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Improved Water Purification Rates in Solar System using Plasmonic Particles

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ABSTRACT

In 21st century the requirement of clean water is one of the most important need of the hour. Efforts have been taken to provide suitable sufficient water to worldwide population. Global climate changes and water quality deterioration act as major setbacks in production of clean water. Current nanofabrication methods are capable enough to improve waste water treatment efficiency as well as proper disposal of waste water. Here we report a quantitative study which compares two of the popular waste water treatment processes on a nanoparticle scale which are nanoparticle dispersions [amorphous carbon nanoparticles dispersed in ethylene glycol and Multi-walled carbon nanotubes (MWCNTS) dispersed in distilled water] to conventional process of waste water treatment (TiNOX coated copper substrate) their relative thermal efficiencies have been compared under similar operating conditions. It has been found that higher average stagnation temperatures are achievable if the electromagnetic radiation is allowed to directly interact with a heavy mass of fluid.

Keywords: Nanoparticle, Solar systems, Water purification.

1. Introduction

Solar energy is one of the most inexhaustible source of energy. This energy can be utilised to clean waste water to such extent that it is available for drinking purposes too. For large fresh water bodies, it is not a viable choice to use conventional distillation processes like thin film distillation, reverse osmosis, multi-effect fresh evaporation and electro dialysis. Extensive use of surface-based absorbers is seen in today's date, in which the solar irradiance is first absorbed by a solid surface and then transferred to a working fluid via convection or conduction heat transfer. The particles whose electron density can be coupled with an electromagnetic radiation of wavelengths which are larger than the particle due to the nature of dielectric metal contact between the particles and the medium are called plasmonic particles or plasmons. This report does a comparative study between the thermal efficiencies of volumetric absorption based vs surface absorption based systems.

2. Waste Water Purification Using Solar System With Nano Particles

Purification of waste water has always been an area of concern. Various studies and researches have been done on the present topic. Some of them were reviewed during project.

G.X. Chen et. Al. used a glass petri dish container as the target for preparation of carbon nanoparticle using a pure glassy vitreous carbon plate for surface based water purification. Prior to preparation, both the target and petri dish were rinsed with acetone and ethanol followed by de-ionised water in an ultrasonic cleaner. To ensure uniform laser ablation during the laser ablation process the target is immersed in de-ionised water to a depth of about 5 mm below water's surface. Which ensures uniform dispersion of nanoparticles that are formed in water. To ablate the target, a 7 ns laser operating at the wavelength of 532 nm was used. The obtained solution at 532 nm in a UV-visible measurement had almost 100% transparency. The obtained colloidal solution was then collected and condensed to increase the concentration of carbon nanoparticles. The solution was vibrated in an ultrasonic cleaner before the actual measurement to ensure the uniformity of particle dispersion and also to avoid possible aggregations formed during heating of the solution.

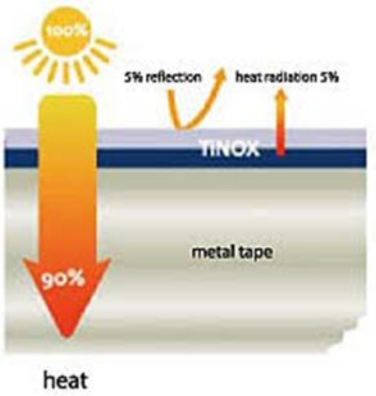


Fig. 1. Increased thermal efficiency rates observed with TINOX coating.

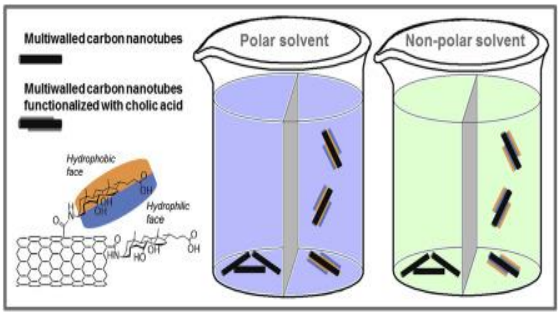


Fig. 2. MWCNTs reaction to polar and non-polar solvents.

Todd Otanicar et. Al. did a comparative study of performance of volumetric absorption based and surface based system. These two individual experimental studies were done at IIT Ropar and UNSW, in this comparison he took two sets of nanoparticle dispersions 1. Amorphous carbon nanoparticle and 2. Ethylene glycol in multiwalled carbon nanotubes (MWCNTs) in distilled water. Similar setup of pure liquids (ethylene glycol and distilled water) was placed in contact with (TINOX) copper substrate. Readings were noted of surface based absorption system to show that the spatial temperature of fluids are higher at solar selective surface. This observed difference in spatial temperatures in two cases prove the fact that as the magnitude of the flux crossing thermal barrier increases, the spatial temperature distribution increases. In case A, magnitude of incident flux is high as compared to case B in which it has a low relative incident flux. As the volume fraction of the nanoparticles increase, the temperatures near the free liquid surface also tend to increase. The probable cause of this phenomenon is that with an increase in volume fraction, the attenuation of incident flux essentially takes a thin layer in the region of the free liquid surface.

