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Optical properties of various nanofluids used in solar collector: A review

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ABSTRACT

Different properties of nanofluids have been studied by the researchers since the last two decades. Most of the studies have focused on the thermal properties of the nanofluids. However, optical properties have considerable contribution to heat absorbance in nanofluids. Therefore, it is necessary to study the different parts of solar spectrum (optical properties) to utilize nanofluids in solar thermal applications. The optical properties (absorption, transmittance, scattering, and extinction coefficient) based on metal, metal oxide, carbon nanotubes, graphite, and graphene have been reviewed thoroughly in variation with particle size and shape, path length, and volume fraction. The present investigational outcomes about the nanofluids showed that optical solar absorption increased accordingly with increasing nanoparticle size and volume concentration. However, there were some conflicting results on the effects of nanoparticle size on absorption, in which the particle size has an insignificant effect on overall optical properties. Moreover, it was observed that path length has some remarkable effects over optical absorption of nanofluids. The experimental results revealed that the transmittance of nanofluids has indirect relation with nanoparticle size, volume fraction, and path length. The scattering of light is directly proportional to the volume concentration and particle size of metallic particles. Overall, results of various elements showed that the presence of large particles and particle agglomerates leads to significant amount of light scattering. As a result, overall extinction coefficient will be increased. Therefore, an optimization of these properties need to be maintained for stable and cost-effective nanofluid.

1. Introduction

In hot climates, the excessive use of air conditioning requires extensive amount of electricity produced by burning fossil fuel which is not free from environmental pollution. To overcome these problems, environmental friendly technologies are required to generate electricity. The nanofluid based solar heat absorbers are very suitable to generate the electricity. Similarly, solar radiation converted into solar thermal heat can be used for heating water, buildings and process heating in industrial applications. Such type of materials (i.e. nanomaterials) with complete absorption of infrared solar radiation can be used for solar thermal power plants in which heat energy is transferred to other fluid by means of heat exchangers to be used in the electrical generation process. Hence, solar energy is being converted into thermal energy which is further converted into electrical energy using steam turbine. In solar power plants, the radiation coming from sun is redirected to top of a tower by using large mirror tracking along two-axis. These collector mirrors are called heliostats. The concentrated solar light at the top of solar tower transferred the heat energy to the nanofluid specifically called HTF (high-temperature fluid). To attain the required thermodynamic cycle temperature, reflective solar concentrators are used to enhance the performance. A schematic diagram representing the operating cycle of a solar thermal power plant using heliostats receiver is shown in Fig. 1 [1].

A number of materials have been used as heat absorber with either open or closed loop volumetric receiver systems. Nanofluids (colloidal suspension of solid nanoparticles into liquid) have higher thermal properties are promising to be a good absorber of solar collector. The energy of solar light consists of about 44% visible, 3% UV and 53% infrared radiation or heat. The optical study enables us not only use the thermal energy available in infrared region but also enables us to utilize the energy in the visible region [2]. In this way, by tuning fluid to absorb the energy in infrared as well as a visible region, we would be not only able to utilize the most part of the solar spectrum but can also increase our solar absorption efficiency. That is to study the thermal and as well as optical properties of their nanofluids. It was also observed that orientation angle has very important role in performance of any solar collector and maximum efficiency can be achieved by

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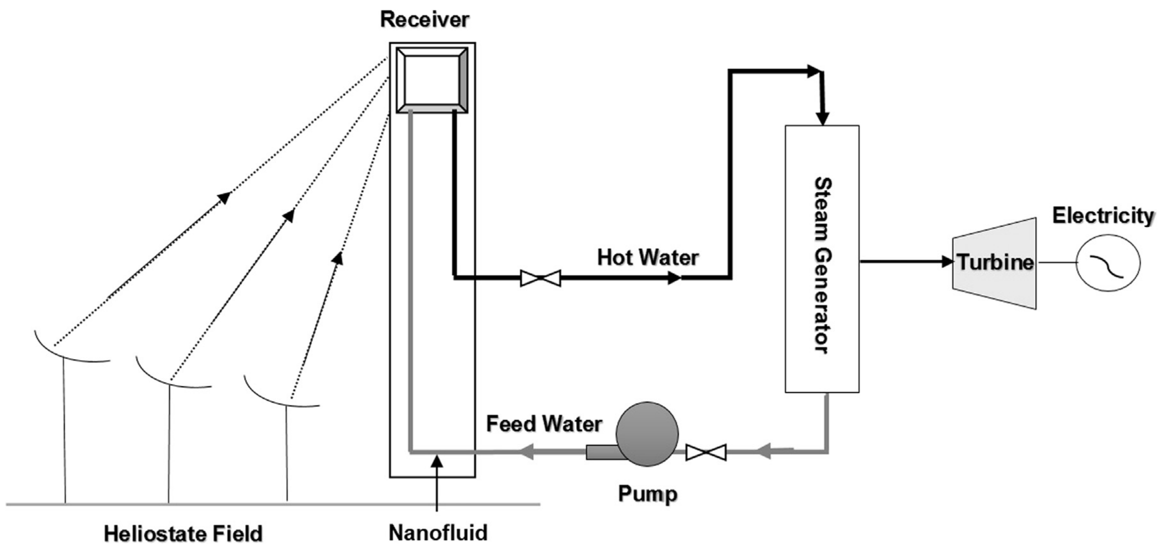

