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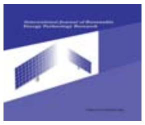

Research article

Experimental Investigation of the Effect of Forced Convection on Solar Thermal Collector Efficiency

Kevin R. Anderson, Raymond Faull, Charles Lowry, Thomas Tran

California State Polytechnic University at Pomona,

3801 West Temple Ave, Pomona, CA, 91768, USA

Phone: 1+909-869-2687, FAX: 1+909-869-4341,

kranderson1@cpp.edu

Abstract

This paper present the results of an experimental investigation aimed at quantifying the effects of forced convection on the efficiency of a flat plate collector. The primary outcomes of this research was to develop a correlation between the air velocity and the convective heat transfer coefficient for a flat plate solar collector and to determine the degree of influence forced convection has on the overall performance of the flat plate collector. In this paper we present a heat transfer correlation versus the local air speed across the collector surface and compare to existing findings reported in the literature. The primary findings herein show that for air speeds in the range of 3 to 4 m/s it has been found that the efficiency of the flat plate collector is 67 % to 52%, respectively. **Copyright © IJRETR, all rights reserved.**

Keywords: Solar thermal, efficiency, forced convection

Introduction

This research study follows others performed in the area of solar collector performance characterization. This study is a continuation of the work of Anderson et al. [1] in which results are presented for the testing of a flat plate solar thermal collector. The motivation herein is to present the solar thermal engineering community with a working correlation which directly relates the solar collector flat plate thermal efficiency to the local air speed and thus parasitic convection losses. To this end, the primary outcomes of this present research was to develop a correlation between the air velocity and the convective heat transfer coefficient for a flat plate solar collector and to determine the degree of influence free convection has on the overall performance of the flat plate collector. In this paper we present a heat transfer correlation versus the local air speed for the collector surface and compare to existing studies in the literature. Additionally, we present empirical data for efficiency of the flat plate collector as a function of convective air speeds. Previous research has been carried out in characterizing the performance of flat plate solar collectors including the summary of Kalogirou [2] in which a survey of the various types of solar thermal collectors and applications is presented. The work of [2] serves as an excellent introduction to the solar thermal energy sector. In the work of Rojas et al. [3], the thermal performance testing of flat-plate collectors is presented by comparing existing standards for testing the performance of flat-plate solar collectors per the ASHRAE 93 Standard and comparing with the EN12975-2 transient test standard. The EN12975-2 standard of [3] employed a refined collector model which includes specific terms for the wind speed dependence and the collector thermal capacitance, which do not exist in the ASHRAE model. The works [4,5] offer a review of solar collectors and thermal energy storage technologies used in solar thermal applications. In the research of Satori [6], convection coefficient equations for forced air flow over flat plate solar collectors is presented. The current research compare the correlations of Satori [6] to the test data collected at Cal Poly Pomona for a SUNEARTH Solar Thermal Collector. Furthermore we offer a relationship between local ambient free convection heat transfer coefficient versus solar flat plate thermal efficiency performance. The novelty of the current work is that we provide a correlation of efficiency to air speed.

Materials and Method

The testing configuration for a liquid-type solar collector is dictated by ASHRAE Std. 93-77, “Methods of Testing to Determine the Thermal Performance of Solar Collectors” ASHRAE 93-77 (1993) per [7]. Figure 1 through Figure 3 show test set-up used by our research group at the Solar Thermal Alternative Renewable Energy Lab at California State Polytechnic University at Pomona’s Mechanical Engineering Department. The test facility consists of the SUNEARTH Flat Plate Solar Collector, a 90 gallon water storage hot water tank, pump, and instrumentation. ASHRAE Standard 93-77 mandates the use of the various components such as the check valve, isolating valves, drain/purge valve, by-pass valve, etc.

Figure 1. SUNEARTH solar collector test hardware

As shown in Figure 2, in order to simulate the effects of wind (forced convection), a set of three fans were placed at the base of the SUNEARTH flat plate collector. These fans were then set at low (10 ft/sec), medium (11.5 ft/sec) and high (12 ft/sec) speeds in order to mimic a range of fluctuations in the local weather and ambient conditions.

Figure 2. Test hardware showing proximity of forced convection simulation fans to solar collector test article

The rationale behind the design of this experiment was largely based on the desire to acquire a database of results with quick turn-around time. For instance, instead of taking data over a period of weeks, or even months while monitoring the long term seasonal fluctuations of local wind gusts, which can be gathered from weather station data, it was decided to actively force the air using the configuration of fans shown in Figure 2.This would allow the investigation to be completed over a period of days versus months having created an “artificial” perturbation environment by forcing the air with the fan array as shown in Figure 2.

