Energy Harvesting Through Optical Properties of TiO_2 and C- TiO_2 Nanofluid for Direct Absorption Solar Collectors

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Abstract- Nanofluids are tailored suspensions of nanoparticles in a suitable base fluid. The discovery of nanofluids by Stephen choi opened a new heat transfer mechanism. Since then several research has taken place to explore thermal, electrical and magnetic property of nanofluids. Nanofluids showed enhanced electrical and thermal conductivities. The nanofluids are also proved as a potential candidate for direct absorption solar collectors (DASC). The present work investigates the effect of nanoparticle volume fraction and the associated optical intensity attenuation with a semiconductor laser diode of wavelength 670 nm. Nanoparticles of Titanium dioxide (TiO_2) and Carbon doped Titanium dioxide (C-TiO_2) are prepared by sol gel and characterized by powder XRD, SEM and UV. Since carbon is a good absorption material, TiO_2 are doped with carbon (C-TiO_2) to increase the absorption of incident radiation. Nanoparticles of TiO_2 and C-TiO_2 with two weight fractions such as 0.04 and 0.08 are dispersed in water and ethylene glycol to obtain TiO_2 and C-TiO_2 nanofluids. The nanofluids are investigated for their sedimentation time. Stability of TiO_2 nanofluid is nine times more than C-TiO_2 nanofluid but C-TiO_2 nanofluid are found to be efficient absorbers than TiO_2 nanofluid. A low volume fraction of C-TiO_2 nanofluid can ensure high stability, low pumping power and good absorption for a DASC.

Keywords: Nanofluid, TiO_2, C-TiO_2, Optical absorption, Laser, DASC.

1. Introduction

Increasing consumption and growing demands of electrical appliances across the globe have posed a threat on the non renewable energy resources and has made us exploit the maximum of renewable energy resources, in which solar energy is the ultimate choice. Solar energy has been investigated for photovoltaic and thermal applications (Duffie, 1980) [1]. A major thrust in materials development is to identify new materials in order to increase the efficiency of solar cells. Materials with ultra fine grain size and nanomaterials have provided an opportunity to tune the band gap and absorption of the existing solar energy. Conventional solar cells transfer the heat from the flat plate to the working fluid and it suffers from the large heat loss. The concept of direct absorption solar collectors in which working fluid acts as absorber and carrier of heat started replacing the conventional solar cells (Otanicar TP,2009) [2]. Since thermal conductivity of pure liquids are extremely less than solid particles, suspension of microparticles gained prominence. But micro-colloidal suspensions have drawbacks like abrasion and sedimentation. Nanofluids were substituted by Robert Taylor (2009) to overcome the above problems [3].The term Nanofluid was coined by Stephen Choi in 1995.[4] Nanofluids are suspensions of nanosized solid particles (1-100nm) in suitable base fluids. Since 1995, nanofluids have been explored as a heat transfer fluid and the best results have been reported by Eastman and Stephen Choi in (2001). In the past five years nanofluids have been also explored for their electrical (Suvankar Ganguly 2009)[5] and magnetic properties(John Philip,2009).[6]

Nanofluids can be prepared by two ways, single step method (H Zhu 2004)[7] or two step method (Eastman 1997) [8]. Single step method is based on simultaneous synthesis of nanoparticle and nanofluid and two step methods involve;

the synthesis of nanoparticles in the first step followed by dispersion in a suitable base fluid in the second step. The success of nanofluid for DASC depends on suitable choice of base fluid and nanoparticles. The best nanofluids have high stability, high absorption of sun light and minimum abrasion. In the present work an attempt has been made to identify the best absorption nanofluid.

