Calculation method to estimate the sunlight intensity falling on flat panel solar system

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Abstract : *Calculation method based on experimental data to estimate sunlight intensity falling on the solar collector has been established. The technique is to evaluate the heat power using the specific heat formula. Light intensity from 3 different light sources has been studied; the results gained by the method were compared against other results directly measured using intensity meter, and both results showed good agreement. The method shows powerful tools, which can estimate the light intensity in the lack of intensity meter. Although, the specific heat formula has been used previously for a estimating different heat transfer purpose, however, this method has advantage by providing approximation results in simple way, and it use to determine the performance of flat panel solar thermal systems under variable solar flux.*

Key words: *Solar absorber, thermal power, transient state, heat lost, specific heat formula, the rate of temperature- time change.*

Nomenclature

Qin	*The incident light radiation upon the absorber.*
Q u	*The useful heat flux flow through the system.*
Q a	*The amount of heat absorbed by the solar*
Q l	*The amount of heat lost by the absorber to the ambition*
Q r	*The incident light reflected back from the absorber*
M	*The absorber mass [kg]*
Cp	*Copper specific heat [400J Kg.K]*
ΔTΔt	*The rate of temperature change in respond to time*
Th	*Absorber temperature*

I. INTRODUCTION

Steady state and transient state are two methods used to evaluate the heat transfer. The steady state is less complicated and more accurate than the transient state, as the transient state method required more assumptions. However, evaluate heat transfer at the transient state has advantage over the steady state, as it's requiring less effort, time and money [1]. Several studies have evaluated the heat transfer within the solar collectors. However, it's mainly focussed on the theoretical calculation in condition where the light intensity is known [2-4]. This study will participate toward filling the gap on the literate by determining light intensity and heat transfer in flat panel solar system theoretically.

The quantity of the heat power within a substance at no phase change depends constant and changeable values, temperature change as variable value, the substance mass and the specific heat are the constant value, and by evaluating the temperature gradients heat power can be determined. In order to estimate the heat power absorbed by the solar collector (solar absorber) using the specific heat formula, the temperature difference between the absorber and surrounding environment has to be small in order to neglect the heat lost. The presented method is required measuring the absorber temperature, therefore, experiments were conducted, this done by exposing solar absorber to light source, and recording its temperature as function of time, and by determining the variable rate of temperature change, the quantity of the heat power will be determined, as the method require no heat lose, and assuming all the energy falling on the absorber is absorbed, therefore, small temperature change (y) as function of time (x) from the measured heating curve (the transient period) is considered. The slope of line is mathematical relation between y - x variables. It's one way of determining the heat transfer at transient state, and it has been commonly used to evaluate the heat transfer [5-7]. In this case, the slope will be used to determine the rate of temperature –time change, in order to determine the heat absorbed using specific heat formula.

II. PRINCIPLE OF THE TECHNIQUE

When flat panel solar system expose to light source (Qin), some of this light is reflected back (Qr), while the remaining is received and converted into useful heat by the absorber (Qu), in this case the heat balance equation become as follow;

$$Q_{IN} = Q_R + Q_U \qquad (1)$$

The useful heat (Qu) is the heat which power the solar TEG system, therefore, the aim is to determine the Qu. When the flat solar absorber alone (without the TEG and water system) expose to light source, in the heat balance equation, the heat absorbed by the absorber (Qa), is equal to the heat lost from the absorber to the surrounding (Ql)

$$Q_U = Q_A + Q_L \qquad (2)$$

The mechanism of the heat transfer within the absorber is shown in “Fig1.”:

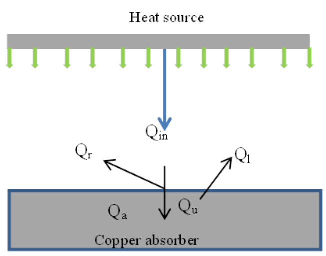

Figure 1: The energy analysis of exposing solar absorber to light source

Heat lost (Ql) from the absorber to its surroundings is mainly due to convection and radiation effects, and it is proportional to the temperature change (ΔT) of the absorber, the smaller ΔT the less Ql, and when Ql is very small, then it can be neglected from the calculation, in such a condition and from (equation 2), the net of useful heat will be equivalent to the heat absorbed.

