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Performance improvement in solar water heating systems—A review

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ABSTRACT

Solar energy is free, environmentally clean, and therefore it is accepted as one of the most promising alternative energy sources. The effective use of solar energy is hindered by the intermittent nature of its availability, limiting its use and effectiveness in domestic and industrial applications especially in water heating. Conversion of solar energy into thermal energy is the easiest and most used method. The efficiency of solar thermal conversion is around 70% but solar electrical direct conversion system has an efficiency of only 17%. Solar water heating systems are mostly suited for its ease of operation and simple maintenance. Many research papers revealed that the improvement on thermal efficiency of solar water heating systems resulted in techniques to improve the convection heat transfer. Solar water heating systems are classified into two broad categories as passive and active systems. Passive techniques have been used to improve the convective heat transfer. The techniques like insertion of twisted tapes and its geometry, etc., play a vital role to improve the performance of solar water heating systems. This review paper summarizes the previous works on solar water heating systems with various heat transfer enhancement techniques include collector design, collector tilt angle, coating of pipes, fluid flow rate, thermal insulation, integrated collector storage, thermal energy storage, use of phase change materials, and insertion of twisted tapes. This paper also discussed the methods to optimize and simulate the solar water heating systems to understand flow and thermal behavior in solar collectors that would lead to the improvement of the thermal performance of solar collectors.

Contents

1. Introduction

In recent years solar energy has been strongly promoted as a viable energy source. One of the simplest and most direct applications of this energy is the conversion of solar radiation

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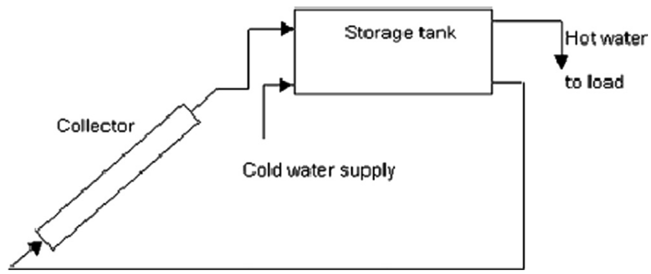

Fig. 1. Schematic diagram of a typical thermosyphon solar water heating system.

into heat. Solar energy is recognized as one of the most promising alternative energy options. On sunny days, solar energy systems generally collect more energy than necessary for direct use. Therefore, the design and development of solar energy storage systems, is of vital importance and nowadays one of the greatest efforts in solar research. These systems, being part of a complete solar installation, provide an optimum tuning between heat demand and heat supply. Hence way that the domestic sector can lessen its impact on the environment is by the installation of solar flat plate collectors for heating water.

A Solar Water Heating System (SWHS) is a device that makes the available thermal energy of the incident solar radiation for use in various applications by heating the water. Hot water is essential both in industries and domestic applications. It is required for taking baths, washing clothes and utensils, and other domestic purposes in both the urban and rural areas. Hot water is also required in large quantities in hotels, hospitals, hostels, and industries such as textile, paper and food processing, dairy, and edible oil. The SWHS consists of solar thermal collectors, water tanks, interconnecting pipelines, and the water, which gets circulated in the system. Fig. 1 illustrates the typical thermosyphon solar water heating system [1]. Solar radiation incident on the collector heats up the tubes, thereby transferring the heat energy to water flowing through it. In brief, solar energy incident on the flat-plate collector is absorbed by the black-chrome coated copper plate and thereby heats the water in the riser tubes which circulates due to density difference, i.e. the thermosyphon effect. Solar Water Heating systems are grouped into two broad categories as passive and active solar water heating systems. The passive solar water heating systems generally transfer heat by natural circulation as a result of buoyancy due to temperature difference between two regimes; hence they do not require pumps to operate. They are the most commonly used solar water heating systems for domestic application. Active solar water heating systems have electric pumps, valves, and controllers to circulate water or other heat-transfer fluids through the collectors.