2. Experimetal

2.1. Preparation TiO_2 and C-TiO_2.nanoparticles

TiO_2 nanopowders were prepared via sol–gel method using titanium tetraisopropoxide (TTIP) and ethyl alcohol as the starting materials. All the reagents used were of analytical grade. 10 ml of Titanium tetraisopropoxide was dissolved in absolute ethanol (20ml) and 30 ml of distilled water was added to solution to maintain the particular viscosity. The solution was stirred slowly with constant speed using a magnetic stirrer (Placeholder1) for 40 minutes at room temperature. In order to obtain nanoparticles, the gels were dried at 50°C for 1.5 hr to evaporate water and organic material to the maximum extent. The dried powders were calcined at 400ºC for 2 h after the hand-milling for the preparation of TiO_2 nanoparticles [9]. A flow chart for synthesis of TiO_2 nanoparticles is represented in Fig. 1 and the nanopowders of TiO_2 before hand-milling is shown in (Fig. 2). C-TiO_2 nanopowders were prepared via sol–gel method using titanium tetraisopropoxide (TTIP), distilled water, ethyl alcohol and glucose as a source of carbon. Titanium tetraisopropoxide (10 ml) was dissolved in absolute ethanol (20ml) and 0.1 g of glucose was added to the solution.

Fig 1. Flow chart for synthesis of TiO_2 nanopowders

Fig. 2. TiO_2 nanopowder before milling.

Fig. 3. C-TiO_2 nanopowder.

Finally, 30 ml of distilled water was added to maintain the particular viscosity of solution and it was slowly stirred for one hour. The gels were further dried at 50 °C for 1 hr. The dried powder was calcined at 250°C for 4 hours to obtain nanopowders of carbon doped TiO_2 (Fig 3).

2.2. Preparation of TiO_2 and C-TiO_2 nanofluid.

The prepared TiO_2 and C-TiO_2 nanoparticles were dispersed in water medium and the samples were prepared with two weight fractions of 0.04 and 0.08. In the same way the TiO_2 and C-TiO_2 nanoparticles were dispersed in ethylene glycol medium for two weight fractions of 0.04 and 0.08. Sonication was done at a frequency of 42KHZ for each sample. TiO_2 and C-TiO_2 nanofluids in water are shown in fig. 4 and 5 respectively. Table I gives the weight fraction of the base fluid and nanoparticle used for present study.

Table 1. List of samples prepared for optical attenuation, Water (W) – Base fluid, Ethylene Glycol(EG) – Base fluid

S. No	Samples	Weight fraction
1	TiO_2 W	0.04
2	TiO_2 W	0.08
3	TiO_2 EG	0.04
4	TiO_2 EG	0.08
5	C-TiO_2 -W	0.04
6	C-TiO_2 -W	0.08
7	C-TiO_2 -W	0.04
8	C-TiO_2 -W	0.08

Fig. 4. TiO_2 nanofluid

Fig. 5. C-TiO_2 nanofluid

2.3. *Sedimentation test*

Ideal nanofluids have high stability and poor suspensions, which changes the thermal and absorption properties of nanofluid drastically. The importance of stability of nanofluids and different methods of sedimentation analysis and mechanisms is discussed by Sayantan Mukherjee, 2013 [10]. In the present work sedimentation is evaluated by gravitational sedimentation column method for TiO_2 and C-TiO_2 nanofluid as shown in fig. 6 and fig. 7. The interfacial layer distance is observed as a function of time to obtain the sedimentation plot.

2.4. *Optical Attenuation*

In order to identify the best nanoparticle for a given base fluid and to increase the efficiency of absorption. Optical attenuation of nanofluids were investigated with semiconductor laser diode with wavelength 6700 Å. Optical attenuation for nanofluids were investigated by varying distance and volume fraction. Optical attenuation was taken for TiO_2 nanoparticle for weight fraction of 0.04 and 0.08 in 60 ml of base fluids with attenuation distance from 0.1m to 1m (Fig. 8).

3. Experimetal

3.1. *Preparation of TiO_2 and C-TiO_2 nanofluid.*

Constant stirring on a magnetic stirrer after 30 mins showed a milky white solution, which confirms the formation TiO_2 nanopowders. After drying at 50 °C, TiO_2 was clearly obtained, which are light yellow in color as shown in figure 2. On addition of glucose and continuous stirring, the color of TiO_2 change to light brown color, which indicates the presence of carbon in the TiO_2.

