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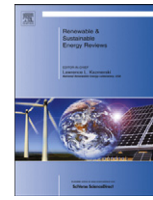

An experimental platform for heat pipe solar collector testing

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ABSTRACT

An experimental platform for testing solar collectors has been designed and built at Southeast University, China. In this article, the structure and the detailed operation of this platform are presented. The performance of an evacuated heat pipe solar collector, in which a heat-pipe is used to transfer the heat from the collector to the water, is investigated experimentally by using the developed platform. The investigation is focused on the instantaneous efficiency and its correlations with the receiver and absorber areas, the effective heat capacity, the incidence angle modifier and the pressure drop. In addition, the theoretical analysis of the solar collector is carried out for these parameters. The thermal behavior and performance of this solar collector is acquired through the experimental results by using this developed platform. This platform is also suitable for experimental investigation of other types of solar collectors.

Contents

1. Introduction

There have been significant scientific and technological developments in the solar collectors. A solar collector is a special kind of heat exchanger that transforms solar radiation energy into heat [1]. Solar thermal utilization for water heating has been developed very rapidly in China [2]. Solar water heating systems have huge demand not only in the Chinese market but also in the international market. There are many solar water heating enterprises in China, which operate under socialized manufacturing structure as it reduces investment risks and also rationalizes resources [2]. At present, solar collectors have been classified as flat plate, glass vacuum tube collector and heat pipe collector. Rojas et al. [3] has tested the thermal performance of the solar flat plate collector according to the ASHRAE 93 and EN 12975-2 standards and compared the different test results under steady

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state and transient conditions. The ASHRAE 93 uses prescribed environmental conditions for a range of collector fluid temperatures for finding the performance of collector under steady state conditions. The EN 12975-2 uses large range of environmental conditions for analyzing the performance of collectors under transient conditions. Villar et al. [4] has presented a transient 3-D mathematical model for flat plate collectors based on mass and energy balances. It can be configured for different configurations of tubes as well as transparent/semi transparent plates. Khoukhi et al. [5] have analyzed the flat plate collector for the effects of convection heat transfer to the thermal loss and performance of the collector considering the absorption-emissivity factor. Budihardjo et al. [6] has developed a mathematical model for the glass vacuum tube collector using water as the heat transfer medium, and included the optics and heat losses property of tubes, and compared the performance of the vacuum tube collector with the flat plate collector. The limitation of this is that it can be used for a low pressure systems and lower circulation rate of the fluid in the vacuum tube collector. Fernandez-Garcia et al. [7] has presented a review of the parabolic-trough solar collectors and their applications to supply the thermal energy upto 400 °C. Mathioulakis et al. [8] has developed a solar collector experimental system comprising of heat pipe and water-storage tank, and analyzed the system performance. The obtained results showed that comparatively high efficiency could be achieved. It can be used for heat-pipe hot water system optimization. Rittidech et al. [9] investigated the plate collector adopting a curved heat pipe and analyzed the influence of solar irradiance and ambient temperature on the collector performance. This analysis incorporates the natural forces of gravity and capillary action. It has additional benefits such as corrosion free operation. Chun et al. [10] have studied the heat pipe solar water heater using different heat transfer medium and analyzed (experimentally) the temperature distribution pattern of the heat pipe under low level solar irradiance. It was focused on finding the most suitable configuration of the system for possible commercialization in Korea. Hussein et al. [11] has investigated transient thermal behavior of heat pipe flat plate collector focusing on the influence of solar irradiance, the material and thickness of heat absorption plate, etc on the thermal performance of the collector. Riffat et al. [12] presented a theoretical model for analyzing heat transfer processes in a thin membrane heat-pipe solar collector, and also the model results were validated through experimental data. Muneer et al. [13] has analyzed the potential of solar thermal energy for Turkish textile industries considering life cycle assessment and relevant economics of solar water heater. Hussein [14] has investigated the effect of wickless heat pipe cross section geometry and its working fluid filling ratio on the performance of flat plate solar collectors experimentally. Different cross section geometries have been included in this study. Hu et al. [15] has investigated the optimal thermal and exergetic performance of solar thermal power system. Yulan et al. [16] analyzed the heat transfer of the compound parabolic concentrator CPC heat pipe vacuum solar collector, and calculated and compared the efficiencies of several collectors. Xue-song et al. [17] has computed the thermal loss coefficient and efficiency of the CPC heat pipe collector. Yunfeng et al. [18] combined a composite parabolic concentrator with a heat pipe plate collector, adopted an iodine-tungsten lamp to simulate the solar irradiance and performed experimental investigation and comparison with the CPC heat pipe plate solar collector and ordinary plate solar collector by focusing on the collector efficiency. Jianhong et al. [19] studied a flat plate solar collector in a solar air conditioning system and their experimental results showed that adding a transparent polycarbonate sheet in the gap between the glazing and the absorber of the collector would reduce the thermal losses and improve the performance of the collector. Jun-feng et al. [20] compared the all-glass vacuum tube solar water heating systems with the heat pipe solar water heating system for instantaneous efficiency under forced circulation conditions and concluded that the heat pipe tube has less heat losses and better performance. The most of the above mentioned researchers mainly focused on flat plat and vacuum tube solar collector.

