Analysis of the Performance of a Solar Water Heating System with Flat Collector

Aurea Lúcia Georgi Vendramin, Carlos Itsuo Yamamoto, Carlos Eduardo Camargo Nogueira, Anderson Miguel Lenz, Samuel N. Souza Melegari

Abstract**—**The thermal performance of a solar water heating with 1.00 m2 flat plate collectors in Cascavel - PR, is which presented in this article, paper presents the solution to leverage the marketing of solar heating systems through detailed constituent materials of the solar collector studies, these abundant materials in construction, such as expanded polyethylene, PVC, aluminum and glass tubes, mixing them with new materials to minimize loss of efficiency while decreasing its cost. The system was tested during months and the collector obtained maximum recorded temperature of outlet fluid of 55°C, while the maximum temperature of the water at the bottom of the hot water tank was 35°C. The average daily energy collected was 19.6 MJ/d; the energy supplied by the solar plate was 16.2 MJ/d; the loss in the feed pipe was 3.2 MJ/d; the solar fraction was 32.2%, the efficiency of the collector was 45.6% and the efficiency of the system was 37.8%.

Keywords**—**Recycled materials, energy efficiency, solar collector.

I. Introduction

THE use of solar energy to produce hot water for residential purposes is one of the most viable applications of this clean energy and mass source in developed countries, but the main barrier to their massive use is its high cost. Overcoming this barrier would help to alleviate our energy matrix from non-renewable energy sources. Recycling, as well as solar thermal energy, has a number of advantages among which the reduction of environmental impact, the generation of income and employment, besides energy conservation. A practical example is the solar water heater cost, represented both by the low cost of the materials and by simplifying the process of assembly and installation.

The Flat Plate Collector (FPC) has the mission to absorbing the most efficient possible manner the solar radiation and to convert it into usable heat energy through its transfer to the heat carrier fluid.

The used materials to manufacture the plate must have high thermal conductivity to reduce resistance to heat flow by conduction. FPC, Fig. 1, consists of five main elements: a transparent cover (transparent glass 3 mm), PVC pipe 32 "(painted with gloss black paint), the aluminum plate omega shaped has on its side slope of 45 degrees every 2.5 cm, the thermal insulation (polyurethane expanded foam TYTAN PRO 30) and the housing.

Fig. 1 Flat plate collector (FPC)

The transparent cover is in charge of producing the greenhouse effect, reducing losses by convection and guaranteeing the tightness of the sink to water and air, in union with the housing and the seals. The greenhouse effect achieved by the cover causes a portion of the radiation that passed through the cover and reaches the PVC collector pipe is reflected to the transparent cover, with a wavelength for which it is opaque, retaining the radiation inside. This effect defines the characteristics of coverage: high transmittance of solar radiation; low transmission coefficient for long wave; low coefficient of thermal conductivity; high reflection coefficient for the length of the long wave radiation emitted by the collector plate. The heat absorbed by the aluminum plate painted gloss black and retained within the FPC and is transferred to the water by the columns of PVC, also painted black. Though simple, a solar heating system has key details in its manufacture and installation, for a proper operation.

The sizing of the solar collector in relation to the water tank or accumulator is very important to limit the temperature to levels that maintain the rigidity of PVC (maximum temperature of 55°C when applied to systems where the heated water decreases its density and begins to move in

Georgi Vendramin Aurea Lucia is with the Ufpr, UFPR - Av. Brasil,6282, Sala42, Central Park, Cascavel – PR, Brazil, ZIP Code: 85801-000 (e-mail: aureavendramin@hotmail.com)
Yamamoto, Carlos Itsuo is with the Lacaut ETs - Departamento de Engenharia Química - Setor de Tecnologia Usinas Piloto – Bloco A, UFPR - Centro Politécnico - Jardim das Américas, Curitiba – PR, Brazil. P.O.Box 19024, ZIP Code: 81531-990 (e-mail: citsuo@gmail.com)
Camargo Nogueira, Carlos Eduardo is with the UNIOESTE - Lene - Laboratório de Energia - Unioeste – Rua Universitária 1619, Jd. Universitário - Cascavel – PR, Brazil. (e-mail: carlos.nogueira@unioeste.br).
Lenz, Anderson Miguel is with the Unioeste – Rua Universitária 1619, Jardim Universitário - Cascavel – PR, Brazil. ZIP Code: 85814-110 (e-mail: andersomm25@gmail.com)
Souza Melegari, Samuel N is with the UNIOESTE - Lene – Laboratório de Energia (e-mail: melegsouza@hotmail.com)

towards the box, starting a process and natural water circulation, called thermosiphon), without causing softening of the material and, consequently compromising the structure of the solar or the entire set causing leaks or even destruction of the solar collector. The correct dimensioning allows the water flowing in the collector is heated and also limits the temperature to safe levels to PVC.