3.2. *Structural Characterization*

Figure 9 shows the power X-ray Diffraction pattern of TiO_2 nanopowder after calcination at 400 °C for 2hrs. The powder X-ray diffraction pattern of prepared TiO_2 nanoparticle was confirmed with JCPDS-89.4203 data. The 2θ values of the broad peaks at 25.36, 37.91, 48.04, 55.05 shows the anatase phase of TiO2 nanoparticles [11]. Average grain size of TiO_2 and C-TiO_2 were determined by the Debye-Scherer formula $D = 0.91\lambda / (\beta\cos\theta)$ and were found to be 42.77 nm and 49.74 nm. The presence of additional peaks near the diffraction angle of 25 in the XRD pattern (fig. 10) is evidence of carbon in the powdered sample. The SEM picture (fig. 11) shows nanoparticles with agglomeration. The agglomeration may be reduced with surfactants during preparation of TiO_2 or changing the experimental conditions. Surfactants are not advisable for this application, because they would alter the optical absorption of nanofluids. The size of the nanoparticles were measured from the SEM picture and they are in the range of 50-100nm.

3.3. *Sedimentation characterization of TiO_2 and C-TiO_2 nanofluid*

Fig 6. Sedimentation of TiO_2 nanofluid

Fig. 7. Sedimentation of C-TiO2 nanofluid

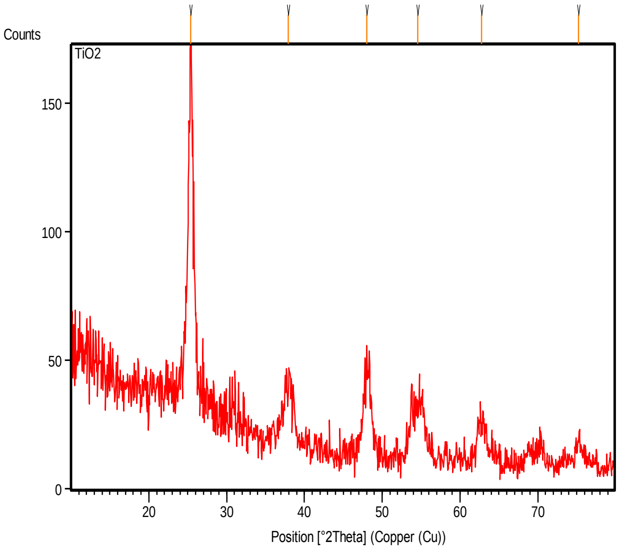

Fig. 8. Powder XRD pattern OF TiO_2 nanopowder

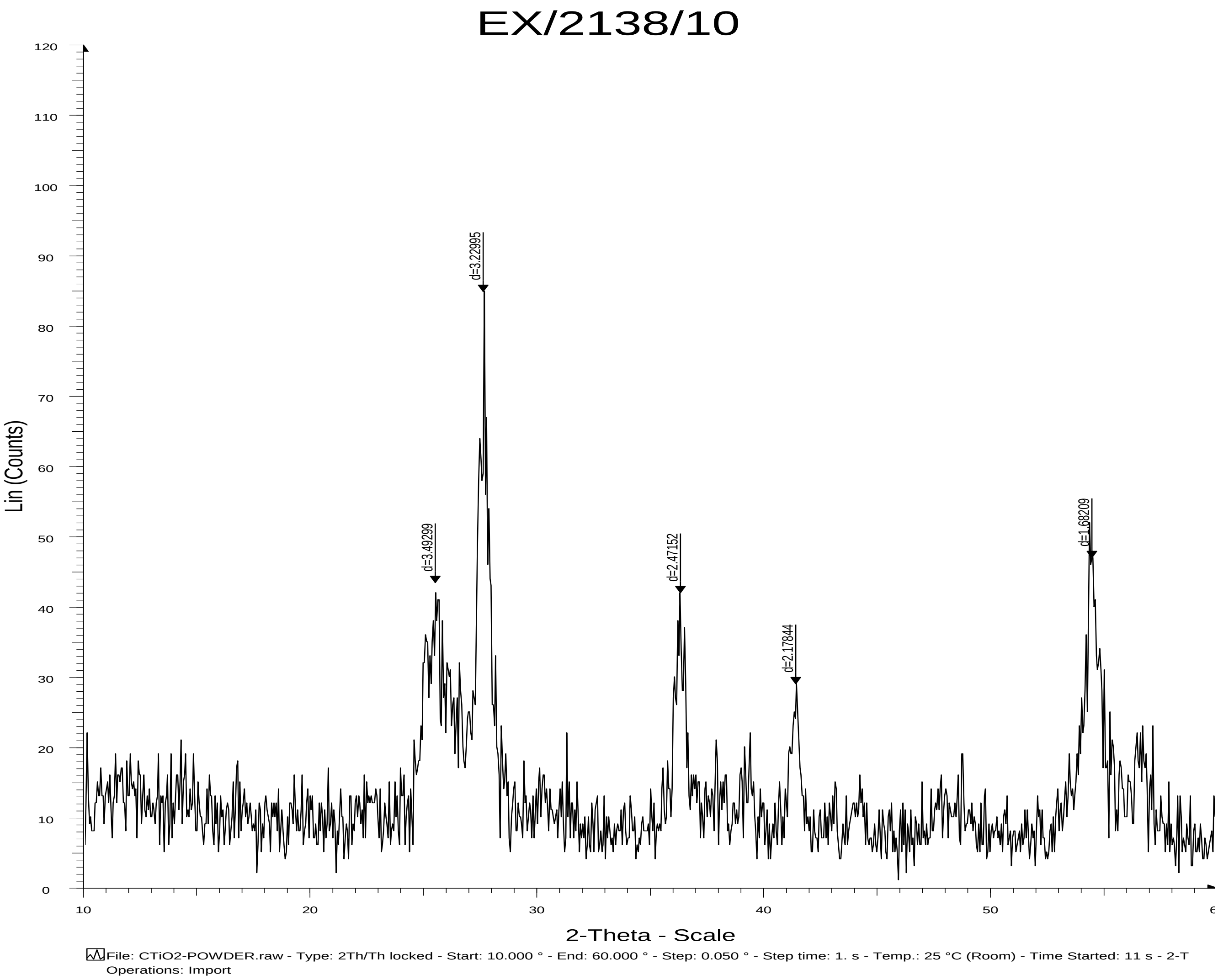

Fig. 9 Powder XRD pattern of C-TiO_2 nanopowder

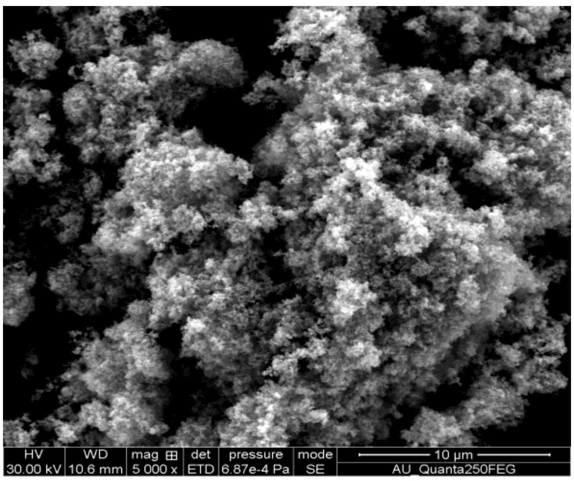

Fig 10. SEM picture of TiO_2 nanopowder

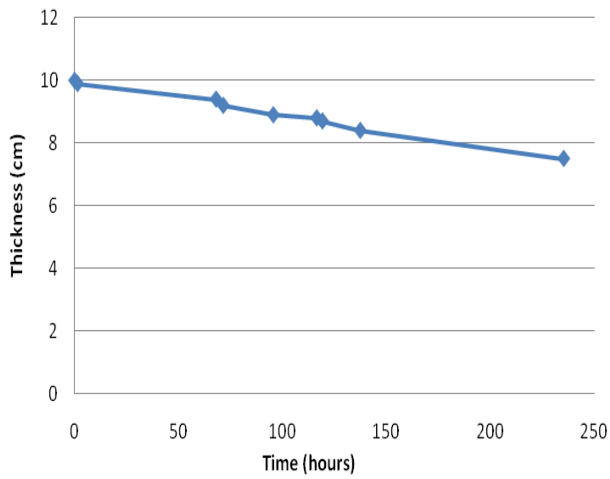

Fig. 11. Sedimentation of TiO_2 nanofluid.