The active solar water heating systems generally have higher efficiencies, their values being 35–80% higher than that of the passive systems [1]. It is more complex and expensive. Accordingly, it is most suited for industrial applications where the load demand is quite high. On the other hand, the passive systems are less expensive and easier to construct and install which is more suitable for domestic applications where demand is low or medium.

The thermal performance of SWHS is influenced by inlet water temperature, solar irradiance, ambient temperature, flow rate, inclination of the flat-plate collector, height of the hot water tank, wind speed, relative humidity etc. The storage tank too plays an important role in accumulating the energy obtained from solar collector. The performance of the SWHS largely depends on the collector's efficiency for capturing the incident solar radiation and transferring it to the water. Generally the parameters that influence the thermosyphon effect are thermo-physical properties of liquid and the temperature of the surface in contact with liquid. With today's SWHS, water can be heated up to temperatures of 60 °C to 80 °C. Heated water is collected in a tank which is insulated to prevent heat loss. Circulation of water from the tank through the collectors and back to the tank continues automatically due to the thermosyphon principle.

Many of the industries use hot water in the range of 70–90 °C. These include dairy, food processing, textiles, hotels, edible oil, chemical, marine chemicals, bulk drug, breweries, and distilleries. These requirements are presently met primarily by combustion of fossil fuels like coal, lignite, and fuel oil. Solar energy, being abundant and widespread in its availability, makes it one of the most attractive sources of energies. Tapping this energy will not only help in bridging the gap between demand and supply of electricity but shall also save money in the long run. According to the Ministry of New and Renewable Energy (MNRE), Government of India, a 100 l capacity SWHS can replace an electric geyser for residential use and may save approximately 1500 units of electricity, annually, under Indian conditions [2]. Thus, a typical family can save 70–80% on electricity or fuel bills by replacing its conventional water heater with a solar water heating system. It has also been estimated that a 100 l per day (lpd) system (2 m^2 of collector area) installed in an industry can save close to 140 l of diesel in a year. So also, usage of solar water heater to supply preheated boiler feed water can help saving 70–80% of fuel bills.

Reduction of pollution and preservation of environmental health are some of the co-benefits of this technology. This is probably why the use of solar energy for water heating has become one of the largest applications of solar thermal systems today. Based on the above mentioned equivalence (100 lpd system saves 1500 units (kW h) of electricity), it is estimated that in generating the same amount of electricity from a coal-based power plant, 1.5 t of CO_2 is released into atmosphere annually. One million SWHSs installed in homes will, therefore, result in reduction of 1.5 million tonnes of CO_2 emission into the atmosphere. Clearly, SWHS is one of the most cost effective, viable, and sustainable options available for hot water generation today. The maximum Solar intensity/Heat flux for Indian climate is taken as (Salem, Tamilnadu, India) is 702.85 W/m^2.

2. Heat transfer enhancement techniques in solar water heating systems

Topic on the research of solar energy has become a matter of great concern due to energy crisis all over the world. The direct applications of solar energy (i.e. thermal application of solar energy) are simpler and more feasible application compared to indirect applications (i.e. photoelectric application) to generate electricity by using solar radiation. Flat plate collector is the central component of any solar water heating system. The efficiency of a solar water heating system is based on the performance of flat plate collector. Flat-plate solar collectors are the devices which absorb the solar radiation, transform it into heat, and to heat passing media (usually air, water, or oil). Flat-plate solar collectors are simpler than concentrating collectors to be used in domestic and industrial needs, which are constructed with the blackened absorber to transfer the absorbed energy to the flowing medium, transparent cover to reduce convection and radiation losses to atmosphere, and back and side insulation to reduce conduction losses. Hence, the most of the research works have been focused on the performance improvement of flat plate collector. The characteristics of thermosyphon systems are based on the absorber plate and its design, selective coatings, thermal insulation, tilt angle of the collector, and working fluids, etc.. Several designs of solar collectors have been analyzed by the researchers to enhance the thermal behaviour of thermosyphon systems.