Analysis on Viscosity and Stability of Chinese Ink Nanofluids

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Abstract. Chinese ink nanofluids were prepared successfully by “two-step” method. The optical properties of Chinese ink nanofluids were investigated. And the effects of the base fluid types and ultrasonic time on their dispersion stability also were investigated. Results show that Chinese ink have high absorption characteristics and very low transmittance on light radiation in the wavelength range of 190-1100 nm; The dispersion stability of nanofluids increases first and then decreases with the increase of ultrasonic dispersion time. There is an optimal ultrasonic dispersion time of 90 min; the base fluid has a certain influence on the dispersion stability of Chinese ink nanofluid, among which DMF base solution has the best dispersion stability, followed by thermal conductive oil. Ethanol has no obvious improvement compared with water, both of which have lower dispersion stability than DMF and thermal conductive oil. This research provides a fundamental guidance for the preparation of Chinese ink nanofluids and their further application in Solar photo-thermal conversion.

1. Introduction
In recent decades, energy resources face serious challenges with the increase of population and environmental degradation. The use of clean and renewable energy to solve the energy consumption problem has great potential for the development [1]. There are two strategies to utilize solar energy: photo-electric conversion and photo-thermal conversion [2]. Photo-thermal conversion is considered one of the most simple and direct ways to use solar energy, which the key problem is how to improve the photo-thermal conversion efficiency [3]. And it is the precondition of realizing high efficiency of photothermal conversion to realize wide frequency and efficient optical absorption [4].

Nanofluids are prepared by dispersing nanoparticles (metal, metal oxides, nonmetallic inorganic compounds, organic compounds with particle size less than 100nm) into the base solution in a certain proportion and method to form a uniform and stable suspension [5, 6]. Nanofluids have much higher thermal conductivity than pure fluids and nanomaterials generally have the phenomena of blue shift, red shift and wide absorption band, which have excellent optical absorption properties. These excellent thermal transport and spectral absorption properties has been employed nanofluids to be used to improve the solar photo-thermal conversion [7, 8].

However, the particle size of nanofluids is distributed in nanometer level, which has high surface energy. Small nano size and large specific surface area make particles agglomerate easily, which leads to the decrease of dispersion stability of Nanofluids and the loss of superior properties of nanomaterials [9]. Therefore, in order to obtain practical applications, nanofluids must be evenly and stably distributed in the base solution, forming a suspension with good uniformity, high stability and low agglomeration [10]. At present, there are three methods to solve the problem of dispersion stability of nanofluids: 1. Adjust PH value of nanofluid suspension. 2. Use surfactant or dispersant. 3.
Use ultrasonic vibration [11, 12].

Chinese ink, as a carbon based coating, was widely used in traditional calligraphy and painting. Yang’s group [13] found that Chinese ink nanofluids have better dispersion stability and higher photothermal conversion performance compared with copper, copper oxide and carbon black nanofluids, making them have great application prospects in the field of photothermal conversion. Then Yang’s group [14] found that the addition of Chinese ink nanoparticles in seawater significantly increased the evaporation rate of seawater, and the evaporation rate increased first and then decreased with the increase of mass fraction.

At present, we still need more in depth research on the optics and stability of Chinese ink nanofluids. Further research will provide a fundamental guidance for the preparation of Chinese ink nanofluids and their further application in Solar photo-thermal conversion. In this work, Chinese ink nanofluids were prepared successfully by “two-step” method. The optical properties of Chinese ink nanofluids were investigated. And the effects of the base fluid types and ultrasonic time on their dispersion stability also were investigated. The best ultrasonic time and dispersion solution were given under the experimental conditions.

2. Experiment

2.1. Preparation of Chinese ink Nanofluids
A two-step method was employed to produce Chinese ink nanofluids. The fume ink ingot (Hukaiwen Ink Company, Anhui, China) was processed into fine particles and collected into a mortar Using a speed-regulated electric grinder (Sendeli, JD108). And then Chinese ink nanoparticles were prepared after fully grind for 30 minutes. Chinese ink powder was dissolved into a beaker containing 100ml of deionized water. Then suspension was dispersed for 30 minutes by using an ultrasonic disperser (SCIENTZ, Scicentz-IIID). Finally, the Chinese ink nanofluids were successfully prepared.