A plot of interfacial layer and the time required reveals the sedimentation velocity of TiO_2 and C-TiO_2 nanofluid with water as base fluid (fig. 12 and 13). Sedimentation time is reported after 25% reduction in interfacial layer thickness as 9.79 and 1.046 days for TiO_2 and C-TiO_2. This may be due to the density difference between TiO_2 nanoparticles and Carbon doped TiO_2 nanoparticles, size of nanoparticles, interaction among the nanoparticles.Thus TiO_2 nanofluids are more stable than Carbon doped TiO_2 nanofluids. In order to increase the stability of Carbon doped TiO_2 nanofluids, lesser volume fraction of nanoparticles or addition of surfactants with minimum optical absorption is necessary.

3.4. *Optical Attenuation with Nanofluids*

Colloidal suspensions are capable of absorbing and scattering the incident light from the source. This is applicable to direct absorption solar cells due to the presence of nanofluid as the collecting medium. Nanofluids can absorb sunlight to depending on their composition, volumefraction, characteristics of nanoparticle (shape, size, colour etc), which decides the efficiency of DASC. The investigation of optical absorption of nanofluids is performed with a laser source and the investigation is varied

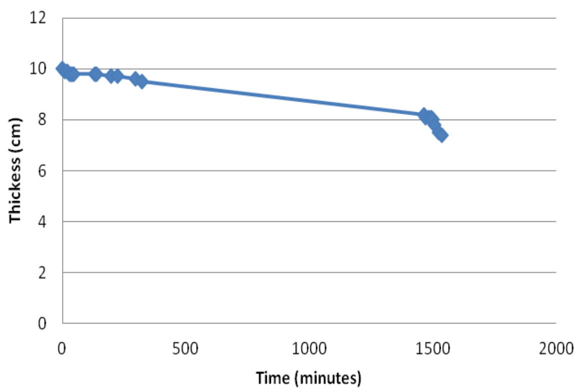

Fig. 12. Sedimentation of TiO_2 nanofluid

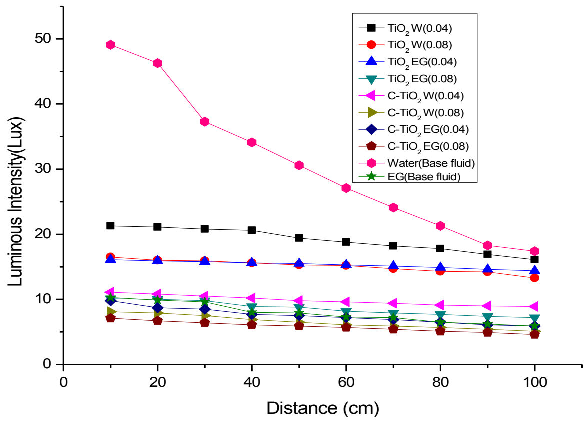

Fig. 13. Optical attenuation in nanofluids

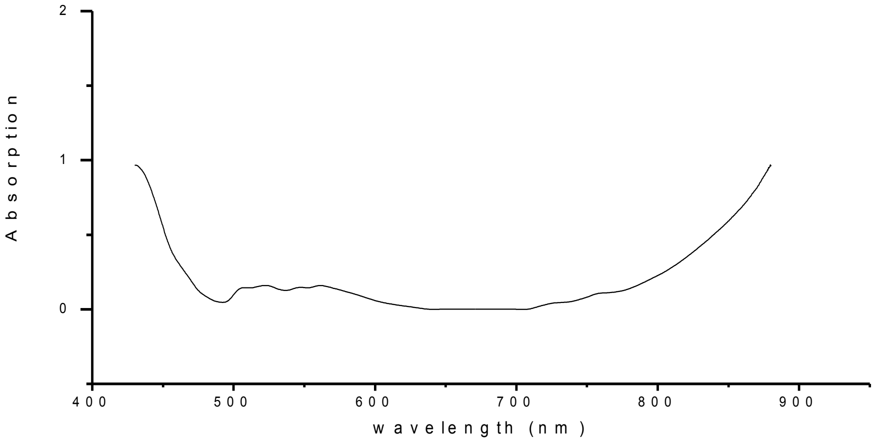

Fig. 14. UV-Vis absorption spectrum of TiO_2 nanofluids

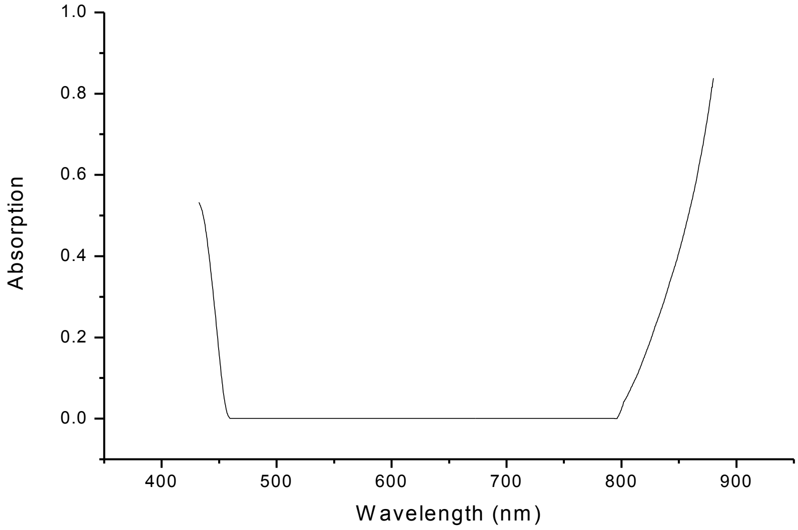

Fig. 15. UV-Vis absorption spectrum of C-TiO_2 nanofluids

with distance, nature of nanoparticle and volume fraction of the nanoparticles in the base fluid. Figure 14 indicates the maximum absorption of light by C-TiO2 nanoparticles with water and ethylene glycol as the base fluid. Thus C-TiO_2 nanofluids with EG (0.08) show best absorption.

