



Experimental study on solar thermal conversion based on supercritical natural convection



Xin-Rong Zhang^{a,b,*}, Yalong Zhang^a, Lin Chen^a

^a Department of Energy and Resources Engineering, College of Engineering, Peking University, Beijing 100871, China

^b Beijing Key Laboratory for Solid Waste Utilization and Management, Peking University, Beijing 100871, China

ARTICLE INFO

Article history:

Received 14 September 2012

Accepted 19 August 2013

Available online 14 September 2013

Keywords:

Supercritical fluid

Natural convection

Solar thermal energy

Carbon dioxide

ABSTRACT

In this paper, experimental investigation into the basic characteristics of solar thermal conversion using supercritical CO₂ natural convection are presented. Natural circulation of supercritical fluids can be easily induced and even a small change in temperature can result in large change in density close to the critical point. The supercritical experimental system carefully designed and operated in this study. It is found that an obvious and continuous long-time drop of solar radiation would not affect the CO₂ flow rate, temperature and pressure very much, if the solar radiation is in a relatively high-value level. This continuous drop can induce obvious drops in the CO₂ flow rate, temperature and pressure only when the solar radiation is in a low-value level. Furthermore, it is observed that a long-time drop and low-value in the solar radiation may make the flow rate temporarily become zero, which should be paid more attention in future system design and operation. The collecting efficiency increases with the comprehensive coefficient and this pattern is contrary to that of water based system. In addition, it is found that there exist optimal flow rate and CO₂ charge amount for system overall performance. This kind of solar thermal conversion has a higher collecting efficiency in spring and winter than summer and autumn; a better performance in cold and low-radiation region than hot and high-radiation region.

© 2013 Elsevier Ltd. All rights reserved.

1. Introduction

Among various solar utilization methods, solar thermal conversion has become one of the most promising kinds. Solar thermal conversion systems can be categorized into low-temperature solar thermal kinds, which usually do not use sunlight concentration, and medium-temperature and high-temperature solar thermal systems. Among those methods, low-temperature solar thermal systems have the potential to supply a significant number of households and commercial buildings with heating and/or cooling. Solar water heater is one of the most promising applications of low-temperature solar thermal systems [1–7]. In recent years, a lot of studies have been carried out in the field of solar water heater and low temperature solar thermal convection [8–16], which are mainly for the solar water heaters of water-in-glass evacuated tube type [17,18].

In traditional solar water heaters, both forced convection and natural convection are used. In natural-convective solar heaters, water is usually used as working fluid. Many previous studies were carried out to explore the flow dynamics, heat transfer and performances for natural circulation kind of solar water heaters [5]. From those studies, the natural-convective solar water heater owns a deficient characteristic, because water is an incompressible fluid and its natural convection is relatively weak under the solar heating condition. As an effort of improving the efficiency from solar to thermal energy, supercritical fluid was proposed as working fluid in solar collectors [19]. Supercritical fluid is a substance at a temperature and pressure above its thermodynamic critical point. Fig. 1 shows the thermo-physical properties of supercritical CO₂. As shown in Fig. 1, the most important is that, close to the critical point, small changes in pressure or temperature can result in large changes in thermo-physical properties. The data shown in Fig. 1 is obtained from a Program Package for Thermo-physical Properties of Fluids (NIST Fluid Thermodynamic and Transport Properties database, version 8.0). Especially the density of supercritical fluid varies significantly as a function of temperature near the critical temperature. Such characteristics in thermo-physical properties allow a strong natural convection flow to be developed in the solar

* Corresponding author. Department of Energy and Resources Engineering, College of Engineering, Peking University, Beijing 100871, China. Tel.: +86 10 82529066; fax: +86 10 82529010.

E-mail addresses: zhxrduph@yahoo.com, chenlinpk06@163.com (X.-R. Zhang).

