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EVALUATION OF THE INFLUENCE OF SOLAR RADIATION IN THE EFFICIENCY OF FLAT PLATE COLLECTORS

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Abstract. *One factor of great relevance for the applicability of the collectors is their thermal efficiency. This characteristic can be affected by several factors, such as the ambient temperature, the flow rate and the solar radiation. In this work, we intend to evaluate the influence of solar radiation on the efficiency of a flat plate collector. We selected a model available in the national market, which has frequent characteristics among models of the same category. Experimental tests were carried out using a solar simulator, varying the intensity of simulated solar radiation in the range of 700 to 1000 W / m², allowed by ABNT NBR 15747: 2009. The other test conditions were not altered. From the obtained data, the thermal efficiencies and the specific monthly productions of energy were calculated with the objective to verify in which range of solar radiation the flat plate collector presented better performance.*

Keywords: *efficiency, flat plate collector, solar radiation*

1. INTRODUCTION

Energy resources are essential for the growth of a nation as they are used by man in his basic needs, such as the generation of work and energy (ABRAVA, 2008). Therefore, as the population increases, energy consumption also increases so that energy sources gradually become the focus of research due to its environmental and socioeconomic impact. The largest energy source in the world is based on fossil fuels, as described by IEA (2011). Renewable energy sources accounted for only 13.3% of the world scenario in 2009. It is necessary to increase the contribution of renewable and low environmental impact sources in the global energy matrix.

Solar energy is a clean, renewable and inexhaustible energy. A solar collector is a special heat exchanger system, which turns solar radiation into heat (Duffie and BeckMan 2006). The solar collector is a system composed of: collector box (galvanized iron), insulation (fiberglass, polyurethane), frame (copper), glass (tempered glass, transparent glass), gaskets (rubber) (MAXOULIS, et al., 2007) .

All these components influence the thermal efficiency of the flat plate collector; however, other factors are also able to change this index. As, for example, the efficiency increases with the increase of the flow and with the ambient temperature, and decreases with the temperature of entrance of the water (Maia, et al., 2016). In addition, the wind velocity also distorts the efficiency of the collector, which can increase the efficiency of a solar collector by 20% in a place where the effect of wind is lower (Ladas, et al., 2017).

The need, therefore, is to analyze each factor individually to know the ultimate impact on the system. Solar radiation is a variable that is considered by much that directly influences the thermal efficiency of the collector. However, a study that evaluated this parameter was not found in the literature.

Unlike the field tests, the control of uncertainty-generating variables, such as radiation, is easily controlled in a solar simulator, in which it is possible to monitor all desired parameters, such as temperature, wind speed, and collector flow (Sowmy, et al., 2016).

These experiments, with solar simulators, follow the standard of ABNT NBR 15747-2: 2009 (ABNT, 2009), for the accomplishment and accreditation of the tests. By this, the association informs the values of the parameters that can be tested. Solar radiation can be varied from 700W / m² to 1000W / m². As the influence of these parameters is not known, the test results may be different if repeated under different solar radiation conditions. In this work, we intend to perform thermal performance tests of a flat solar collector maintaining the flow conditions and ambient temperature, varying the solar radiation between 700 W / m² and 1000 W / m².

2. METHODOLOGY

Experiments to determine the efficiency of the collector were made according to the normalization defined by the Brazilian association of technical norms ABNT NBR 15747-2 (ABNT, 2009). The solar simulator of the Grupo de Estudos em Energia (GREEN) of the Pontifícia Universidade Católica de Minas Gerais was used by the authors. The simulator has 8 lamps that total a power of 40 kW and have a spectrum of radiation similar to the natural radiation emitted by the Sun.

The norm NBR 15747-2 (ABNT, 2009) defines that the collector must be tested with clear sky conditions, provided by the solar simulator. It is desirable that the ideal inlet temperature for first measurement has variation of up to 3°C relative to ambient temperature. The maximum water temperature should reach a value close to 80°C.

A standard solar collector was selected for testing, with the dimensions specified in Table 1. The mass flow rate and wind speed were maintained within the deviations allowed by the standard, and the solar radiation was varied according to the values given in Table 2.

Table 1 – Specification of the solar collector used

External area (m²)	Open area (m²)
1,5	1,42

Table 2 – Schedules test

Test	Radiation (Wm^{-2})
A	700
B	850
C	1000

Seven (7) temperature measurements were performed at the entrance of the collector and 7 (seven) measurements at the exit of the collector of the solar collector. In addition, from the efficiency values found, the collector will be classified according to the PBE - Brazilian Labeling Program, which varies from A to E. Its evaluation depends on the Specific Monthly Energy Production - PMEe, as shown in Table 3.

