CHAPTER: 19

NANOFLUID SELECTION PROCEDURE FOR SOLAR COLLECTOR APPLICATIONS

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ABSTRACT

Nanofluids are still-developing fluids that demonstrate heating properties better than those of traditional fluids. Nanofluids are used to achieve maximum thermal properties with minimal concentrations, achieved via even distribution and steady mixing of nanomaterials with the base fluids. Nanofluids play a crucial part in diverse heating applications, including automobile industries, heat transfer devices, and solar power production. Heat transfer improvement in solar collecting device is a significant concern for energy efficiency, dense designs, and various working temperatures. The paper provides a detailed overview of the thermophysical properties of nanofluids with its use in solar collecting device. Recent studies highlight the traditional heat transmission using nanofluids and their definite applications in solar collectors.

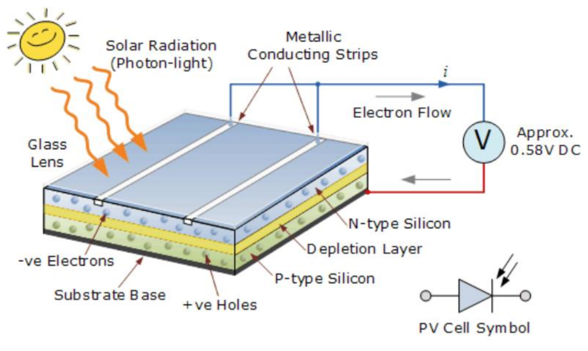
Keywords: *Nanofluid, Selection, Procedure, Solar Collector, Applications*

1. INTROUTION

Solar energy is the bulk huge energy source, reaching the Earth at approximately **4×10^{15}** MW, which is 200 times greater than global energy consumption. It is considered environmentally friendly and clean. Solar power generation has grown rapidly, increasing by 86.3%, and renewable energy sources now contribute 2.1% to total energy consumption, raises from 0.7% in 2001. First heat transfer nanofluids was developed by Choi [1] have also gained attention in the context of solar energy. Nanofluids, with particles smaller than 100 nm, have much greater heat conductivity in comparison to base fluids. Research shows that their When circumstances are stationary, heat conductivity rises. Studies focus on the performance of their heat properties, especially viscosity, density heat conductivity and convective heat transfer. Nanofluids are depending on the concentration, type, size of nanomaterial, offer significantly improved heat transmission compared to normal fluids. Comprehensive reviews cover their thermophysical properties. This article overviews these properties and their applications in solar collectors.

Technologies of Green Energy: Renewable, sustainable, and consistently replenished. Alternative sources include solar, hydro, wind, geothermal, biofuels, and tidal power. Solar energy is harnessed through solar heat collectors and solar photovoltaics.

Solar PV: In 1839, discovered the way to generate electrical current into a solid material using sunlight as shown in figure 1. Certain materials exhibit the photovoltaic effect, converting luminescence energy into electrical energy at the atomic level. This was the first explored in 1876, with a selenium solar cell having 1-2% efficiency [2]. Albert Einstein described the PV effect in 1904 with theory of photon. Jan Czochralski's 1916 invention for a process to develop pure silicon in crystalline form was pivotal for modern electronics. Early silicon solar cells had about 6% efficiency, much lower than today's cells which reach 14-20%. High initial costs stalled widespread adoption, but as costs decreased and environmental concerns grew, interest in solar technology surged.



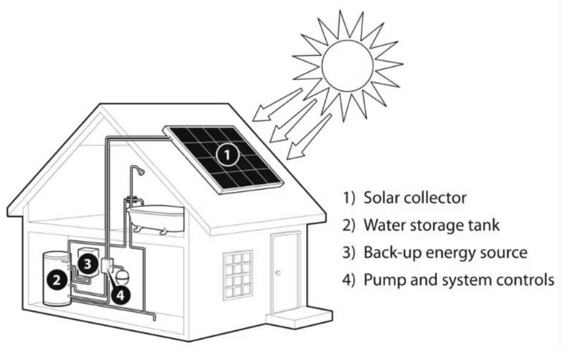


Figure:(1) Solar Photovoltaic Figure:(2) Solar Collector

Solar Collectors (Thermal)

These collectors are more efficient, achieving up to 70% efficiency by using water or other heat transfer liquid for water heating, domestic heating, and low-temperature industrial uses. They outperform directly the conversion of energy for a solar system, which typically have17% efficiency for generation of electricity [3]. Mirrors glasses are used with tracking device in Concentrating solar power (CSP) systems to centralize sunlight into a small beam for traditional power plants. Various CSP technologies include solar power tower and parabolic trough collectors. Recent innovations are integrating the technologies of nanofluid to make better the performance and efficiency of these solar thermal setup.