The aluminum plate below the PVC tubing is secured at its bottom by a sheet of thermal insulation to avoid heat losses to the outside. The main feature is the insulating withstand high temperatures without deteriorating, the material used expanded polyurethane. Aluminum is a light, soft and sturdy metal. It has a gray appearance and was painted gloss black.

Aluminum was used as a non-toxic metal, non-magnetic and does not create sparks when exposed to friction. Pure aluminum has about 20 MPa and 400 MPa when it is inserted in an alloy. Its density is approximately one third of steel or copper. It is very malleable, very ductile, suitable for mechanization and casting, as well as having excellent corrosion resistance and durability due to the protective oxide layer. It is the second most malleable metal; being the gold the first one and the sixth most ductile. Aluminum material is the most important non-ferrous metal and has high industrial importance due to its excellent physical and chemical properties, as according Perry (1980) "is a lightweight metal (density = 2.7 g/cm3, i.e. a third of the density of steel) with low melting point (660 C when the purity of 99.80%), "with high specific resistance mainly in the form of alloys, as well as other properties such as long life, corrosion resistance, excellent thermal conductor and electric, good reflective properties and infinitely recyclable.

The thermal insulation composed of expanded polyurethane foam has a density in their properties between 30-80 kg/m³, compressive strength of 200 N/mm², thermal conductivity about 0.023 W/m•K, coefficient of friction $\mu = 0.0135$, the coef. conductivity equal to 0.030 kcal/h • m • ° C, and its optimum working temperature is around -40 to 115°C, high tensile, flexural and impact, light and does not conduct electric current, allows wide flexibility project, enabling molding wrapped to collector pieces.

The carcass of the FPC is composed of a profile of recycled aluminum (collecting, pressing, casting and rolling).

Solar energy collectors are the key component of the so SWHSs (solar water heating systems), and evaluate its thermal performance is vital. A number of studies on the performance of FPCs were performed under steady state conditions and nearly -dynamic test in the following standard EN 12975-2 [1] and ASHRAE 93-86 [2]. Zambolin and Del Col [3] conducted a comparative performance analysis of the thermal performance of plate tube collectors in Padova, Italy. They presented a new set of data collected for both flat plate collectors and evacuated tube collectors tested simultaneously steady and nearly-dynamic state proficiency tests following the standard EN 12975-2. Tiwari et al. [4] analyzed the performance of solar FPCs manufactured in India, with values ranging between 5.139 and 7.024 Frut.

Amer et al. [5] have developed a method for characterizing the transient dynamic behavior of solar FPCs and validated and the results obtained from the steady-state tests based on ASHRAE standard 93-86. They also investigated the effect of inlet temperature and incident angle on the parameters of the collector. Chen et al. [6] conducted tests to evaluate the gains of two solar FPCs at different flow rates.

Consequently, other studies have focused on evaluating the performance of SWHSs in real time and conditions. Michaelides and Eleftheriou [7] studied the behavior of an FPC SWHS with 3 m2 and a hot water tank 68 L in Cyprus based on data collected over two years. Ayompe et al. [8] compared the year-round energy and economic performance of the two SWHSs with flat plate collectors and evacuated tube collectors that operate under the same weather conditions in Dublin, Ireland. Building Research Establishment [9] evaluated the performance of a SWHS in Cambridgeshire, UK, which had a flat plate solar collector panel (Clearline V30) manufactured by Solar Viridan, UK. The test rig included an automated system that incorporated the effects of the auxiliary heating system (boiler or immersion heater) and daily use of hot water in the average European household described by the term “ciclo” of the European Union (EU M324EN) equivalent to 100 L at 60°C. The results showed that more than one year, the controller 3 m2 generated AC-5266 MJ of heat counting by 57% the need for hot water. This paper presents results on the analysis of the thermal performance of a SWHS with 1.00 m2 FPCs using data from a study conducted in Cascavel, Paraná, Brazil.