Table 3 – Classification of collectors according to PMEe

Class	Variation of PMEe (kWh/mês-m^2)
A	PMEe > 80,3
B	73,3 < PMEe < 80,3
C	66,3 < PMEe < 73,3
D	59,3 < PMEe < 66,3
E	52,3< PMEe < 59,3

Monthly Energy Production (PME) is calculated by the following parameters:

$$PME = \frac{30 \, x \, 1000}{3600} . \eta med . K\theta . H . Aaber \tag{1}$$

Where,
H: Global Solar Radiation Incidence in Daily Mean 17.6 MJ / m 2,
ηmed: average thermal efficiency,
Aaber: opening area of the solar collector used (m ^ 2),

Kθ: is the correction factor for the angle of incidence and is calculated according to the standard ABNT NBR 15747-2: 2009 for the angle of 25º,

The average thermal efficiency is calculated from equation 2, where it is obtained by integrating the Thermal Efficiency function [η (x)] of the solar collector.

$$\eta med = (\int_0^{x'} \eta(x)dx) + x' \tag{2}$$

Where, x 'is the upper limit, determined by the PORTARIA INMETRO n ° 301/2012 for flat plate collectors, with a value of 0.044.

Therefore, for the calculation of the Specific Monthly Energy Production (PMEe) it is calculated by:

$$PMEe = \frac{PME}{Aext} \tag{3}$$

Where, Aext is the external area of the solar collector used (m ^ 2).

In the test, the values of solar radiation incident on the flat plane collector, the water inlet and outlet temperature, the water flow through the collector and the ambient temperature are measured. The temperature values were measured with the aid of PT-100 thermoresistors. To measure the solar radiation, a class I pyranometer was used and the flow rate was measured through an ultrasonic flow meter.

From the data obtained by the experiment, one can then calculate the instantaneous thermal efficiency of the collector is provided by:

$$\eta = \frac{Q^{\cdot}}{A.G} \tag{4}$$

Where,
$Q^{\cdot}$: heat transfer from the collector (W),
A: Collector area (m²),
G: Solar radiation (W / m²).

Therefore, to calculate the thermal efficiency, it is necessary to calculate the instantaneous power extracted $Q^{\cdot}$:

$$Q^{\cdot} = m . c_f . \Delta T \tag{5}$$

Where:
cf: specific heat of water (J / kg.K),
m: fluid mass flow rate (kg / s),
Δt: temperature difference of incoming water and water leaving the collector (°C).

The average temperature of the fluid is used to calculate the efficiency of the collector being used in the variable: (Tm-Ta) / G. Thus the average temperature of the fluid is given by:

$$T_m = Tin + \frac{\Delta T}{2} \tag{6}$$

Where,
Tin: inlet temperature (°C)
Tm: mean temperature of the fluid (°C),
Δt: temperature difference of incoming water and water leaving the collector (°C)

The instantaneous efficiency (η) can be obtained by means of statistical adjustment using the least squares method, and then generate the instantaneous efficiency curve of the formula:

$$\eta = \eta_0 - a_1 T_{mi} - a_2 G(T_{mi})^2 \tag{7}$$

At where,
η: instinct efficiency,
η_0: lossless collector efficiency,
a_1: coefficient of heat loss (W / m².°C)
a_2: coefficient of heat loss due to temperature (W / m².°C²)
T_{mi}: reduced temperature difference (m².°C / W)
The reduced temperature difference is calculated by:

$$T_{mi} = \frac{Tm - Ta}{G} \qquad (8)$$

Where,

Tm · : reduced temperature difference (°C),

Tm: mean temperature of the fluid (°C),

Ta: ambient temperature (°C) and

G: Solar radiation (W / m²).

3. RESULTS

Figure 1 shows the experimental efficiency curve for the test A obtained for a radiation of 700 W / m². The line represents the theoretical curve derived from a statistical fit, according to eq. (5). It is observed that, for an abscissa of 0.02, which corresponds to the average value for bath, the efficiency is 53,83%. This level of solar radiation is the most used by laboratories accredited by the General Coordination of Accreditation of Inmetro.

The Specific Monthly Energy Production (PMEe), as indicated in Table 4, is 74,02 kWh / month*m². These values indicate a classification of thermal performance "B", according to Ordinance No. 301 of June 14, 2012.
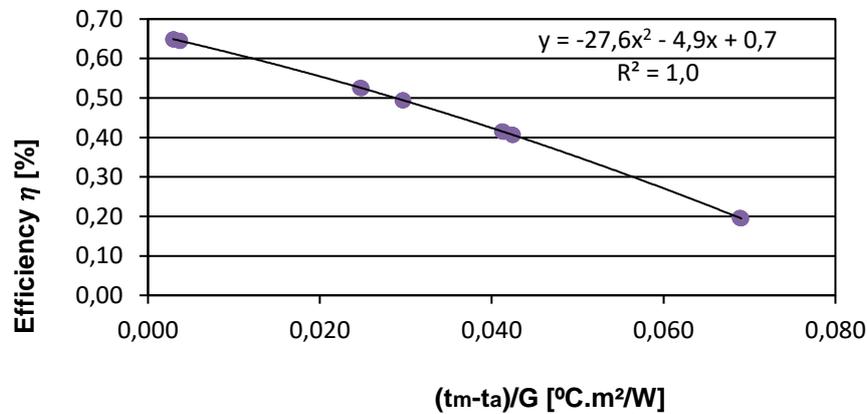

Figure 1 – Efficiency curve for test A

Figure 2 shows the experimental efficiency curve for the test B obtained for a radiation of 850 W / m². The line represents the theoretical curve derived from a statistical fit, according to eq. (5). It is observed that, for an abscissa of 0.02, which corresponds to the average value for bath, the efficiency is 53.33%. This level of solar radiation is the most used by laboratories accredited by the General Coordination of Accreditation of Inmetro.