2. NANOFLUIDS

Nanofluids are mixtures of liquids and solid nanoparticles, formed when small metallic or non-metallic solid particles disperse throughout a liquid. These nanoparticles, often smaller than 100 nm, interact at the molecular level with base fluids like fibres, tubes, wires, and rods. This interaction enhances heat conduction, making nanofluids a novel and efficient class of fluid for heat transfer. Nanofluid enhances heat transfer through a combination of both convection, conduction, and additional transfer of energy via molecule collisions and dynamics. Metallic nanofluids, balanced to base liquid such as oil and water, exhibit improved thermophysical properties something like thermal diffusivity, viscosity, heat transfer conductivity, and coefficients of heat transfer for convection. Recently, nanofluids have demonstrated significant promise in various applications, particularly in thermal storage and collectors for solar energy. Most recent reviewer have covered in theoretical and experimental studies on the thermo-physical characteristics and heat transport behaviour of nanofluids [4], their potential continues to be explored across diverse fields.

Nanofluids and their Types

These are broadly divided into two kinds: metallic and non-metallic varieties. Eastman et al. [5] explored their microscale and atomic behaviours, revealing temperature-dependent effects, increased critical heat flux, and enhanced thermal conductivity. Nanoparticles including Al, Cu, Si and Ag can be found in metallic nanofluids. Semiconductors (like TiO_2), carbon nanotubes (MWCNT, SWCNT), and composite materials are examples of non-metallic nanofluids. Innovative materials and designs are being explored for their applications, focusing on how nanoparticles interact within the liquid phase.

Nanofluids Thermo-physical Properties

Nanofluids which contains metallic particles exhibit enhanced thermo-physical characteristics, including thermal conductivity, density, specific heat, as shown in table1.These improvements are influenced by the nanoparticles' volume percentage, size, and form, as discussed in [6].

Table 1, Thermo-physical properties of various materials

Material Type	Specification of Material	Chemical Formula	Thermal Conductivity (w/m K)	Density (kg/m^3)	Sp. heat (J/kg. k)
Metallic Solids	Copper	Cu	381	8978	388
	Aluminium	Al	237	2700	900
	Silver	Ag	429	10,490	429
Non-metallic Solids	Silicon	Si	36	2320	765
	Alumina	Al_2O_3	40	3690	773
	Copper oxide	CuO	33	6000	551
	Silica	SiO_2	148	2330	970
	MWCNT	--	3000	2600	710
	SWCNT	--	3500	1400	1380
Non-metallic Liquids	Water	H_2O	0.607	997	4180
	Ethylene Glycol	EG	0.255	1111	2400
	Engine Oil	--	0.146	884	1900

Thermal Conductivity

Research on nanofluids containing CuO, Al_2O_3, and Cu particles shows significant improvements in heat transmission. Studies report a 60% increase with Water/oil base fluid HE-200 at 5% volume dispersion [7], and a 20% increase with CuO and Al_2O_3 in water/ethylene glycol at 4% volume dispersion. Other investigations confirm enhancements in thermal conductivity and heat transmission by various percentages [8]. studies have examined Cu nanoparticles in water and transformer oil, as well as 26 nm SiC nanoparticles in ethylene glycol with deionized water using a temporary hot wire technique. Research on Fe-based nanofluids with 10 nm Fe nanoparticles in ethylene glycol showed mixed results, indicating challenges with thermal conductivity due to particle agglomeration. Variations between experimental and numerical data across studies are notable. the research highlights that nanofluids can enhance thermal conductivity by 5% to 10% compared to base fluids like water or PAO. However, the improvement varies based on factors such as molecule size and inherent the thermal conductivity of base fluid. The findings indicate that while nanofluids offer enhancements, they may not always significantly outperform standard base fluids in terms of thermal conductivity.

Density

Density in nanofluids refers to the mass of the mixture per unit volume, influenced by the root fluid (just like water, oil, or ethylene glycol) and nanoparticles (such as metal oxides, carbon nanotubes, or graphene oxide) dispersed within it. The density of nanofluids impacts their thermal conductivity and viscosity, crucial for efficient heat transfer. Measurement methods like density gradient ultracentrifugation ensure accurate determination of nanofluid densities due to the small size and low concentrations of nanoparticles.

