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Photothermal conversion characteristics of gold nanoparticles under different filter conditions

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ABSTRACT

In this article, plasmonic nanopaerticles (PNP) were used to improve the solar thermal conversion efficiency and the abortion prosperity under eight different wavelength spectrum was compared. Gold nanoparticles (GNP) is synthesized through an improved citrate-reduction method, which was used to illustrate the photo-thermal conversion of PNPs under a solar simulator with eight filters. Experimental results showed that the best light intensities at wavelength of 710 nm could reach 0.004 W/cm^2 when applied to two suns. With the increase of the irradiation time, the GNP temperature increased linearly and the temperature could be increased by 3.5 K within 300 s. In addition, there were no infrared, no visible light, and no UV filters utilized to compare GNP photothermal conversion efficiencies in three main spectrum regions. As eight filters were applied in the current experiment, more specified wavelength spectrum and longer time need to be tested for the purpose of optimisation.

1. Introduction

Nowadays it can be recognized that nanomaterials could produce completely different characteristics from the traditional material in terms of surface effect, small size effect, quantum size effect and other physical and chemical properties. Nanomaterials has been widely applied in the fields of energy, chemicals, automotive, construction, microelectronics and information. Nanotechnology has become a hot topic in the nanomedicine, nanochemistry, nanoelectronics, nanomaterials, nanobiology and other public areas.

Nanofluids (NNFs), as part of the nanomaterials, which attracts wide range applications in practical. Combining photovoltaic with solar thermal utilization such as solar heat and power plant, it can improve the utilization of the solar radiation, reducing the operating temperature of the battery pack. Thus, the power generation efficiency can be improved tremendously. In the solar power plants, due to the heat transfer medium working at a temperature range of 300–700 °C, nanofluids properties of the metal will be impacted accordingly. What's more, the nanoparticles will be precipitated and accumulated. Accordingly, further research is needed for solar power applications.

Kim et al. [1] applied thermal energy balance to analyze the thermal performance of a U-tube solar collector using 20% PG (propylene glycol) as the working fluid. In their study, solar collector efficiency was calculated and energy savings was predicted for various nanofluids, such as MWCNT, CuO, Al_2O_3, SiO_2 and TiO_2. It was found that the solar collector efficiency increased in the following order from greatest to least: MWCNT, CuO, Al_2O_3, TiO_2, and SiO_2 nanofluids. Kim et al. [2] experimentally investigated the efficiency of a U-tube solar collector as a function of the concentration of Al_2O_3 nanofluid and the size of the nanaparticles. It was concluded that the Al_2O_3 nanofluid was effective in increasing the efficiency of the U-tube solar collector. In the research work of Al-Nimr and Al-Dafaie [3], a mathematical model was developed to test the transient temperature distribution of the silver nanofluid pond at different volume fractions, heat transfer coefficients and exposure time conditions. Comparing with conventional solar pond and conquered the traditional brine ponds troubles, presented nanopaticles had obvious advantages in solar storage. Chen et al.

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Nomenclature

A	area (m^2)
c	specific heat (J/kg·K)
d	particle diameter (m)
I	solar intensity (W/m^2)
L	distance of light travelled (m)
m	mass (kg)
p	Radiation transmitted through a sample (W/m^2)
P_0	Incident ratiation (W/m^2)
SAR	specific absorption (W/g)
T	Temperature (K)
t	time (s)
Greek	
ε	extinction coefficient
ø	volume fraction(%)
η	photothermal conversion efficiency
Δ	difference
Subscript	
n	nanoparticle
w	water
UV	Ultraviolet Rays
VIS	visible
IR	Infrared Spectroscopy

[4], Kosuga et al. [5], Lenert and Wang [6] and De Boni et al. [7] set up test rigs to investigate the absorption of the gold or silver nanoparticles at different specialized wavelength range of 500–1000 nm. All their experimental results showed that the temperature increased remarkably and the efficiency was analyzed as a direct absorption solar collector.