II. Methodology

To establish the quality of energy performance and express its need for energy saving, it was decided to conduct a pilot project (prototype), located in the city of Cascavel - PR with Latitude 24 ° 59 'South, Longitude 58 ° 23' West and medium altitude 785 meters, the residential building Smart Home UNIOESTE campus. Its thermal performance was monitored over a period of winter. The SWHS had a tank of 100l of water (called boiler), the best performance of the solar heater collector fixed flat plate was made on account of the greater amount of annual hours of sun exposure with no deviations superiore of 15^0 the Geographic North (in Southern Hemisphere). System performance data were collected every 5 minute.

III. Measurement and Data Logging

Consider the amount of solar energy that reaches (FPC) the flat plate solar collector with solar receiving area of dimensions of 1.20 x 0.83m, considering the quality of the celestial vault in relation to an isotropy or anisotropy of the sky and its brightness. The measurement of the solar radiation at the site of research has been done by a pyranometer manufactured by Kipp & Zonen, model CMP3, with a sensitivity of 15.30 microvolts / watt.m2 installed near the collector, and the amounts of radiation and temperatures water flow were measured and stored in the Datalogger in 5 in 5min, for comparison with the results of the heat energy of the system.

IV. Analysis of Energy Performance

The energy performance indices evaluated in this study include: energy collected, and supply useful energy losses in pipes, solar fraction efficiency of the solar collector and system efficiency.

A. Energy collected: The useful energy collected by the solar collector is calculated:

Qc=MCP(Tc,the-TCi) (1)

B. Useful energy and supply losses in pipes: The useful energy emitted by the solar collector to the hot water tank is given as:

Qd = m Cp (Tsk; i - Tsk;o) (2)

C. Solar Fraction (SF): Relationship between the yield of solar radiation to the water heating requirement, and it is given:

SF = Qs / (Qs + Qaux) (3)

D. Efficiency Solar Collector:

Ƞ c = [MCP (Tc, o - Tc, i)]/ACGT (4)

E. System efficiency:

Ƞ c = [MCP (Tsk; i - Tsk; o)] / ACGT (5)

V. Results and Discussions

A. Daily Performance

Three typical representatives of the relevant meteorological conditions in Cascavel days were used to analyze the daily performance of the FPC and SWHS. They consist of cloudy weather (09/08/2014), clear sky (08/26/2014) and intermittent cloud covered (07/23/2014). Fig. 2 shows graphs of solar radiation during the three days. The maximum daily solar radiation was 875.2 W/m2 on overcast days, 1120.6 W/m2 in clear sky day and 962.7 W/m2 on days with cloudy skies.

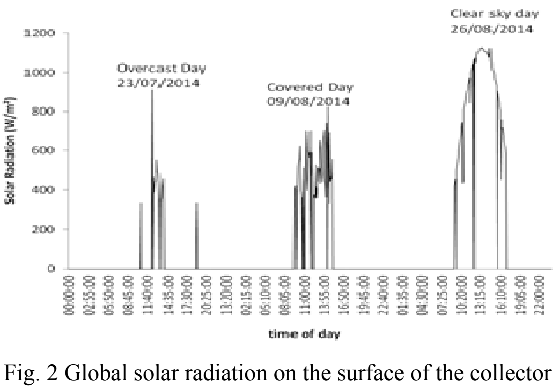

Fig. 2 Global solar radiation on the surface of the collector characteristic for three days

Fig. 3 shows graphs of characteristic temperature for the three days.

There was a variation in temperature between 11^0C and 24.2^0C.

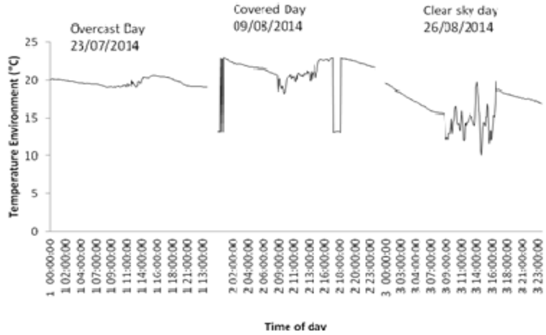

Fig. 3 Ambient temperature characteristic in three days

B. Daily Variation in Temperature

Fig. 4 shows plots of daily variation solar temperature at the outlet of the collector (Tc, o) the water temperature at the bottom of the hot water (Tb t) tank, the inlet temperature of the cold water to the hot water tank (TCW i). It is seen an increase in (Tc, o) due to solar gain through the collector, and causes a delayed Tb, t increasing. The time interval is caused by the time it takes for the heat exchange between the fluid and the water in the tank, as well as driving fluid conduction through the tank to the sensor Tb, t. Cold water supply was from a box located in the Smart Home that the prototype was installed. Short-term variations in the TCW, I, results occurred with changes in temperature of the boiler where the hot water tank was installed. It is seen that however, during the day of clear sky the Tout not drop below 37^0C, so due to the relatively greater amount of heat emitted by the solar collector throughout the day. This shows that there is a continuous flow of clear days; the SWHS would need to provide evening with a reduced amount of auxiliary energy (electricity).