Viscosity

Research on nanofluids explores viscosity as a key property. Studies show that the viscosity of SiO_2 nanofluids rely on the proportion of nanoparticles in their volume [9]. Another study on alumina nanoparticles in commercial engine coolants found that adding the right amount of surfactant (oleic acid) stabilizes the nanofluid. Small additions of alumina nanoparticles can make the base fluid non-Newtonian while maintaining Newtonian behavior at specific temperatures.

Heat Transfer through Convection

In recent years, research on nanofluids in forced convective heat transfer has shown promising results. Studies indicate a two-fold decrease in heat resistance in parallel channels and straight tubes. For Cu/water nanofluids, heat transport is significantly enhanced with minimal impact on friction factor [10]. Similarly, Al_2O_3-based nanofluids have been found to increase the coefficient of film convective heat transfer. In recent years, research on nanofluids has extensively explored their experimental heat transfer properties emphasizes forced convective heat transfer in straight tubes and parallel channels. Studies have consistently shown a two-fold decrease in heat resistance. Specifically, Cu/water nanofluids demonstrated increased heat transmission without significant impact on friction factor [10]. Wen et al. also observed enhanced convective heat transfer coefficients with Al_2O_3-based nanofluids. Recent research has highlighted a consistent decline in natural convective heat transfer, influenced by nanoparticle dynamics and interactions. Studies using water-based nanofluids like CNT, CuO, SiO_2, and TiO_2 have shown that CNT nanofluids can achieve heat transfer improvements comparable to Al_2O_3. Adjusting flow conditions and fluid concentration, as suggested by Ding et al., can optimize heat transmission. Positive results were also noted for CuO nanofluids under various wall boundary conditions. However, increasing nanofluid concentration beyond 0.3% volume fraction has minimal impact on heat transfer coefficient [11], with potential improvements ranging from 2% to 5%.

About Solar Energy

From the early 1920s to the mid-1950s, the solar industry grew until natural gas became the dominant heating fuel due to its low cost. Solar energy has since been used for heating homes, water, and electricity generation. The spectral distribution of solar radiation reflects the Sun's surface temperature of around 6000K. Solar energy, with its high thermodynamic quality, originates from the Sun, which is more accessible and hotter than traditional engineering sources. Earth's atmosphere and surfaces operate at much lower temperatures (around 230 K and 260–300 K, respectively). When solar radiation enters the atmosphere, interactions such as absorption and scattering occur: absorption converts radiant energy to heat, emitted as longwave radiation, while scattering can redirect radiation without changing wavelength, sometimes resulting in reflection. Solar collectors use receiver glass tubes to channel sunlight to absorber tubes, leveraging natural heat flow and the greenhouse effect to trap solar energy. Solar irradiation from the Sun measures around 63 MW/m^2, but due to Sun-Earth geometry, this reduces to 1 kW/m^2 at the Earth ground surface. Concentrating solar setups can control this limitation in high solar flux scenarios, efficiently converting solar radiation into solar thermal energy.

Solar Collector Classification

Solar thermal concentrating systems convert solar radiation into thermal energy at focal points. They are categorized into line-focus (e.g., linear Fresnel collectors, parabolic troughs) and point-focus (e.g., central receiver systems, parabolic dishes) concentrators. Common types include parabolic dishes, parabolic troughs, and power towers. Parabolic dish systems, for example, follow the sun's path and direct its light onto a focal point receiver, achieving high solar energy conversion efficiency, with temperatures up to 1000 °C possible at the receiver. Solar thermal concentrating systems convert solar energy into electricity, especially in modest power output scenarios. Parabolic troughs focus sunlight onto receiver tubes along their focal line (Fig. c), often enclosed in transparent glass to minimize heat loss. These systems, equipped with single- or dual-axis tracking, can achieve receiver temperatures up to 400 °C.

Flat-plate solar collectors consist of absorber plates, glazing (typically low-iron glass), insulation, and recovery tubes for heat transmission fluids as shown in figure 3. Enhancements like adding a Teflon layer as second glazing. Hellstrom et al. found that this approach increased performance by 5.6% at 50°C operating temperature [12]. By using a Teflon honeycomb to reduce convection losses have been shown to significantly improve collector performance. Antireflection treatments on the glass cover also enhance efficiency by reducing reflection losses improved 6.5% increase in production at 50°C operating temperature. These improvements aim to maximize solar energy absorption and minimize heat loss, increasing overall collector efficiency.