2.2. Characterization Methods
The element composition of Chinese ink was determined by Energy Dispersive Spectrometer (EDS). Particle size and shape was characterized by a Transmission Electron Microscopy (TRTEM, JEM-3010, JEOL). Surface microtopography particle size was characterized by scanning electron microscopy (SEM, HITACHI S-4700). The absorption and transmission spectra of Chinese ink nanoparticles were measured by spectrophotometer (G9, uv1900, China).

The dispersive stability of Chinese ink nanofluid was measured by the spectrophotometer method. The nanofluid was subjected to 30 hours of static experiment. During the experiment, the supernatant of Chinese ink nanofluid was absorbed by rubber head dropper every 6 hours and its absorbance was measured by spectrophotometer. The closer the absorbance of the sample is to the original value, the better the dispersion stability of the nanofluid.

3. Results and Discussion

3.1. Composition Characterization of Chinese Ink
As shown in figure 1, the main component of Chinese ink material is carbon, which accounts exceed 70%. Therefore, Chinese ink should be classified as a kind of carbon material, which has some special properties of carbon material. In addition, there are nitrogen, oxygen, sodium, chlorine, copper, etc. It can be seen from the composition elements that the main component of Chinese ink is carbon black, which also ensures that it can be Used in the field of solar photothermal conversion as photothermal materials.

3.2. Characterization of Chinese Ink Nanoparticles
As shown in figures 2a and 2b, The Chinese ink powder is composed of irregular spherical and flaky particles by physical grinding method. Rough structure and large specific surface area contribute to
eliminate the transmission and reflection of sunlight, which improve the light capture capacity. The diameters of carbon particles range from about 50 to 100 nm after full grinding which meet the requirements of nanomaterials. The size of carbon particles can be tailored by different-time grinding treatment.

![Figure 1](image1.png)

**Figure 1.** The EDS energy spectrum of Chinese ink.

![Figure 2](image2.png)

**Figure 2.** (a) SEM image of Chinese ink nanoparticles; (b) TEM image of Chinese ink nanoparticles.

### 3.3. Optical Properties of Chinese Ink Nanofluids

As shown in figures 3a and 3b, in the ultraviolet wavelength range of 190-220 nm, there is an absorption peak of about 200 nm, which increases sharply and then decreases sharply. And the decreasing gradually trend is shown in the wavelength range of 300-1100 nm. The absorption characteristics of visible light range are slightly higher than that of near infrared band, but the overall difference is not significant. As shown in figure 4a, in the ultraviolet wavelength range of 190-220 nm, the transmittance is less than 7%, which has strong absorption to the radiation of this band; In the wavelength range of 300-1100 nm, there is no obvious fluctuation in absorbance and transmissivity. It can be seen that Chinese ink nanofluids have high absorbance and low transmittance. The optical performance of visible band is better than that of near-infrared band. It shows that Chinese ink is an excellent light absorbing material for efficient absorption of sunlight.

### 3.4. Dispersion Stability of Chinese Ink Nanofluids

#### 3.4.1. Influence of Ultrasonic Time on Chinese Ink Nanofluids

Chinese ink powder was dissolved into deionized water, then the five Chinese ink nanofluids according to the ultrasonic time of 0min, 30min, 60 min, 90 min, 120 min were prepared, respectively.
3.4. Influence of Base Fluid on Chinese Ink Nanofluids. The Chinese ink particles were dispersed into water, DMF, ethanol and conductive oil (volume ratio of 1:4), respectively. Then the suspensions were ultrasonic dispersed. Finally, Chinese ink nanofluids dispersed in different base fluid were
prepared, respectively.

As shown in figure 4b, The DMF base fluid has the best dispersion stability and there is no agglomeration in the 30 hours static experiment, followed by thermal conductive oil which greater improve dispersion stability. Ethanol has no obvious improvement compared with water, both of which have lower dispersion stability than DMF and thermal conductive oil. Among them, water based nanofluids show the worst dispersion stability.

