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Chinese ink: High performance nanofluids for solar energy

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ABSTRACT

Nanofluids have shown competitive performance on solar thermal collection. This work proposes the application of Chinese ink as nanofluid in solar photo-thermal conversion. The dispersion stability of the nanofluid was characterized by spectrophotometer. Compared with reported Cu, CuO nanofluids, that of Chinese ink has shown more satisfied stability of dispersion. The obtained results reveal that the nanofluid of Chinese ink has surprisingly higher efficiency of photo-thermal conversion than that of Cu and CuO nanoparticles. Carbon black is determined for Chinese ink nanofluid to convert solar photo to heat. Bone glue coated on the surface of Chinese ink nanoparticle also plays a significant role that it prevents the carbon black nanoparticles from aggregation and deposition. The preparation process of Chinese ink is pretty simple and the raw materials are cheap and widely available, which promises the large-scale industrial applications of Chinese ink for solar thermal collections.

1. Introduction

Energy shortage and ecological crisis is becoming increasingly serious, thus the development and utilization of new energy is imminent. Solar energy is clean and abundant [1,2]. The amount of solar radiation received by the earth is 5.4×10^{24} J per year, which equals to 1.8×10^{14} t standard coal. If 0.1% of the solar radiation on the earth is converted to electrical energy with a conversion rate of 5%, the annual generating capacity will be up to 5600 TWh, which is 40 times of the current world's energy consumption. Therefore, the collection of solar energy is not only important to relieve the crisis of energy shortage, but also significant for reducing emission from fossil energy consumption.

At present, there are two main types of solar energy utilization, solar thermal collection and solar photovoltaic technology. Solar photovoltaic technology [3] is relatively mature and widely used, but the production process of the solar photovoltaic cells is of high energy consumption and pollution [4]. In contrast, solar thermal collection is one of the most economic and effective ways for solar energy utilization [5], since it mainly obtains physical producing stages [6]. In solar thermal collection systems, solar thermal collectors are the core components, in which the solar radiation is absorbed and converted into heat [7]. The working fluids play an important role in solar thermal collection, whose photo-thermal conversion performance depends on the content, form and dispersion stability of the fluid. Efforts have been done on the employment of water, thermal oil, molten salt, liquid sodium, air, carbon dioxide and helium as working fluids [8]. However, the problem of low storage efficiency and high cost still needs to be solved for the practical and wide applications of solar thermal collection.

Recently, nanofluids have been found excellent in the absorption of light and thermal transportation [9–14], which makes them good candidates as working fluids for solar thermal collections [15–18]. Previous work revealed that nanofluids are able to be used to absorb solar radiation directly, enhancing the efficiency of thermal collection [19,20]. However, nanofluids usually suffer from aggregation and deposition poor after a period of application. Therefore, the general approach to deal with this problem is to disperse the nanoparticles ultrasonically and to add dispersant and stabilizer, etc. [21].

At present, due to their excellent thermal, mechanical and optical properties [22], carbon materials have also attracted special attentions for solar thermal collections, such as carbon nanotube [23–26] and grapheme [27–29]. However, such materials are of high cost and complex preparation process [30], which makes it difficult for their wide applications in practice. Carbon black nanoparticles may be an alternative for their low cost and wide availability. Povacz et al. [31] explored the effect of carbon black on the performance of black-pigmented polypropylene materials in solar thermal utilization, and found that the polypropylene compounds containing a small percentage of carbon black showed an integral solar absorbance of about 95% and an integral infrared emittance from 93% to 95%. However, the problem of aggregation still need to be solved for carbon black nanoparticles, because their small size gives rise to enhanced van der Waals attraction

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[32].

Chinese ink is also a kind of carbon material whose main component is carbon black [33]. As an important kind of painting material, Chinese ink first appeared in Shang Dynasty two thousand years ago, and have been playing a significant role in the Chinese painting and calligraphy. In order to make writing smooth, ancient Chinese gradually solved the problem of carbon black being lack of dispersion stability in the Chinese ink in the long history. Yan et al. [34] found that Chinese ink could be used as a solvent and a dispersant to prepare composites composed of multi-walled carbon nanotubes and polyvinyl alcohol. Thus Chinese ink itself is stable and may be an ideal material for solar energy collection.

Therefore, Chinese ink was proposed for solar thermal collection, and the aim of this work is to check the possibility of its nanofluid for solar photo-thermal conversion. For this purpose, the dispersion stability of several reported nanofluids was investigated for comparison through the method of spectrophotometric assay. In addition, experiments have been carried out to examine the performances of solar photo-thermal conversion for Chinese ink.

2. Experimental

2.1. Materials and preparation of nanofluids

Chinese traditional ink is made from soot, bone glue, and a small amount of spices and preservatives. The soot comes from the incomplete combustion of plant, plant oil and mineral, and its main content is carbon black. In the traditional manufacturing process, the bone glue and spice are mixed into the soot, and then was pressed into ink sticks by a die. According to the selected smoking material, Chinese ink can be classified as pine-soot ink, tung-oil ink, smoke paint ink, oil smoke ink, etc. In this work, pine-soot ink was used and purchased from supermarket. The pine-soot ink is generally produced from pine burning ash. As shown in Fig. 1, this kind of ink is of high blackness, and can be easily dispersed in water. The electrical grinder (Sendeli, JD108) was used to grind the pine-soot ink stick into powder, and then the powder was dissolved into water according to a certain mass fraction. The nanofluid of Chinese ink was made without ultrasonic dispersion.