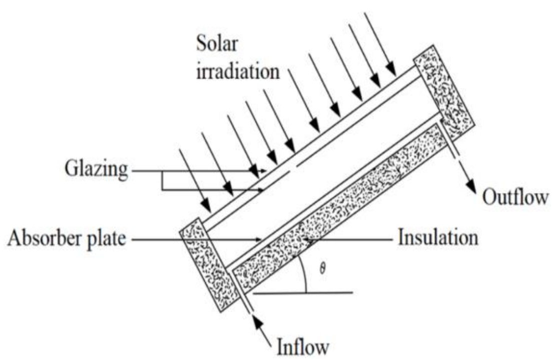


Figure:(3) Flat Plate Solar Collector

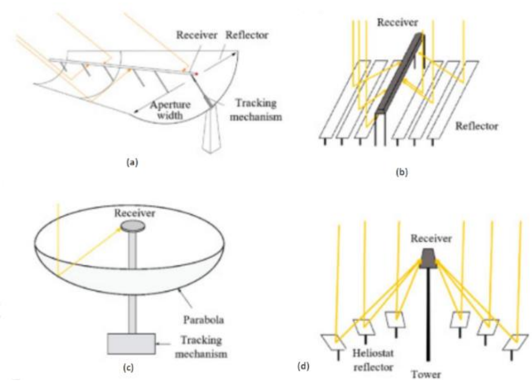


Figure:(4) Solar Concentric Collector

Parabolic dish collectors utilize mirrors shaped like parabolic dishes to concentrate the solar energy at the receiver that is situated at the mirrors' central point as shown in figure 4 (c). These collectors employ Stirling or Brayton engines connected to the receiver to generate power by heating heat transfer fluids to specific operating temperatures and pressures. Prototypes of these systems, with power outputs varying from 7-25 kw have been installed in distinct locations across the United States.

Parabolic trough collectors concentrate solar radiation along a focal line as shown in figure 4(a), achieving temperatures of 350 to 400 degrees Celsius. They use parabolic mirrors to focus sunlight onto a black metal receiver, which absorbs the heat. These collectors can be oriented for optimal sun tracking, significantly improving solar energy collection efficiency compared to fixed orientations, as shown in studies.

Solar power towers generate electricity by using heliostats large lenses that trace the sun to straight sunlight onto a light source a top a tall tower. The intense heat at receiver, reaching temperatures over 1000°C, produces steam of high-pressure. This steam is then used to generate electricity. Advanced thermal collectors optimize efficiency and reduce heat loss, enhancing the performance of solar power towers in generating renewable energy.

Utilizing Nanofluids in applications of Solar Collector Applications

Nanofluids improve heat transfer and are increasingly used in solar collectors to enhance efficiency. They address limitations in traditional direct absorption solar collectors by integrating advanced nanofluid technologies. Studies, such as those by Tyagi et al. [13], explore theoretical advancements in low temperature nanofluid established solar collector designs. Experiments with water based Al_2O_3 nanofluids showed that varying particle volume fractions (0.1% to 5%) significantly improved solar collector efficiency. Changes in glass cover transmissivity and collector height also influenced efficiency positively. Efficiency increased notably (up to 8%) within volume fractions of 0.8% to 1.6%, with little correlation found between nanoparticle size and efficiency.

Taylor et al. [14] found that using Thermonol/graphite VP-1 nanofluids in 10-100 MW tower collectors for solar electricity could potentially increase efficiency by up to 10% compared to traditional solar collectors. Experimental results suggested a 5-10% efficiency boost within the receiver area with nanofluid use. Additionally, the study estimated a potential annual additional income of $3.5 million with effective implementation. Li et al. [15] investigated Al_2O_3/water, MgO/water, and ZnO /water nanofluids in sun collectors in tubes, finding that nanofluids with volume fractions below 10 parts per million could absorb 95% of incoming solar radiation efficiently. Yousefi et al. [16] studied Al_2O_3/water nanofluids with concentrations of 0.2% and 0.4% and particles sizes of 15 nm in flat plate solar collectors to evaluate their efficiency. Both studies demonstrate the potential of nanofluids to enhance solar collector performance by improving absorption and heat transfer capabilities.

Yousefi et al. [17] studied MWCNT/water nanofluids in solar collectors with flat plates, finding Weight fraction of 0.2% nanofluid increased efficiency by 28.3%, Addition of Triton X-100 surfactant and higher mass flow rates further boosted efficiency by 15.63%, pH levels, particularly at the isoelectric point, significantly influenced collector efficiency. Their study provides detailed experimental and numerical data on using nanofluids to predict solar collector achievement. Khullar et al. [18] studied the use of aluminium-based nanofluid in a concentrating parabolic solar collector. They found that using this nanofluid outcome in a 5–10% advancement in thermal efficiency compared to traditional concentrators. This suggests that nanofluids could be a promising enhancement for solar collectors, potentially increasing their energy efficiency.