Analysis of the above phenomena shows the dispersion stability of nanofluids will be affected by the dispersion base fluid. Due to the strong polarity of DMF base fluid, Chinese ink nanoparticles exhibited the best dispersion stability in DMF base fluid. The thermal conductive oil has a large density and viscosity. The tendency of sinking due to its own gravity and the probability of particle collision will be reduced. Therefore, the dispersion stability of Chinese ink nanoparticles in the thermal conductive oil base fluid will also be greatly improved.

4. Conclusion
In this work, Chinese ink nanofluids were prepared successfully by “two-step” method. First, Microstructure of Chinese ink nanoparticles were characterized. Subsequently, spectrum characteristics of Chinese ink nanofluid were investigated and a good light capture capacity was revealed. Finally, the effects of the base fluid and ultrasonic time on their dispersion stability also were investigated. The main findings are summarized as follows.

(1) Carbon is the main component of Chinese ink material, which mass proportion has reached over 70%. Therefore, Chinese ink should be classified as a kind of carbon materials, which has some special properties of carbon material.

(2) High absorption and low transmissivity characteristics was achieved by Chinese ink nanofluid for light radiation in the wavelength range of 190-1100nm. This kind of broad-band spectral absorption ability lays the foundation for its use as photothermal conversion material.

(3) Time of ultrasonic dispersion can effectively improve the dispersion stability of Chinese ink nanofluids. The dispersion stability of nanofluids increases first and then decreases with the increase of ultrasonic dispersion time. 90min is the best dispersion time;

(4) The base fluid has a certain influence on the dispersion stability of Chinese ink nanofluids, among which DMF base solution has the best dispersion stability, followed by thermal conductive oil. Ethanol has no obvious improvement compared with water, both of which have lower dispersion stability than DMF and thermal conductive oil.

Reference
[1] Huang J, He Y R, Chen M J, et al. 2019 Separating photo-thermal conversion and steam generation process for evaporation enhancement using a solar absorber Applied Energy 236 244-252.
[2] Qin C Y, Kim J B, Gonome H, et al. 2020 Absorption characteristics of nanoparticles with sharp edges for a direct-absorption solar collector Renewable Energy 145 21-28.
[3] Liu C Q, Wang D B, He Y, et al. 2019 Solar energy absorption and photothermal conversion performance at medium temperature based on magnetic nanofluids Science Bulletin 64 (z2) 3041-3048.
[4] Wei T Q, Li X Q, Li J L, et al. 2018 Research progress of interfacial light vapor transformation Science Bulletin 63 (14) 1405-1416+1404.
[5] Choi S U S 1995 Enhancing thermal conductivity of fluids with nano-particles ASME Fed 231 (1) 99-105.
[6] Ding T T, Li Z C, Zhou Y, et al. 2018 Research progress of nanofluids New Chemical Materials 46 (08) 9-14.
[7] Otanicar T P, Phelan P E, Prasher R S, et al. 2015 Nanofluid-based direct absorption solar collector Journal of Renewable & Sustainable Energy 2 (3) 033102.
[8] Mao L B 2008 Study on the Preparation and Properties of Solar Energy Absorption and Heat Transport Nano Black Liquor (Guangdong University of Technology).

[9] Mohammad H E, Ali A, Mohammad R, et al. 2015 Experimental determination of thermal conductivity and dynamic viscosity of Ag-MgO/water hybrid nanofluid Pergamon 66.

[10] Li X, Yang M C and Zhu Y Z 2018 Experimental study on the preparation and thermal stability of oil-based CuO nanofluids Silicate Bulletin 37 (07) 2285-2290.

[11] Zhong G J, Zhai Y L, Bao G R, et al. 2020 Analysis of factors affecting the stability and viscosity of nanofluids Journal of Materials Science and Engineering 38 (01) 74-80+87.

[12] Xuan Y M and Li Q 2000 Study on enhanced heat transfer of nanofluids Journal of Engineering Thermophysics 21 (4) 466-470.

[13] Wang H, Yang W M, Cheng L S, et al. 2018 Chinese ink: High performance nanofluids for solar energy Solar Energy Materials and Solar Cells 176 374-380.

[14] Ding Q, Guan C F, Zuo X H, et al. 2019 The application of Chinese ink nanoparticles in solar sea water distillation Modern Chemical Industry 39 (08) 89-92.