Figure 3. Test hardware showing data acquisition system

The data acquisition set-up is shown in Figure 3. The following instrumentation was used for this experiment, Type K Thermocouples, G ½ Flow Sensor, Arduino UNO Microprocessor Data Acquisition board, and a Daystar DS-05 Solar Meter. The flow sensor was connected to an Arduino UNO microprocessor board for data collection to a laptop PC. The flow rate of the water through the collector was 1.2 gpm = 9.6 cubic ft / hr. The pressure of the water in the collector was 35 psi. The mass flux flow rate of the SUNEARTH FPC had a nominal value of 0.-2 kg/s-m^2 (14.7 lb/hr-ft^2). The sampling rate uses on the OMEGA data logger was as follows: insolation was recorded every 10 minutes, efficiency was recorded every 30 minutes.

Results and Discussion

The first stage of the testing was to compare heat transfer correlations across flat plate collectors published in the literature to the current data. To this end the work of Satori [6] was used as a reference. The work of [6] includes a comprehensive summary of various correlations postulated by several researchers over a span of decades. The results for the convection testing are shown in Figure 4. Figure 4 shows that the heat transfer coefficient is a linear function of the air speed per (1)

$$h = aV + b \qquad (1)$$

where *a*,*b* are empirically determined constants, and *V* is the air speed. (1) is of the same form offered by Goswami et al. [8] for modeling convection across a flat plate solar thermal collector.

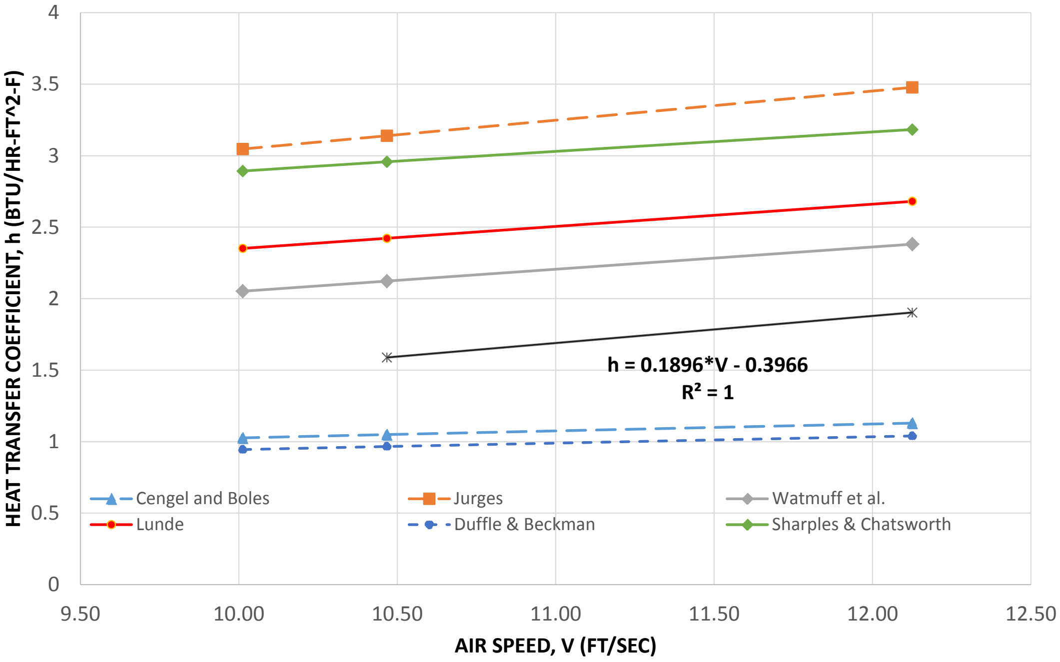

Figure 4. Results for convection testing

Figure 4 shows the heat transfer coefficient h (BTU/hr-ft^2-F) plotted against the air fan speed V (ft/sec) for our test apparatus overlaid in comparison with the correlations of Cengel and Boles [9], Jurges [10], Watmuff et al. [11], Lunde [12], Duffie and Beckman [13], and Sharples and Chatsworth [14]. As can be seen in Figure 4, the current findings agree both qualitatively and quantitatively with the findings given by [9-14]. In particular the studies of [11,14] which have the same focus as the current research are seen to behave as an upper bounds for the present work, as can be seen in Figure 4. The next portion of the investigation was performed which involved quantifying the effect of convection losses on the overall efficiency of the flat plate collector's performance. This phase focused on collecting data and generating results for the performance testing of the solar collector as a function of the air speed. These results are shown in Figure 5.