The Specific Monthly Energy Production (PMEe), as indicated in Table 4, is 73.33 kWh / month*m². These values indicate a classification of thermal performance "B", according to Ordinance No. 301 of June 14, 2012.
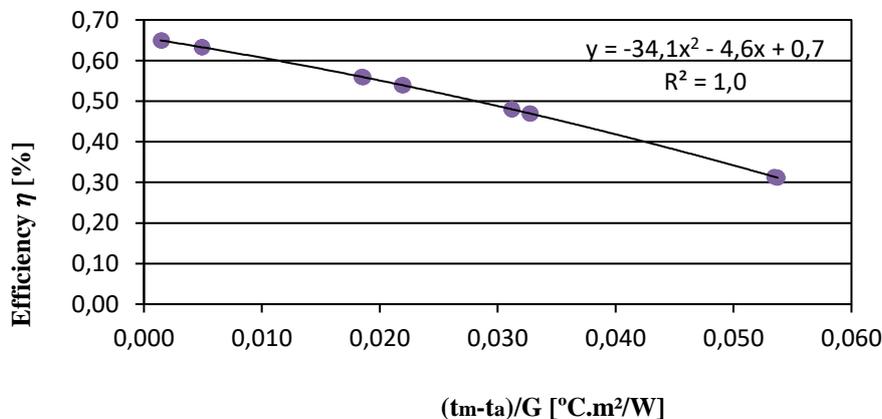

Figure 2 – Efficiency curve for test B

Figure 3 shows the experimental efficiency curve for the test C obtained for a radiation of 1000 W / m². The line represents the theoretical curve derived from a statistical fit, according to eq. (5). It is observed that, for an abscissa of

0.02, which corresponds to the average value for bath, the efficiency is 53.31%. This level of solar radiation is the most used by laboratories accredited by the General Coordination of Accreditation of Inmetro.

The Specific Monthly Energy Production (PMEe), as indicated in Table 4, is 73.30 kWh / month*m². These values indicate a classification of thermal performance "B", according to Ordinance No. 301 of June 14, 2012.
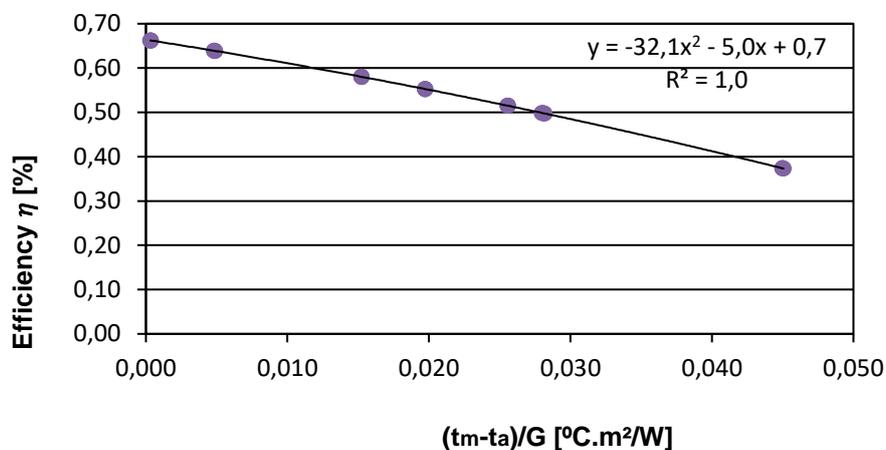

Figure 3 – Efficiency curve for test C

The Table 4 is a brief summary of some important information extracted from the results of the three experimental data.

Table 4 – Test B

	Efficiency (%)	PMEe	Classification	Maximun Temperature (ºC)
Test A	53,83	74,02	B	71,00
Test B	53,33	73,33	B	72,53
Test C	53,31	73,30	B	73,89

4. CONCLUSION

In this paper was evaluated the influence of different radiation level on an efficiency test of a flat plate collector. The results of the three experimental shows that the calculated efficiencies were almost the same for the three distinct radiation conditions, with higher temperatures being obtained when having a higher radiation level, as expected. It was concluded that for higher solar radiation higher temperatures are obtained than for lower solar radiation. However, because the efficiency calculation takes into account the energy (through the radiation) offered to the collector, it is concluded that the highest temperature difference is compensated by the highest radiation and the efficiency of the solar collector is almost the same when operated in these three different solar radiation conditions.

5. ACKNOWLEDGEMENTS

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