Titan C. Paul et al. [19] investigated the use of NEILS in upcoming stage of solar collectors. They found that: thermal conductivity increased by about 5% with different base fluids and ionic concentrations. Al_2O_3 nanoparticles increased nanofluid heat capacity by 23%, and silica nanoparticles increased it by 26%. Convective heat transfer capacity improved by 20%. These results indicate significant enhancements in thermal properties and heat transfer capabilities, which could advance the efficiency effectiveness of solar collector.

Otanicar et al. [20] explored how nanofluids—containing CNTs, Graphite, and Ag nanoparticles can enhance the efficiency of Direct absorption solar collectors (DASC). They found that using these nanofluids can increase efficiency by up to 5%. They also studied the impact of particle size, noting that 30 nm graphite nanoparticles can boost efficiency by 3%, while 20-40 nm silver nanoparticles can increase it by 5%. Their work involved both experimental validation and numerical simulations to compare results. He and colleagues [21] demonstrated remarkable luminescence heat conversion at a 0.5% weight concentration of CNT/water nanofluids properties suitable for vacuum tube solar collectors. M. Faizal et al. [22] explored that using MWCNT nanofluids with flat plate solar collectors could potentially reduce their size by 37%.

3. RESULTS AND FUTURE SCOPE

Addressing climate change and securing a low-carbon energy supply are urgent concerns as global population and living standards rise. Scaling up terawatts of affordable sustainable energy is crucial, alongside strategies in order to lower CO_2 emissions. Future studies ought to prioritize understanding energy transfer mechanisms and advancing green energy technologies, particularly in solar thermal applications using nanofluids. In solar thermal engineering and other sectors, achieving higher heat transfer rates is critical. Nanofluids are important due to their potential to enhance coefficients of heat transmission in liquids under low pressure and high boiling points. This can lead to reduced pumping power requirements in solar collectors and other thermal applications. Nanofluid applications in solar energy, especially in solar thermal applications, are still in early stages and not yet optimized. Challenges like synthesis techniques, manufacturing costs, and nanofluid characteristics affect practical use. Future advancements in nanotechnology may address these hurdles, improving efficiency in solar energy applications.

Nanofluids are emerging as promising heat transfer fluids in solar collectors, offering potential improvements in efficiency for thermal engineering systems. However, research highlights both current hurdles and future opportunities to optimize their performance and address environmental considerations. Key obstacles to experimental work with nanofluids include particle agglomeration, stability issues, and concerns about the deterioration and rusting of heat-transfer apparatus. Enhanced numerical representations, like two-phase mixture models, are crucial for accurately simulating different solar collector applications. Recent studies emphasize that volume fraction and particle size are critical factors influencing the performance of solar collectors using nanofluids. Factors like weight %, volume percentage, and pH also play significant roles in nanofluid performance. Future research aims to explore nanofluids' potential in energy storage devices and high-temperature applications through theoretical and experimental analyses across diverse environmental and geographical conditions. This aims to optimize nanofluids for practical use in various thermal applications.

Researchers are exploring using nanofluids in solar collector technology applications at a fundamental level. There is promising potential for combining nanotechnologies with solar fuel to achieve clean and green energy goals in solar collector applications.

Nomenclature Abbreviations			
PAO	Poly-Alpha Olefins	CSP	Concentrating Solar Power
NCPSC	Nanofluid based Concentrating Parabolic Solar	DASC	Direct Absorption Solar Collector
DASC	Direct Absorption Solar Collector	CNT	Carbon Nano Tube
SWCNT	Single Wall Carbon Nano Tube	MWCNT	Multi Wall Carbon Nano Tube
NEILS	Nanoparticle Enhanced Ionic Liquids	PV	Photovoltaic

REFERENCES

1. *Choi SUS. Developments and applications of Non-Newtonian flows. ASME FED.1995; 66: 99-105.*
2. *Luque A, Hegedus S. Handbook of photovoltaic science and engineering. England: Wiley; 2003.*
3. *Aisankar S, Ananth J, Thulasi S, Jayasuthakar ST, Sheeba KN. A comprehensive review on solar water heaters. Renewable and Sustainable Energy Reviews. 2011; 15-6: 3045-3050.*