$$Q_U \approx Q_A \qquad (3)$$

The specific heat formula states that the heat power absorbed by the absorber (Qa), is equal to the product of the absorber mass, m, its specific heat capacity, Cp, and the rate of temperature of change in respect of time.

$$Q_A = M.C_P\,.\ \Delta T.\Delta t^{-1} \qquad (4)$$

Then

$$Q_U \quad M.C_P\,.\ \Delta T.\Delta t^{-1} \qquad (5)$$

Equation 5 indicates that Qu can estimated by measuring for a material with known m and cp. It is clear that ΔT has to be particularly small for the technique to be valid. Such validity can be checked by the linearity of ΔT vs. Δt. “Fig 2” shows the classic heating curve of the absorber temperature, where the temperature is plotted as a function of time. Although the overall heating curve is not linear, an approximate linear relationship between ΔT and Δt can be seen during the initial irradiation period, as shown clearly by the inset in “Fig 2”.

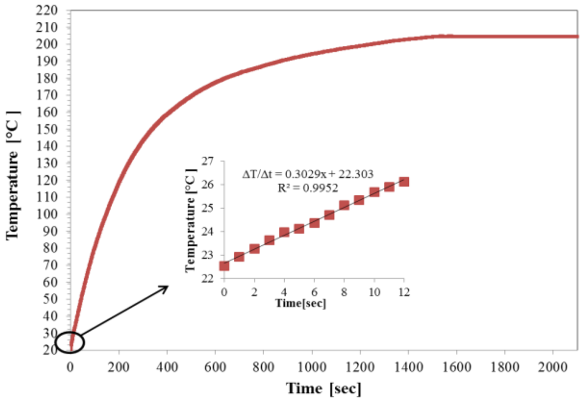

Figure 2 : Classic heating curve of a solar absorber. The inset represents the temperature change of the absorber during the initial period of irradiation, which shows a linear relation between ΔT & Δt.

This result indicates that (equation 5) can be employed to determine the thermal energy flux converted from solar radiation by measuring the slope of the heating curve during the initial linear period (Note: the results shown are intended to demonstrate the validity of the experimental techniques only. For clarity, experimental details are not included here but will be reported in experimental section). The heat retained in the absorber (Qa) decreases with increasing temperature of the absorber due to heat loss (Ql). Qa at any given time can be estimated by determining the corresponding slope on the temperature profile of the heating curve shown in "Fig 2". Using an approximate approach, the slopes ($\Delta T . \Delta t^{-1}$) was calculated at every three minute intervals. The corresponding Qa can he determine as a function of temperatures as shown in "Fig 3". With the knowledge of Qu and Qa, which were determined from "Fig 3", the heat loss (Ql) from the absorber can be estimated using (equation 2). The results are shown in "Fig 3".

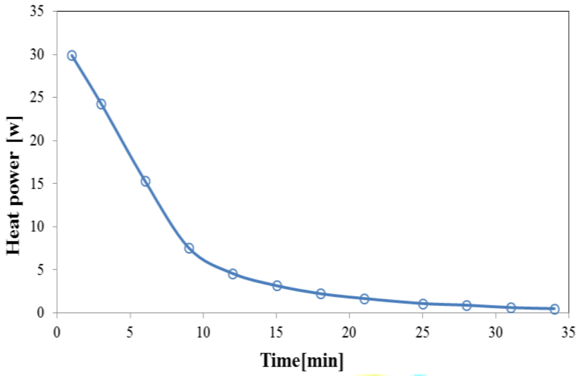

Figure 3: The net heat produced and retained in the absorber as a function time (estimated using the slope method).

