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Thermal performance of integrated collector storage solar water heater with corrugated absorber surface

Rakesh Kumar*, Marc A. Rosen

Faculty of Engineering and Applied Science, University of Ontario Institute of Technology, 2000 Simcoe Street North Oshawa, Ontario L1H 7K4, Canada

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ABSTRACT

An investigation is reported of the thermal performance of an integrated solar water heater with a corrugated absorber surface. The thermal performance of the rectangular collector/storage solar water heater depends significantly on the heat transfer rate between the absorber surface and the water, and on the amount of solar radiation incident on the absorber surface. In this investigation, the surface of the absorber is considered to be corrugated, with small indentation depths, instead of plane. The modified surface has a higher characteristic length for convective heat transfer from the absorber to the water, in addition to having more surface area exposed to solar radiation. The corrugated surface based solar water heater is determined to have a higher operating temperature for longer time than the plane surface. It means during the operation of water heater, more solar energy is converted into useful heat. However, this modification has reduces the efficiency of the system marginally.

1. Introduction

The solar water heater is a well developed technology for water heating in many countries, including Canada. Numerous solar water heater designs are available in the market, reflecting the needs of different locations and applications [1]. Some designs are simple and others complicated. Forced circulation-type solar water heaters with antifreeze are considered the best option in many cold climatic countries like Canada, due to large variation in the air temperature and freezing conditions [2]. However, these systems are expensive and have payback periods of up to 20 years or more. Natural convection or thermosyphon solar water heaters are popular in many developing countries due to their simple designs and grid power independence [3].

Another version of a solar water heater, the integrated solar water heater or built-in-storage (BIS), has been proposed and tested by several researchers [4–10]. The simple design of this type solar water heater has a good potential for many developing countries and also for countries with cold climates (for seasonal applications). The integrated solar water heater provides a simple and economic application of water heating via solar energy. This collector/storage system is integrated, as the collection of solar energy and storage of hot water occur in a single unit. The long term performance of a built-in-storage solar water heater was studied by Garg [11]. To extend the scope of suitability of the BIS system for year round applications, the use of night insulation, transparent insulation and phase change materials have been considered [12–14].

Evevit et al. [15] proposed a modified form of the BIS solar water heater, known as triangular built-in-storage (BIS) solar water heater. Detailed theoretical studies of this system have been reported by Kaushik et al. [16,17]. The triangular BIS system exhibited better overall performance than the rectangular design, due to enhanced heat transfer between the absorber surface and the water. A new form of BIS system was recently proposed by Cruz et al. [18]: the trapezoidal BIS solar water heater. In this design the storage shape is trapezoidal and the absorbing surface is inclined at 45° from horizontal. Tarhan et al. [19] has investigated the temperature distribution in trapezoidal BIS solar water heater with/without phase change materials. Madhlopa et al. [20] has done experimental study of temperature stratification in an integrated collector/storage solar water heater with two horizontal tanks. All these modifications of the integrated solar water heaters are intended to increase system efficiency and usefulness for practical applications.

The thermal storage ability of the solar water heater is important, as it dictates to a large extent the duration of time the collected thermal energy can be retained and consequently the applicability of the device. Thermal energy storage has been examined in great detail by Dincer and Rosen [21].

In the present study a modification to the shape of absorber surface is suggested and analysed. A corrugated instead of plane absorber surface is considered. A small corrugation depth is

* Corresponding author. Tel.: +1 905 721 8668; fax: +1 905 721 3370.
E-mail address: rakesh.kumar@uoit.ca (R. Kumar).

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considered (less than 1 mm). It was assumed that the surface can still considered plane for solar radiation collection. The modified surface has a higher characteristic length, which affects the convective heat transfer coefficient from absorber surface to water, in addition to having more surface area exposed to solar radiation. The performance of the modified rectangular BIS system is compared with the non-modified version, in terms of design and operational parameters. It is observed that the proposed solar water heater convert more solar energy into useful heat than the rectangular BIS system.

2. Design details

In present study the shape of integrated solar water heater is rectangular and the area of the absorber surface is calculated for different depths of corrugation (Fig. 1). The volume of water in the tank is fixed at 100 litres. All the surfaces of the storage tank are made of 20 gauge galvanised iron sheet. Only small corrugation depths on the absorber surface are considered. The depth of corrugated surface is varied between 0.0004 m and 0.001 m. The incident solar radiation is evaluated for such small depths treating the absorber surface as plane. The area of each groove is calculated based on the depth of corrugation and the total number of grooves in a 1 m length of water heater. The tank bottom and sides are insulated with a 5 cm thick layer of fibreglass. A transparent glass cover is located at the top of absorber surface to minimize top losses. The effect of a night insulation cover on the performance of water heater is also assessed. When solar radiation strikes the glass cover, most is transmitted to the absorbing surface while part is reflected. The absorber surface absorbs most part of incident radiation. The angle of inclination of the absorber surface is taken to be equal to the latitude of location to maximise the amount of incident solar radiation. This angle also impacts natural convection heat transfer. The system is south facing.