2.1. Radiative Heat Transfer In Surface And Volumetric Absorption Based Systems

One of the most dominant type of heat transfer is radiative heat transfer which shows the solar irradiance absorption capability and losses from these solar thermal systems. Hence in order to study the performance of solar thermal systems, it is a prerequisite to understand.

Solar irradiance absorption capability is a characteristic of surface material. A surface having absorptivity α is able to absorb absorptivity times the incident flux ($\alpha_s I_0$).

For volumetric absorption systems, it depends on both the material (absorption coefficient $K_{a,v}$) and the thickness (*y*) of the liquid layer. Equations (1) and (2) depict the energy absorption capability for the volumetric absorption configurations in Figs. (a) and (b), respectively.

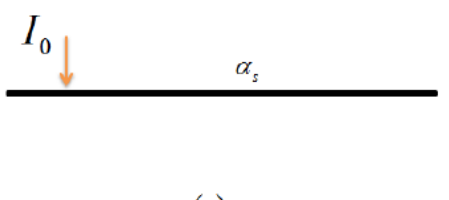
$$\mathbf{E_{absorbed} = I_0 [1- exp(-K_{a,v}y)]} \quad (1)$$

$$\mathbf{E_{absorbed} = I_0 [1- exp(-K_{a,1}y_1 - K_{a,2}y_2 ......- K_{a,n-1}y_{n-1} -K_{a,n}y_n)]} \quad (2)$$

Now case of a nanofluid the absorption capability can be easily manipulated via control of layer thickness and volume fraction of nanoparticles. Fig. 1c denotes a similar nanofluid-based volumetric system. The nanofluid layers may create a non-uniform spatial distribution, agglomeration and size distribution. In theory it is possible to design a volumetric based absorption system such that it has absorptivity [for instance, a nanofluid layer (amorphous carbon nanoparticles dispersed in ethylene glycol) of 2 cm can theoretically absorb about 99 % of the incident solar irradiance] greater than equal to that of commercially available solar selective surfaces [such as TiNOX coated copper substrate (actually constituted of multiple layers such as protective antireflective layer, absorber layer, bonding layer, and copper substrate) having solar weighted absorptivity of 95%. The heat loss due to radiation from the surface depends on the total hemispherical emissivity (ε_s)

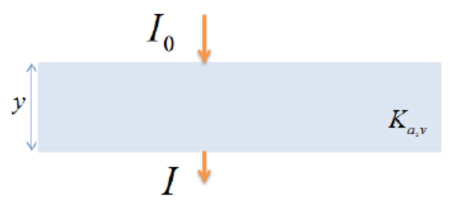
of the surface and are given by Eq. (3) as

$$\boldsymbol{E_s = \varepsilon_s \sigma T_s^4} \quad (3)$$



(a)

Fig. 3(a). Schematic of energy absorption mechanism in typical surface absorption –based system.



(b)

Fig. 3(b). Schematic of energy absorption mechanism in liquid layer of thickness *y*.

3. Conclusion

To conclude, we report a theoretical study in which we did a quantitative comparison of a conventional surface absorption-based system having a solar selective surface to a nano fluid based system. Apart from the radiative heat transfer the heat transfer due to convection also plays a major role in actual surface absorption-based system, the accuracy of heat transfer due to convection mode is negligible as the working temperatures and solar concentration rise. The current study highlights that in such cases the nanofluid-based volumetric absorption system is proven to be more efficient. There has been no evidence of that at a certain volume fraction, the volumetric system performs most efficiently. Plus there has been evidence that at higher stagnation temperatures (I.e. in case of volumetric absorption based systems) the cumulative effect of higher optical efficiency and the subsequently higher conversion efficiency of radiant energy into the thermal energy in the working fluid.

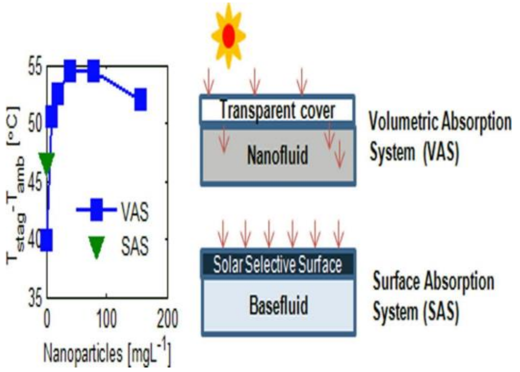


Fig. 4. Comparison of ambient temperatures of VAS and SAS.

Surface absorber	Working Fluid	Stagnation temperature above ambient (ºC)
TINOX coated copper substrate	Ethylene glycol	46.60±0.29
Amorphous carbon nanoparticles coated copper substrate	Ethylene glycol	42.46±0.48

Table. 1. Comparison of stagnation temperatures between SAS and VAS above ambient temperatures.

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