4. Patel HS, Das SK, Sundarajan T, Nair AS, George B, Predeep T. Thermal conductivity of naked and monolayer protected metal nanoparticles based nanofluids: Manifestation of anomalous enhancement and chemical effects. Applied Physics Letters.2003; 83: 931-2933.
5. Eastman JA, Phillpot, Choi SUS, Keblinski K. Thermal transport in nanofluids. Annu. Rev. Material. Res.2004; 34: 219-246.
6. Engy Elshazly, Ahmed A. Abdel-Rehim, Iman El-Mahallawi, Thermal performance enhancement of evacuated tube solar collector using MWCNT, Al_2O_3, and hybrid MWCNT/ Al_2O_3 nanofluids, International Journal of Thermofluids 17 (2023) 100260A.
7. Eastman JA, Choi US, Li S, Thompson LJ, Lee S. Enhanced thermal conductivity through the development of nanofluids. Materials Research Society Symposium Proceedings. Materials Research Society, USA. 1997; 457: 3-11.
8. Masuda H, Ebata A, Teramae K, Hishinuma N. Alteration of thermal conductivity and viscosity of liquid by dispersing ultra-fine particles (Dispersion of γ- Al_2O_3, SiO_2 and TiO_2 ultra-fine particles). Netsu Bussei. 1993; 7: 227-233.
9. Madhusree Kole, Dey TK. Viscosity of alumina nanoparticles dispersed in car engine coolant. Experimental Thermal and Fluid Science.2010; 34(6): 677-683.
10. Xuan Y, Li Q. Investigation on convective heat transfer and flow features of nanofluids. Transactions of the ASME, Journal of Heat Transfer.2003; 125: 151- 155.
11. Fotukian SM, Nasr Esfahany M. Experimental study of turbulent convective heat transfer and pressure drop of dilute CuO/water nanofluid inside a circular tube. International Communication of Heat Mass Transfer.2010a; 37: 214–219.
12. Y. Tian, C.Y. Zhao, A review of solar collectors and thermal energy storage in solar thermal Applications, Applied Energy 104 (2013) 538–553.
13. Tyagi H, Phelan P, Prasher R. Predicted efficiency of a low-temperature nanofluid based direct absorption solar collector. Journal of Solar Energy Engg.2009; 131: 041004.
14. Taylor RA, Phelan PE, Otanicar TP, Walker CA, Nguyen M, Trimble S, Prasher R. Applicability of nanofluids in high flux solar collectors. Journal of Renewable and Sustain Energy.2011; 3: 023104.
15. Li Y, Xie H, Yu W, Li J. Investigation on heat transfer performances of nanofluids in solar collector. Material Science Forum.2011; 694: 33–36.
16. Yousefi T, Veysi F, Shojaeizadeh E, Zinadini S. An experimental investigation on the effect of Al_2O_3-H_2O nanofluid on the efficiency of flat-plate solar collectors. Renew Energy.2012; 39: 293-298.
17. Yousefi T, Shojaeizadeh E, Veysi F, Zinadini S. An experimental investigation on the effect of pH variation of MWCNT-H_2O nanofluid on the efficiency of flat-plate solar collectors. Solar Energy.2012; 86: 771-779.
18. Khullar V, Tyagi H, Phelan PE, Otanicar TP, Singh H, Taylor RA. Solar energy harvesting using a nanofluids-based concentrating solar collector in: Proceedings of MNHMT2012 3rd Micro/Nanoscale Heat & Mass Transfer International Conference on March 3–6, Atlanta, USA, 2012.
19. Titan C.Paul, Morshed AKM M, Jamil A.Khan. Nanoparticle enhanced ionic liquids (NEILS) as working fluid for the next generation solar collector. Procedia Engineering, 5th BSME International Conference on thermal engineering.2013; 56: 631-636.
20. Otanicar TP, Phelan PE, Prasher RS, Rosengarten G, Taylor RA. Nanofluid based direct absorption solar collector. Journal of Renewable and Sustain. Energy.2010; 2: 033102.
21. He Y, Wang S, Ma J, Tian F, Ren Y. Experimental study on the light-heat conversion characteristics of nanofluids. Nanosci. Nanotechnol Letters.2011; 3: 494–496.
22. Faizal M, Saidur R, Mekhilef S. Potential of size reduction of flat-plate solar collectors when applying MWCNT nanofluid. 4th International Conference on Energy and Environment (ICEE 2013), Conf. Series: Earth and Environmental Science.2013; 16: 012004.