Investigations aimed at the heat pipe solar collector are comparatively deficient, and mostly concentrated on the CPC heat pipe collector, more specifically on efficiency and thermal losses of the collector. Comprehensive theoretical and experimental researches with more emphasis on the heat pipe solar collector are not reported. In this work, the mathematical model has been presented for doing the performance analysis and also in finding the heat capacity of the heat pipe solar collector has been presented and also the specialized solar collector experimental set-up (test bench/platform) has been developed (Institute of Energy and Environment, Southeast University, Nanjing 210096, China) in China. The main parameters of the heat pipe collector such as temperature, flow rate have been controlled and measured by using two-stage heating through heat exchanger. This developed test bench has been used for performance analysis (through experiments) of the heat pipe solar collector. The effective heat capacity and also the incidence angle modifier of the collector are analyzed for experimental and theoretical results.

2. Experimental system (test bench)

The experimental platform/test bench for the solar collector performance evaluation is illustrated in Fig. 1. It consists of the tilted stand for solar collector, water system, temperature controlling system, flow rate controlling system and related measuring instruments, etc. In this system, the water is used as a heat transfer medium and water supplying circuit consists of the main water tank, pump, pipelines etc, and it is a closed-loop system. The water in the main tank is delivered through the pipeline by using the variable frequency pump, flows through the valve, the filter, the second-stage heater and the flow meter and into the test solar collector. Its temperature increases because of absorption of heat in the collector, and then flows back to the main water tank through the cooling water heat exchanger (as a close-loop system). The pipeline from the main water tank to the solar collector and from the exit of the collector to the temperature measuring point of the working medium is insulated for reducing the thermal losses and also to increase the accuracy of temperature controlling and measurement. There is an endoscope in the pipeline before the inlet of the collector in order to observe whether there are impurities or air bubbles in the working fluid. And there are exhaust valves at the outlet of the collector and in the main water tank so that the hot water can be discharged through the exhaust valves when the measurement procedure is in the high temperature state. In this experimental platform, the water temperature control system comprises the heater in the main water tank, the second-stage heater and the cooling water heat exchanger, and a two-stage heating method are used. The water in the main tank is heated to within the 1% range of the setting inlet temperature of the collector by a power heater at first, and then it is delivered through the pipeline, and is trimmed by the mini-watt second-stage heater, which is thyristor controlled. The second-stage heater has a PID regulation and control function, and it can compare the measured collector inlet temperature of the working fluid with the set temperature and then it sends the error (difference) signal to the control system. If the sampling temperature is lower than the original set temperature, the numerical PID controller switches on the thyristor to heat the working fluid, and if the sampling temperature is the same as the