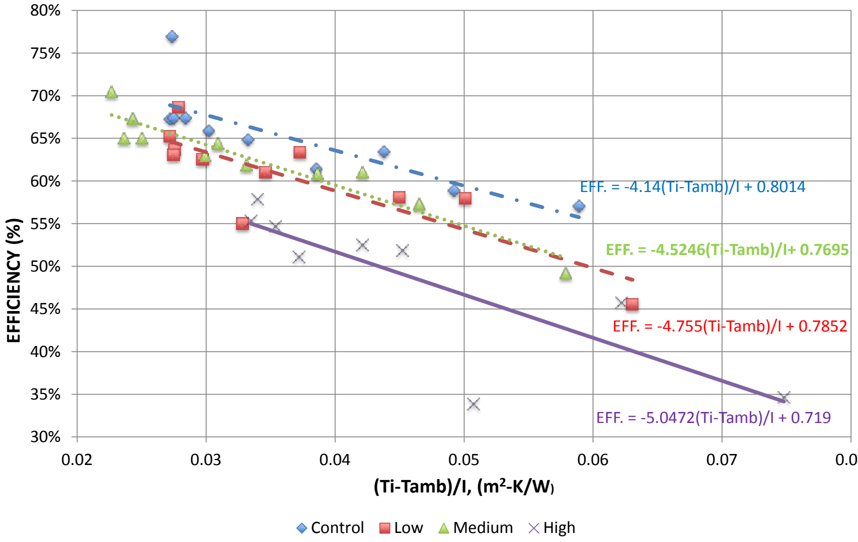

Figure 5. Performance as function of air speed

Figure 5 shows the data and trend lines for the following cases: control (fan air speed = 0 ft/s), low (fan air speed = 10.5 ft/s), medium (fan air speed 11.5 ft/s) and high (fan air speed 12 ft/sec). The results of Figure 5 are in qualitative agreement with those of Goswami et al. [8] and the linear curve fits listed in Figure 5 agree with those previously reported by Anderson et al. [1] for the "control" scenario. The x-axis of Figure 5 is the typical metric used in performance characterization of flat plate solar collectors and can be found in Goswami et al. [8] as shown in (2)

$$\eta = m\Delta T / I + b \tag{2}$$

where η denotes the efficiency, *I* is the solar insolation (W/m^2), *m* is the slope of the performance curve, b the intercept, and *ΔT/I* is given by (3)

$$\Delta T / I = \frac{(T_i - T_{amb})}{I} \tag{3}$$

which can be viewed as a measure of characteristic thermal resistance of the collector. The slope is m= $|F_R U_c|$ W/m^2-K which denotes the heat removal capability of the collector, with F_R = the heat removal factor, and U_c the overall convection heat transfer coefficient. The y-intercept, b $= F_R \tau_s \alpha_s$ takes into account the optical coating of the solar collector, relating the key optical parameter grouping $\tau_s \alpha_s$ into the relationship. Practically speaking, the intercept of the performance plat is the thermal resistance of the overall system, while the reminder of the curve depicts the resistance of the working fluid in the collector. A higher intercept corresponds to a larger convection resistance as shown in Figure 4. The key finding to take away from Figure 5 is that the effect of air speed at a given ΔT/I is to decrease the efficiency of the solar collector. For instance, at any given ΔT/I value along the x-axis, one notes that as the fan is turned on from the control: low: medium: high setting the efficiency drops by at most 10%. The correlation of heat transfer coefficient across the face of the solar collector as a function of air speed is given as (4) as follows:

$$h = 0.1896V - 0.3966 \pm 25\% \tag{4}$$

where h [BTU/hr-ft^2-F] is the transfer coefficient and V [ft/sec] is the air speed. For forced convection air speeds $10 < V < 12$ ft/s ($3.048 < V < 3.6576$ m/s)it has been found that the efficiency range is $67\ \% < \eta < 52\%$.

Conclusion

This experimental investigation has been performed in order to quantify the effects of forced convection on the efficiency of a SUNEARTH flat plate solar collector. In this present study, the heat transfer coefficient across the face of the solar thermal collector has been experimentally determined and compared to correlations found in the published literature, reported as Equation (4) herein. Equation (4) demonstrates that even a small perturbation on the order of 2 ft/sec (0.6096 m/s) can have a substantial impact (a drop of 15% in the efficiency) on the performance of a commercial flat plat solar collector.

Acknowledgement

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