Based on fundamental heat transfer theory, as shown on (equation 6), the heat loss from the absorber at the steady state is mainly caused by convection (the first term) and (radiation the second term).

$$Ql = [h\,Ac\,(Th - Ta)] + [\varepsilon\,\sigma\,Ac\,(Th4 - Ta4)] \qquad (6)$$

Where, h is the convection coefficient, Ac is the absorber area, Th is the absorber temperature, Ta is the surrounding temperature, ε is the emissivity of the absorb surface, and σ is a Stefan Boltzmann constant. The first term on the right of (equation 6) is due to convection and the second term is due to radiation. The values for ε and h were obtained from the literature, which gives ε =1 [8] and h= 5.7 Wm2 K1 [9]. Using the temperatures Th and Ta from the experiment, the heat loss from the absorber can be calculated which is shown by the dashed line in "Fig 4".

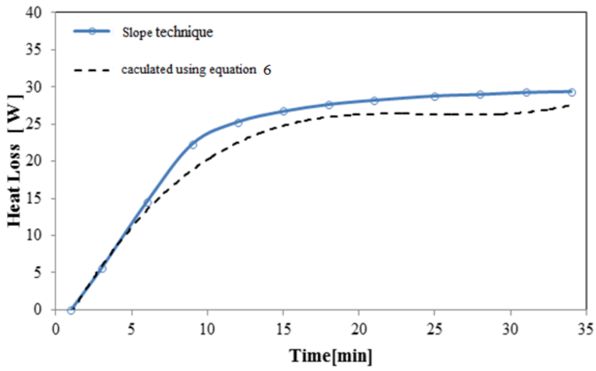

Figure 4: Heat losses determined using the slope technique, compared with that calculation based on heat transfer theory.

It can be seen that the results estimated from both methods are in a reasonably good agreement. These results demonstrate the validity of experimental techniques employed for this research. “Fig 4” compares the results of the heat lost from the solar absorber as function of time, once obtained by the slope technique (solid line), while the other obtained by the calculation of the heat transfer theory. The results show good agreement between the two methods. The results of slope technique shows higher than the theory calculation, this could be due to less estimating of the convection coefficient values obtained from the literate.

III. EXPERIMENTAL PROCEDURE

A copper plate measuring (0.13m x 0.13m x 0.001 m) was painted black on the top surface and exposed to three halogen light bulbs with different light intensities, the bulbs classified based on their electric consumption of 150, 200, and 400 watts. The light source was placed 7.5 cm above the absorber, a channel in the other side of the absorber provided room for a k-type thermocouple to measure the absorber (Th) temperature was affixed as shown in “Fig 1”. Th was monitored, recorded and plotted as a function of time, as illustrated in “Fig 5”. The data were taken from the first second of switching the light and running the experiment. To avoid uncertainty, the absorber temperature was recorded using data logging apparatus (TC-08, Picolog), the initial temperature change at very first few seconds were investigated to insure heat lost is small and negligible.

IV. RESULTS

The temperature of the absorber as a function of time is shown in “Fig 5” which demonstrates a classic heating curve, indicating an initial period of linearity. This is consistent with the approach described above, demonstrating the validity of the assumption employed.

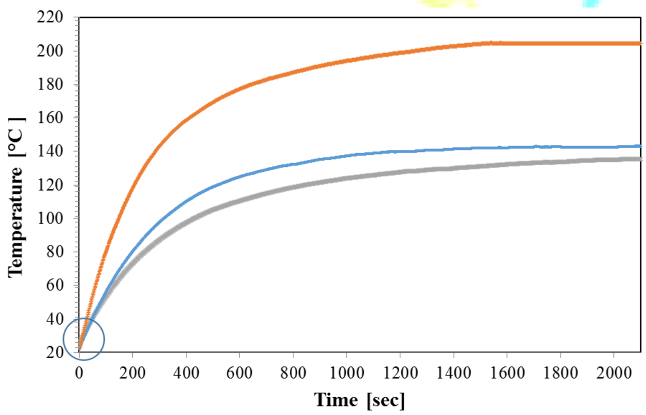

Figure 5: The absorber temperatures (Th) as a function of time in with 3 different light source intensity, the highest temperature curve represent is the light ID of 400 watt, then the light ID of 200watt where the lowest is the light ID of 150.