The working medium in the solar energy systems play an important role in solar absorption. Colangelo et al. [8] investigated the Al_2O_3-therminol nanofluids property, such as stability, viscosity, FI-IR spectra, cluster size and thermal conductivity. It would be very helpful to evaluate the non-Newton fluid characteristic in the solar absorption system. Over the past decades, many researchers devoted to study the nanofluids photothermal absorption characteristics. It is recognized that the rate of the absorption was influenced by nanopaticles length, diameter, volume fraction and particle size distributions [9–12]. Mercatelli et al. [13], Chen et al. [14] and Karami et al. [15] investigated TiO_2, Al, Au, SiO_2, silver, copper-oxide and carbon nanotubes at corresponding optimal heat absorption wavelength of light itself with particle sizes, concentrations, lengths, and diameter. It was found that there is a great difference in the optimum wavelength, that is, with the growth of the nanorod diameter and length, the optimal wavelength increases. Lucas et al. [16] conducted an experimental study to investigate the grand optical absorption at wavelength of 808 nm. It was observed that when the light intensity was increased, the surface of the nanopartical temperature was linear. It was stated that the combined micro-electromechanical systems (MEMS) with the infrared absorbent gold nanoparticals have significant potential application in light-actuated switches and mechanical construction. Kim et al. [17] concluded that taking advantage of nanofluid photothermal prosperity in catalyst would also have a positive effect. Nair [18] performed an experiment to study the 20–30 nm Ag/TiV oxide grain samples in UV-DRS spectra. Their result showed that in the visible light photocatalytic activity of Ag/TiV oxide better three and seven times than TiV oxide and Degussa P25 respectively. Due to different working materials, the line of the absorption TiV/Ag oxide and Degussa P25 decreased abruptly at around 390 nm in UV-DRS spectrum.

In recent years, the application of nanofluid in medical engineering has obtained great achievements. El-Sayed et al. [19] and Ou et al. [20] found that the malignant cells require no more than half of the power energy leading to benign cells nobinary. With anti-EGFR/Au conjugates bonded easily and it has a high efficient absorption near the visible spectrum band. Taking advantage of precious metal heat transfer characteristics, experimental medium is gold nanoparticles in genaral. For example, in the application of killing cancer cells, Ye et al. [21] used nanotubes as the core of the body to stimulate the outsourcing of the organic matter, in particular of the laser wavelength action. The cancer cells would be heated up to 42 °C, then it will be dying. Experimental results showed that the survival rate of the cancer cells significantly decreased. When do experiments on mouse body, equipments can detect concentrations of the different parts of the gold nanotubes in the organs. The 700–900 nm nanoparticles carry drugs as targeted heat by the laser to kill the cancer cells. Liu et al. [22], Bhana et al. [23], Zhou et al. [24] and Paci et al. [25] performed fundamental research on the goldnanoparticles that used in drug manufacturing. In the near-infrared wavelength, gold nanoparticles showed good light absorption properties.

Ebrahimian and Ansarifar [26] studied the nanofluid performance in VVER-1000 nuclear reactor core. Due to the excellent heat transfer coefficient of the nanofluid, it would be an ideal method for cooling annular fuel. With smaller nanoparticle size and bigger volume fraction, the temperature of the fuel center decrease. In addition, it was found that 0.03 vol fraction and 10 nm size of Al_2O_3 achieved the best presentation in regular circulation. Garoosi et al. [27] conducted a numerical study to examine two dimensional containing circular cylinder correlation parameters: Rayleigh number, volume fraction, particle size, type of nanomaterial, shape of the enclosure and the orientation of the hot and cold cylinders etc. However, after Lee and Kang [28] used aqueous solution nanofluids to enhance the CO2 absorption of the base fluid, it is concluded that the effect of the nanoparticles on the mass transfer enhancement is more significant in the region of unsaturated state than that of the saturated state.

Mercatelli's results revealed that 270 nm wavelength absorption up to maximum while at the lowest penetration rate and with the volume increase penetration rate show a downward trend [13]. Although in a low concentration of GNPs based on the fluid i.e. 0.15 ppm, the solution has great performance in photothermal absorption efficiency. In the near-infrared wavelength absorption rate to can be creep to 12 °C within 300 s. Gold nanofluid characteristic with a different circumstance showed different performance in photothermal absorption and radiation [29,30]. Kosuga took advantage of photothermal films in assembling particular energy of the solar spectrumm, temperature rise up to 40 °C only in 100 s [5].

It is aforementioned from the above research works, gold nanofluid has huge perspective in the near future that can be used in heat convention and solar absorption domain. However, previous studies have shown that the extinction coefficient do not represent the real photo-thermal energy conversion process, especially for the photothermal conversion experiment in the whole spectrum. Therefore, it has still much room to investigate the photothermal conversion performance of the GNPs in a single wavelength. The objective of the current work is to use five slices filters to study the photothermal conversion performance of GNPs by measuring temperature changes of the fluid in a single wavelength. In the current study, five different filters will be used to