore, the efficiency of the collector is inversely proportional to the absorber emittance.

However, in the design f passive flat-plate collector, efforts should be geared towards selecting absorber plates with low emittance while paying attention to the thermal and optical properties of the materials. Therefore, passive flat-plate solar collector perform better at a lower mean absorber plate temperature making it a suitable alternative source of energy for moderate energy requirements such as drying fruits and vegetables, warming breeder houses, heating liquid to temperature below 100°C and so on.

3 CONCLUSION

The variations of top loss heat transfer coefficient with absorber plate emittance and air gap spacing of a passive flat-plate solar collector were investigated in this work. The evaluation of top loss heat transfer coefficient was performed based on the convective and radiative heat transfer between the plate and the cover; and the cover and the sky. Also thermal losses and efficiency of the plate were considered.

It was observed that high plate emittance tends to dissipate more heat to the atmosphere and consequently resulted to increase in top loss heat transfer coefficient which led to reduced system performance. Also it was observed that increase in air gap spacing between the absorber plate and the cover plate resulted in decrease in the top loss heat transfer coefficient. A passive flat-plate solar collector was observed to perform better at a lower mean plate temperature and with the orientation at the latitude of the location where the collector is mounted.

Nomenclature

A	-	Area of absorber plate, m^2
C_p	-	Specific heat capacity at constant pressure, KJ/Kg°K
D_i	-	Inside diameter, m
F'	-	Collector efficiency factor
F_R	-	Collector heat removal factor
h_{cp}	-	Convective heat transfer coeffi cient between the absorber plate and the cover, W/m^2k
h_{rg}	-	radiative heat transfer coefficient between the absorber plate and the cover, W/m^2k
h_{rs}	-	radiative heat transfer coefficient from the cover to the sky, W/m^2k
h_w	-	wind loss coefficient, W/m^2k
I	-	radiation intensity, W/m^2k
K	-	thermal conductivity, W/k
L	-	air gap spacing, m
L_p	-	Length of pipe
n	-	number of pipes
Nu	-	Nusselt number
Q_i	-	energy absorber by collector per

		unit time, W
Q_o	-	energy lost per unit time, W
Q_u	-	Useful energy gained per unit time, W
R	-	ratio of total radiation on tilted surface to that on plane of measurement
Ra	-	Rayleigh number
T_a	-	Ambient temperature, k
T_g	-	Cover glass temperature, k
T_i	-	Inlet temperature, k
T_p	-	Plate temp, k
T_s	-	Sky temperature, k
$T_{f,m}$	-	mean fluid temperature, k
U_L	-	overall loss heat transfer coefficient, W/m^2k
U_T	-	top loss heat transfer coefficient,
υ	-	Wind velocity, m/s
α	-	absorptance
β	-	Collector tilt angle, deg.
ε	-	emittance
σ	-	Stefan Boltzmanns constant, W/m^2K^4
t	-	transmittance
$(\tau\alpha)_e$	-	effective transmittance-absorptance product W/m^2k

References

[1]. George P. and William H. (1980). *Solar Energy*; The Royal Society London.

[2]. Rai, G.D. (2004). Solar Energy Utilization, Khanna Publishers, Delhi.

[3]. Dara, J.E. (2010). Modeling and Evaluation of a passive flat-plate solar collector, Nnamdi Azikiwe University, Awka.

[4]. Duffie, J.A. and Beckman, W.A. (1974). Solar Energy Thermal Process, John Willey and Sons, New York.

[5]. Agbo, S.N. (2005). Performance Evaluation and Optimization of NCERD Thermosyphon Solat Water Heater, University of Nigeria, Nsukka.

[6]. Bolaji, B.O. (2006). Flow Design and Collector Performance of a natural circulation solar heater; Journal of Engineering and Applied Science 1(1): 7-13.

[7]. Ihueze, C.C. (1987). Design and Construction of a passive solar heated poultry manure Dryer, University of Nigeria, Nsukka.

[8]. Grag, H.P. (1987). Advances in Solar Energy Technology, Vol. 1, D. Reidel Pub. Com. Holland.

[9]. Nwokoye, A.O.C. (2006). Solar Energy Technology: other Alternative Energy Resources and Environmental Science, Rex Charles and Patrick Limited Nimo, Nigeria.

[10]. Struckman, F. (2008). Analysis of a flat-plate solar collector, Project Report MVKI60 Heat and Mass transport, Lund, Sweden.

[11]. Hottel, H.C. and Whillier, A. (1950). Evaluation flat-plate collector performance, Transaction of Conference on the use of Solar energy, 2, part1, University of Arizon Press.