“Fig 5” represints the absorber under three different light intensity temperature as a function of time, at the first few seconds the absorber temperaure was sharply increased, which indicates that heat lost to the surrounding is small. The temperature region was selected at $\Delta T<6$ K, where good linearity is observed as shown in "Fig 6". The gradients is representing $\Delta T.\Delta t^{-1}$ values, which were used for the calculation shown in (Equation 5).

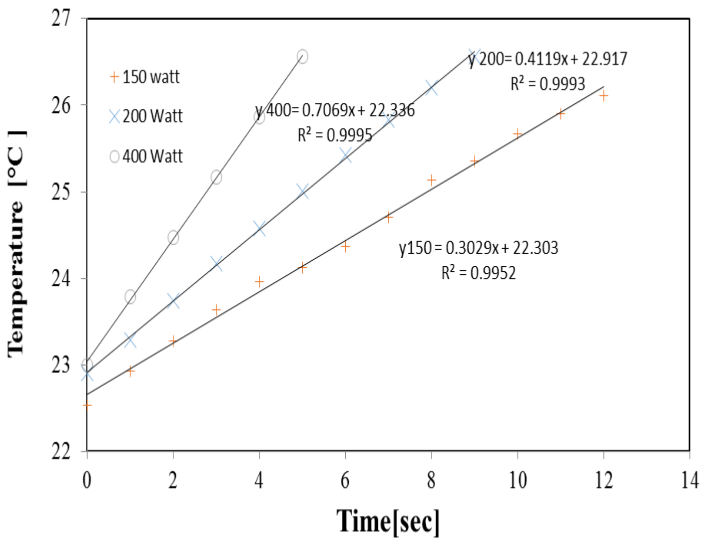

Figure 6: The Absorber temperatures at the first few seconds under two different power source.

The gradients is representing $\Delta T.\Delta t^{-1}$values, which were used for the calculation shown in (Equation 5). Results of the heat absorbed obtaind from the slope were compared against light intensity measurements gathered from (Kipp & Zonen CMP11 Pyranometer) (Table 1). The data from both experimental determination and the direct measurements with the pyranometer showed a good agreement between the theory and the measured methods, with a small differentiation of around 5%. The useful heat power, Qu, measured by the pyranometer was consistently higher than that obtained by the experiment. This is likely to be due to the un-considering of the heat lost from the absorber (Ql).

Table : The calculation of the heat absorbed by the slop method

The light ID	*$\Delta T\Delta t$*	*Intensity[intensity meter] [W.m^{-2}]*	*Intensity [slop technique] [W.m^{-2}]*
150	*0.30*	*1816*	*1775*
200	*0.41*	*2560*	*2420*
400	*0.70*	*4400*	*4150*

To eliminate distortion of the data arising from variation in light intensity, measurements using the pyranometer were conducted at nine different points along the area of the absorber and an average was calculated. The data from both the experimentally calculated and the directly measured showed a good agreement between, with a small deviation of around 5 %. The heat power measured is consistently higher than that experimentally calculated. This is likely to be due to the (Ql) approximation used, where necessarily the absorber is emitting some of heat power to the surrounding.

V. CONCLUSION

A technique to determine the heat absorption by a solar absorber was established and its suitability for this investigation was validated. The technique, referred to as the "slope technique," provides a simple and effective method to estimate the light intensity (heat power) falling in the solar absorber. The results of the developed method were compared with the results obtained by the energy balance based on heat transfer law, the slope technique provides more accurate estimation results because it does not takes into account the estimation of heat convection and radiation effects, which could be less or over estimated. The ability to determining the input energy facilitates the evaluation of the sunlight intensity, consequently, the efficiencies of the Solar system.

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