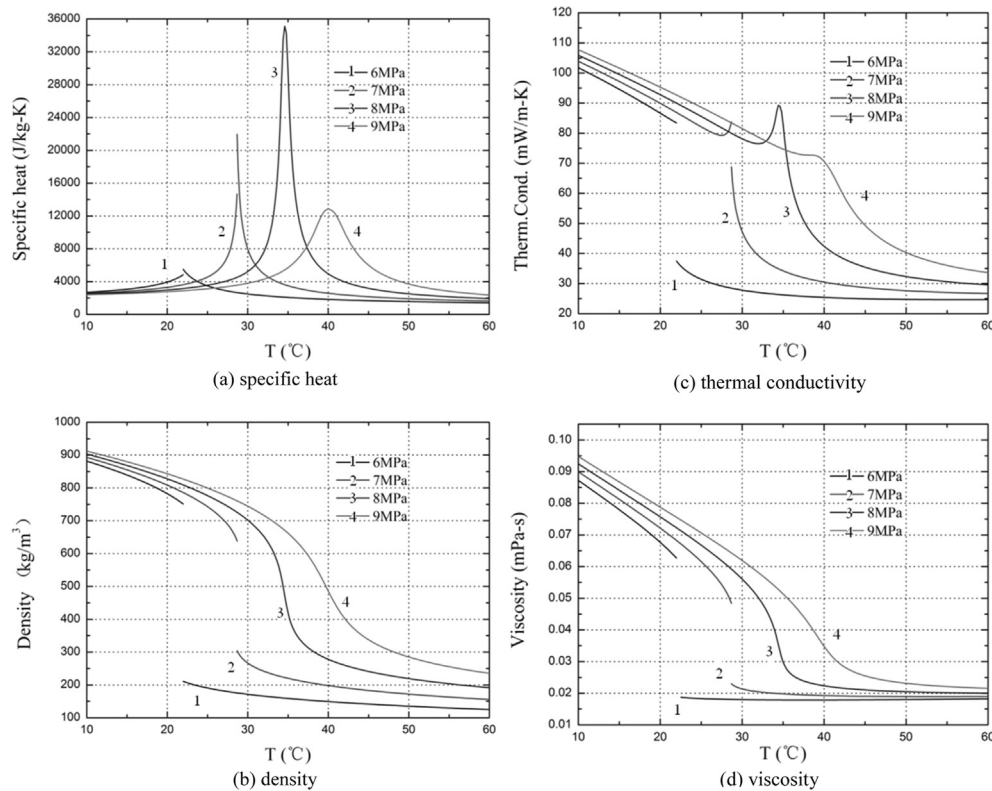


Fig. 1. Variation of thermoproperties with temperature and pressure in the critical region, (a) specific heat; (b) density; (c) thermal conductivity; (d) viscosity.

thermal conversion system [19]. Furthermore, for supercritical CO_2 , its critical temperature is 31.1 °C and that is low enough to be easily reached in the low temperature solar thermal conversion system.

Solar water heater is the most widely used conversion unit around the world. Based on previous basic supercritical fluid tests [19–22], the solar water heater using supercritical fluid can be comprised of two loops: one is a supercritical fluid circulation loop and the other is a water loop. The two loops are coupled with each other by a heat exchanger. In the closed loop with supercritical fluid, the natural convective flow develops as a result of the heating process by solar radiation and the cooling process by the heat exchanging process with water. The supercritical fluid flow in the collector can absorb and transport heat, and then it transport the collected thermal energy to water. Therefore conversion from solar to thermal energy can be achieved. Inside the heat exchanger, supercritical fluid is cooled by the cold water flow (in real application, general tap water can be used). Water absorbs heat from the supercritical fluid and can be pipelined for related domestic or other costumer sides.

A feasibility study was carried out in order to analyze whether the supercritical state can be achieved at the collector outlet and the Reynolds number was measured higher than 1900 in the previous experimental and numerical investigations [19–22]. Furthermore, some characteristics about this kind of solar water heater by supercritical CO_2 were investigated by several experimental tests [20]. The obtained results revealed the supercritical CO_2 flow rate is quite stable and will be less affected by the transient variations of the solar radiation. The solar thermal conversion process can be divided into three periods: starting-up, transition and stable period. High solar thermal conversion efficiency was found at a high mass flow rate and under operation pressure near to the critical point.

However, in the field of supercritical fluid based solar thermal conversion systems, some basic characteristics of such natural

circulation based solar thermal conversion system design and effective operation are still not clear, such as the influence of solar radiation, supercritical fluid temperature and ambient temperature etc. on solar thermal conversion process and efficiency. Also the parameter description and seasonal performances of supercritical systems are still under development. As an extension of the previous study, in this paper, an experimental set-up is tested and systematic investigations are made to further clarify the basic characteristics of this solar thermal collection by supercritical natural convection flow.

2. Experimental set-ups

Based on the concept described above, an experimental prototype of the solar thermal conversion system is tested. This experimental system is specifically designed for using supercritical CO_2 natural circulation flow. A schematic diagram of the experimental set-up is presented in Fig. 3. The built experimental machine is mainly comprised of solar thermal collector, heat exchanger, valve 1, valve 2, hot water tank, valve 3, and measurement and data acquisition system.

To make sure the solar water heater system is feasible, a solar collector with good heat collecting characteristics is required. Therefore, to effectively heat supercritical CO_2 to relatively high temperature state in the experimental set-up, all-glass evacuated solar collector with a U-tube heat removal system. The collector is consisted of a glass envelope over glass tube that is coated with a selective solar absorber coating. The coating has a high solar absorbance of 0.918 and a low emissivity of 0.189. It is applied on the vacuum side of the inner glass tube. The transparence of the glass envelope is 0.92. Such design of the collector allows a maximum operating pressure as high as 15.0 MPa. In the present experimental set-up, evacuated solar collector of 1.69 m² (gross area) is used which is manufactured basically based on the previous

Download English Version:

<https://daneshyari.com/en/article/6769318>

Download Persian Version:

<https://daneshyari.com/article/6769318>

[Daneshyari.com](https://daneshyari.com)