Fig. 1. Schematic diagram of solar thermal power plants using heliostats receiver.

maintaining tilt factor at specific tilt angle. Saidur et al. [3] studied how the optical properties of nanofluids contribute to overall absorption capability of nanofluids. The aluminum nanoparticle in water based nanofluids was observed for this purpose. Water was chosen for this purpose as water is completely transparent to visible region of light spectrum and also have high absorption capability for the wavelength of about and longer than 2.6 µm. On the other hand, aluminum nanofluid has a strong extinction coefficient for shorter wavelengths and at a peak at 0.3 µm. But it has a very weak extinction coefficient for longer wavelengths. Therefore, they deduced that aluminum nanoparticle and water based nanofluids could be used to improve the absorption ability of light in visible and shorter wavelengths. Karami et al. [4] investigated the optical properties of CuO nanofluid with a base fluid which was blend of distilled water and ethylene glycol. The observations were taken at the different temperatures for different volume fractions. The outcomes from experimental observations showed the increase in absorption ability of nanofluid at very low volume concentrations. At 100 ppm concentration, the absorption was increased up to 4 times of the base fluid with same path length of 1 cm. This will lead to an enhancement of the thermal conductivity from 5.6% to 13.7% for this volume concentration and given temperature range. Lee et al. [5] studied water-based multi walled carbon nanotubes (MWCNT) nanofluids. Authors observed that the extinction coefficients of water-based MWCNT nanofluids found to be increased linearly with increasing volume concentrations. Especially, the incident solar energy with a fixed wavelength could be totally absorbed at the penetration depth of 10 cm of the water-based MWCNT nanofluids with extremely low volume fraction of 0.0005 vol%. Luo et al. [6] studied the absorption and scattering of light for graphite based nanofluid. This was further used to analyze the efficiency and temperature distributions of the system. The addition of graphite nanoparticles not only increased in output temperature by 30–100 K but also enhanced the efficiency of the system by 2–25% as compared to base-fluid. At the volume concentration of 0.01%, the photothermal efficiency was 122.7% as compared to a coating. Study revealed that even low volume concentrations of graphite based nanofluids triggered the improvement in temperature distribution and enhance the system efficiency by increasing solar absorption. Lui et al. [7] investigated graphene and ionic liquid based nanofluid. Authors reported that a complete absorption of sunlight can be obtained at higher concentration of graphene. With increase in concentration of graphene, the absorption as well as extinction coefficient increased. It was observed that extinction coefficient of ionic liquid ([HMIM]BF_4) was increased by about 5 cm^{-1} with 0.002 wt% increase in graphene's concentration. It was found that the efficiency of receiver decreased with increased graphene concentration. This may not only improve the absorption of sunlight but also enable us to use higher receiver, lower concentration which further lead to reduction in clogging of nanoparticles throughout the plant. However, it was also found that with increase in graphene concentration as well as receiver height, the efficiency of receiver increased. They deduced that 70% efficiency can be achieved at conditions of 0.0005 wt%, 5 cm receiver height, and at 600 K. Hossain et al. [8] reviewed the optical properties of different nanofluids based on different theoretical models. They emphasized utilization of different parameters to enhance the optical and thermal absorption of solar energy.

The purpose of this study is to accommodate thermal and as well as optical properties of nanofluids to enhance the overall solar energy absorption. Hopefully in future, this study may lead to maximum utilization of solar spectrum in renewable energy applications. In past, major focus of study was heat transfer ability and thermal properties of nanofluids, however some time they either slightly mentioned the optical properties or totally ignored them [9–15]. Some of them enforce on thermal and suspension stability but did not mentioned the optical stability of the nanofluids [16–20]. A comparative study on solar absorption has been performed in the literature [8,21] using different nanofluids, which was not enough to highlight all the aspects, practically. Therefore, a comprehensive study on subject of different types of nanofluids is required which covers all the aspect of the solar absorption and optical stability. The drive behind this article is to gather all the information on the effect of temperature, particle diameter, base fluid, path length, and volume concentration on solar absorption of a nanofluid. A review paper that incorporated all aspect like particle size, particle concentration, temperature, and path length effects over optical properties of a nanofluid is not existed. Some of the review papers had discussed the optical properties of nanofluids but in fact highlighted the thermal conductivity of nanofluids, and they [21,22] did not discuss all optical properties of these fluids like absorption, transmittance, scattering, emissivity and extinction coefficient. Fig. 2 showed a flow chart which graphically explained the contents and structure of this review paper. In this paper, we proposed different nanofluids which may be most suitable for used in solar thermal absorption systems. The optical properties of nanofluids based on metal, metal oxide, carbon nanotubes, graphite, and graphene has been studied and their findings were presented. Further, we have discussed the optical properties of these nanofluids, which are more appropriate with full solar spectrum.