3. Analysis

The authors developed a transient model to analyse the thermal performance of the integrated solar water heater with a corrugated absorber surface. The input climatic variables are hourly values of solar radiation and ambient temperature for a typical day of Toronto. The hourly values of solar radiation were calculated using the data of RETScreen [22] and from various correlations in Duffie and Beckman [23]. Energy balance equations for proposed design are developed for the absorbing surface and the water [24]. We invoke several assumptions in the analysis:

1) As the depth of corrugation is less than 1 mm, it is considered as a plane surface for determining the incident solar radiation, as the impact of corrugation on the beam radiation reaching on the absorber surface is small and, in fact, may be enhanced through greater diffuse and reflected radiation.
2) All thermo-physical properties were considered constant within the operating temperature range of the water heater.
3) There are no lateral gradients in the temperature of the absorber surface and water in the storage tank.
4) All the components of the water heater at the beginning of the heating cycle (morning) are taken to be at ambient temperature.
5) The inlet water temperature during constant flow withdrawal is considered same as the ambient temperature.

An energy balance can be expressed for the absorber surface as follows:

$$m_p c_p \frac{dT_p}{dt} = (\alpha\tau)_e I_t A_p - h_{pw}(T_p - T_w)A_p - U_t(T_p - T_a)A_p \quad (1)$$

The left hand side of above equation represents the change in the thermal capacity ($m_p c_p$) of absorber surface with time. $(\alpha\tau)_e I_t A_p$ is the input solar radiation absorbed by the absorber of area A_p. h_{wp} is the convective heat transfer from the absorber to water and U_t is the overall heat losses from absorber to ambient air. T_p, T_w and T_a are the temperatures of absorber, water and ambient air, respectively.

Similarly, an energy balance can be expressed for the water in the storage as

$$m_w c_w \frac{dT_w}{dt} = h_{pw}(T_p - T_w)A_p - U_{be}(T_w - T_a)A_{be} - \dot{m}c_w(T_w - T_{in}) \quad (2)$$

The left hand side of the above Eq. represents the change in the thermal capacity ($m_w c_w$) of water with time. U_{be} is the bottom and sides losses from the surface area A_{be}. The term $\dot{m}c_w(T_w - T_{in})$ is the quantity of heat withdrawal from the tank with flow rate $\dot{m}$.

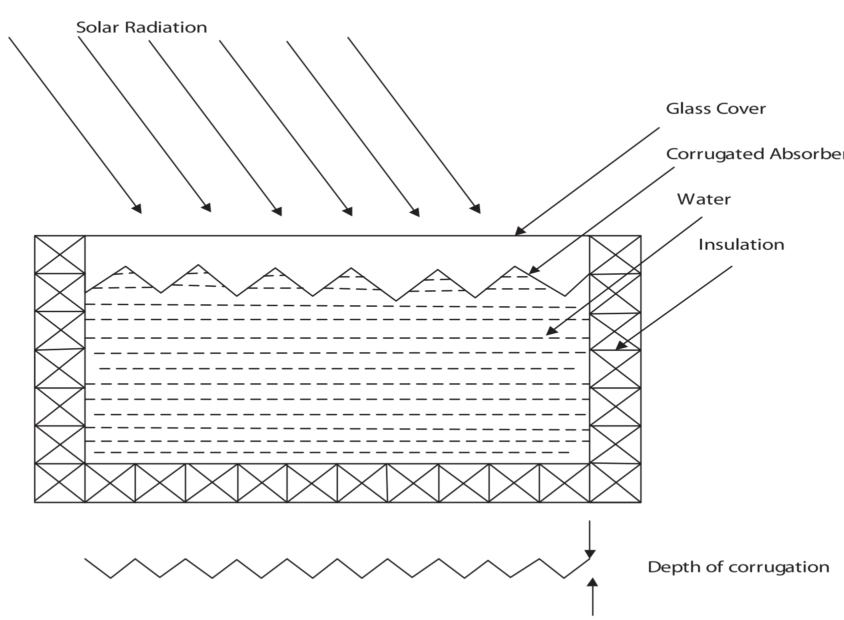

Fig. 1. Cross-sectional schematic of rectangular solar water heater with corrugated surface.