3.5. *Optical Characterization*

The prepared TiO_2 and C-TiO_2 nanoparticles were investigated to understand their optical properties by UV-Visible absorption spectrophotometer at room temperature. The spectrum is recorded from 400 nm to 900 nm as shown in figure 15. C-TiO_2 shows complete absorption in comparison to TiO_2 powders from 460 nm - 800 nm. With increase in wavelength from visible to IR region the absorption of TiO_2 nanoparticle increases gradually but the absorption increases rapidly in C-TiO_2.

4. Conclusion

1. TiO_2 and C-TiO_2 nanopowders were prepared by sol-gel method. Powder XRD results shows that TiO_2 powder has anatase phase and it is more crystalline nature compared to the C-TiO_2. The average grain size of TiO_2 and C-TiO_2 are 42.77 nm and 49.74 nm respectively.

2. It is observed from SEM images that TiO_2 has inhomogenous grain size with high agglomeration and. the average particle diameter is in the range of 50 -100nm.

3. The sedimentation test shows that TiO_2 is more stable than the C-TiO_2 nanofluid. The sedimentation time of TiO_2 and C-TiO_2 is 10.3 days and 1.04 days respectively. Lesser volume fraction of C-TiO_2 nanofluids is necessary for higher stability.

4. The optical attenuation was studied for C-TiO_2 nanofluids with EG of volume fraction 0.08, which shows the maximum absorption. The optical attenuation is performed at a constant wavelength of 670 nm.The results are dependent on wavelength of incident radiation

5. C-TiO_2 nanofluids are better nanofluid than the TiO_2 nanofluid for direct absorption solar collectors.

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