Cu and CuO nanofluids have been found excellent in solar photo-thermal conversion in previous work [13,17]. For comparison, Cu and CuO nanoparticles were purchased from the Hongwu nanometer Marketing Center of Guangzhou Jiechuang Trade Co. Ltd. The purity of these nanoparticles was 99.99%, and the particle sizes of Cu and CuO were 100 nm and 30–50 nm in average, respectively. Nanoparticles of carbon black with an average particle size of 50 nm were purchased from Tianjin Lihuajin Chemical Co. Ltd. The transmission electron microscopy (HRTEM,a JEM-3010, JEOL) was used to characterize the morphology of the nanoparticles.

The bone glue was purchased from Shijiazhuang xu'ermei biological products factory. The purity of these bone glue was 99%, and its main content was bovine bone collagen peptide. According to the traditional Chinese ink production process [35,36], the mass ratio of bone glue and other particles was 1:1 in the comparative experiments.

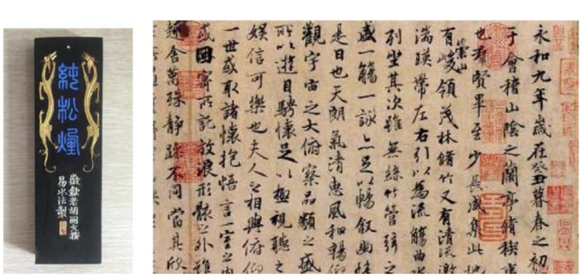

Fig. 1. Pine-soot ink stick and Chinese calligraphy.

2.2. Dispersion stability

Dispersion stability of nanofluid is the key for its application in solar thermal collection [37]. In this work, the dispersion stability of nanofluids was characterized by sedimentation experiment and spectrophotometric assay.

Chinese ink nanopowder with a weight of 0.025 g was dissolved in 50 ml water by stirring, obtaining a nanofluid with a concentration of 0.05 wt%. The same amount of Cu, CuO and carbon black nanopowders was respectively dissolved in 50 ml water, and was ultrasonic dispersed for 10 min by an ultrasonic homogenizer (SCIENTZ, Scientz-IID). The concentration of the Cu, CuO and carbon black nanofluids was also 0.05 wt%.

The dispersion stability of the nanofluids was measured by spectrophotometer (PERSEE, T6). Before measuring, the prepared nanofluids were placed standing and unmoved for centering period of time, and the upper liquid was taken for measurement.

2.3. Photo-thermal conversion

The photo-thermal conversion performance of nanofluids is determined for solar thermal collection. The platform for the solar photo-thermal conversion experiment was set up as shown in Fig. 2. The collecting tube was made of organic glass. Because the weather is difficult to be artificially controlled, we alternatively carried out the experiments of photo-thermal conversion under solar simulators instead of in the sunlight outside. Full-spectrum solar simulators (OSRAM UV300W) were used to simulate the irradiation of sunlight. Four full-spectrum solar simulators were uniformly arranged. At both ends of the tube, two thermocouples (HUAHANW TH10R-EX) were used to monitor the temperature of the nanofluid online.

Chinese ink, Cu, CuO and carbon black nanofluids with a mass fraction of 0.05 wt% were added to the collector respectively, among which Cu and CuO nanofluids were ultrasonically dispersed for 30 min. Then the tube was put under the solar simulator for two hours. The temperature of the nanofluid was taken every minute. During the irradiation process, seven evenly distributed points were selected on the surface of the tube to measure the intensity of light. The measured results revealed that the light was distributed evenly on the surface of the tube, and the light intensity was 13,000 lx in average. After experiment for 120 min, the temperature of the fluid at different time was obtained.

In order to verify the effectiveness of the solar simulators, comparative experiments was also carried out in sunlight outside. Chinese ink, Cu, CuO and carbon black nanofluids with a mass fraction of 0.05 wt% were added to the collector respectively. To note that the Cu and CuO nanofluids were not ultrasonic dispersed. Experiments were conducted on a sunny day with an environmental temperature of 25 °C, and the average light intensity was 80,000 lx. The solar simulators were turned off, and the device was placed in the sunlight for two hours. The temperature evolution at the two ends of tubes with different working fluids was monitored.

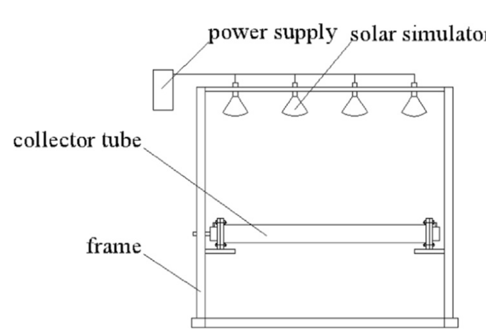

Fig. 2. Solar thermal collection experiment platform.