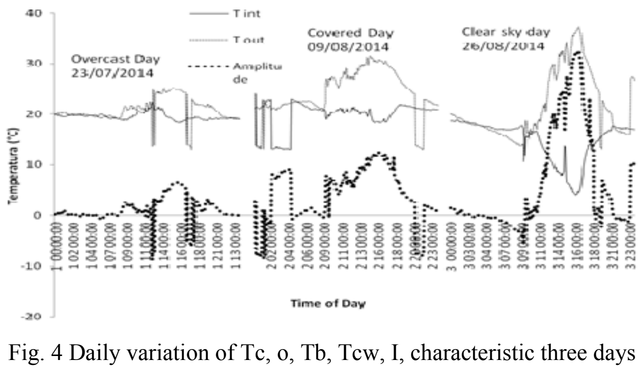

Fig. 4 Daily variation of Tc, o, Tb, Tcw, I, characteristic three days

C. System Efficiency and Efficiency of the Solar Collector

Fig. 5 shows the monthly average daily efficiency of the solar collector. The average daily solar collector ranged from 38.2% in July to 53.9% in September, while the system efficiency ranged from 31.3% in June to 44.7% in September. The average daily efficiency of the solar collector was 45.6%, while the efficiency of the system was 37.8%.

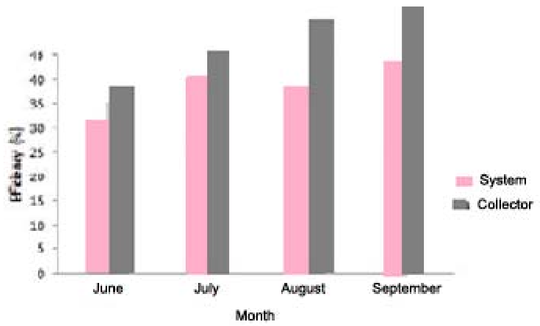

Fig. 5 Monthly daily Average collector efficiency and system efficiency

VI. CONCLUSIONS

The analysis of the energy performance throughout the period of SWHS commonly installed with FPC was performed using a prototype rattlesnake - PR. The SWHS is designed and operated to mimic the operation of real life taking into account the interaction between the FPC and the user.

The results showed that, for a global solar insolation on the collector surface of 15680.4 MJ (corresponds to 4.35 overall and 1.08 kw/ m2), a total of 7150.4 MJ was collected when 5924.0 MJ was delivered to the hot water tank. Solar fraction was 32.2%. The collected daily average energy was 19.6 MJ/d; the daily average energy provided by the plate was 16.2 MJ/d and the losses of energy through the pipes was 3.2 MJ/d. Annual average fraction, solar collector efficiency and system efficiency were 32.2%, 45.6% and 37.8%, respectively.

The maximum temperature recorded in flat plate collector outlet temperature was 55^{o}C, while the total annual loss of heat to the feed tube SWHS was 1171.7 MJ corresponding to 16.4% of the energy collected by the FPC and 19.8% of the energy supplied to the hot water tank. The tubes of the solar power circuit must be kept as short as possible in order to reduce energy loss. The results of this study and of the study by the Building Research Establishment in 2009 revealed that SWHSs with FPCs would generate between 1750 and 1790 MJ/m2/yr of heat in maritime North climate.

CLASSIFICATIONS

Ac	= area of collector (m2)
Cp	= specific heat capacity of solar fluid (J/kg/K)
Ei	= daily solar energy input (MJ/m2/d)
Ec	= energy collected daily (MJ/m2/d)
Gt	= total solar radiation on the surface of the collector (W/m²)
m	= solar mass fluid flow rate (kg/s)
Qaux	= requirement for auxiliary heating (MJ)
Qc	= useful heat collected (J)
Qd	= useful heat delivered (J)
Ql	= supply pipe heat loss (J)
Qs	= solar yield (MJ)
SF	= solar fraction (%)
hc	= efficient collector (%)
hs	= system efficiency (%)

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