APPLICATION OF NANOFLUIDS IN DIRECT ABSORBING SOLAR COLLECTOR: A REVIEW

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ABSTRACT

Miniaturization of devices and energy efficiency are two major driving forces to find new materials and improved designs of solar collectors. Nanofluids are innovative fluids getting worldwide attention due to their inherent characteristics. Nanofluids exhibits enhanced heat absorbing and heat transport ability, credited to nanoparicles suspended in base- fluids. The cardinal factor which is responsible for enhanced heat transfer and absorption ability of Nanofluids is multiplication of surface to volume ratio of nanoparicles.

Nanofluids are nanoparicles suspended in a base fluids, it can be considered liquid nano-composites (homogeneous solution of suspended nanoparicles in base fluids).These Nanofluids are now being used as working fluids to absorb solar insolence and transfer it to another fluids at appreciably enhanced rate as reported by many researcher and nano research centers all over the world.

Our intention behind writing this review is to comprehensively and thoroughly investigate the research work done for improvement of efficiency in Direct absorbing Solar Collectors Using Nanofluids. Review of previous works based on experimental and model studies have established that nanofluids have great potential for cooling various thermal systems. Recent trends also encouraging towards application of nanofluids in PV/T systems to increase overall efficiency of solar energy conversion.

***Keywords*: *Nanofluids, DASC, Base-Fluid, Thermal Efficiency, Optical Depth*.**

I INTRODUCTION

Energy has been major driving force since beginning of civilization. Initially organic and manpower, cattle power were used to fulfill daily basic needs. Conventional resources like coal, water, natural gases, petroleum are being used to propagate the industrial era. Conventional (fossils based) resources still have major role to fulfill huge energy demand for industrial, agriculture and household sector. Conventional resources have its own limitations. These resources will be depleted by 2050 as predicted. These resources are major source of pollution on planet Earth. Since 1970s there has been academic, scientific and technological drive to harness new energy resources, which can replace existing natural resources. Solar energy is the most abundantly and reliable energy resource among all alternative energy resources available. It is also free from pollution and available throughout the year.

It is now generally believed that renewable energy technologies can meet much of the growing demand at prices that are equal or even lower than those of conventional energy. By the middle of 21st century, renewable sources of energy could account for 60% of the worlds electricity market and 40% of the market for fuels used directly[1]. Moreover, making a transition to a renewable energy-intensive economy would provide environmental and other benefits not measured in standard economic terms. It is envisaged that by 2050 global carbon dioxide (CO_2) emissions will be reduced to 75% of their 1985 levels, provided that energy is expected to be competitive with conventional energy [2] Solar radiation, which consists of high amount of energy, can conduct energy of sun to working fluid through photons (quanta of light) [3].

Major shortcoming of solar collectors is its low thermal conversion efficiency. Conventional heat transporting fluids are water or oil based has low heat absorption and heat transfer capacity. Nanofluids are new innovative fluids first postulated by Choi [1]. Nanofluids can be defined as homogeneous solution of nanoparicles of size 1 to 100 nm in base fluid. Nanofluids exhibits enhanced or modified thermo- physical properties. These are thermal conductivity, convective heat transfer coefficient, viscosity and thermal diffusivity compared to base fluids[4].addition of nanoparticle into base fluid can significantly enhances thermo physical[5-8] mass diffusivity [9] and radioactive heat transfer properties of fluid [10]. Volume % of nanoparicles in base fluid remains very small still impact in terms of thermal efficiency observed is very significant. Due to these inherent characteristics, Nanofluids are getting increasing attention among scientific, academic and engineers to develop improved systems and devices which are based on Nanofluids as a heat transporting and absorbing medium. Presently many types of nanoparicles are used to prepare Nanofluids. These are:

- Oxide ceramics (Al_2O_3, CuO,ZnO)
- Metal carbides (SiC, AlC)
- Nitrides (AlN. SiN)
- Metals (Al, Cu, Ag, Au, Mg, Zn)
- Nonmetals (Graphite, Carbon Nanotubes, Fullerenes)
- Layered (Al+Al_2O_3, Cu+C, Cu+CNT)
- Functionalized Nanoparicles.

II MATERIALS FOR BASE FLUIDS INCLUDE

- Water
- Ethylene glycol and other coolants
- Oil and other lubricants
- Bio-fluids
- Polymer based solutions

Addition of nanoparicles in very small volume % in a base fluid can amply enhance thermo- physical properties of fluid as reported by many research papers published in recent years [7-9, 11]. According to a recent research[12]. Nanoparticle volume fraction has significant effect on direct solar collector efficiency. Purpose of this review paper is to progressively analyze applications of various Nanofluids and its impacts on enhancement of thermal efficiency of solar collectors**.**

III PERFORMANCE OF SOLAR COLLECTOR: PARAMETERS

3.1 Stability of nanofluids

Stability of nanofluids means that fluid must retain its basic nature during operating period. Its composition (distribution of nanoparticle in base fluid must not vary with time).Though nanofluids are highly stable compare to micro-fluids still long term stability is an issue of concern for researcher. For commercial use of nanofluids to be applied in heating and cooling systems, long term stability must be addressed.[9]

3.2 Convective heat transfer coefficient

convection is a mode of heat transfer in which heat transfer from solid body is affected by fluid flowing in vicinity of body. Convection can be broadly categorized into two modes: forced convection and natural convection.

3.3 Optical Properties

Our concern for optical properties of nanofluids is those, which are useful to absorb solar radiation. Nanofluids having higher value of extinction coefficient will be more suitable for solar collectors, particularly in volumetric receivers (DASCs).

Otanicar et al.[13] experimentally investigated the optical properties of four fluids (H_2O, propylene glycol, ethylene glycol, and therminol VP-1). These are conventional base fluid for volumetric receiver or DASCs. Measured transmittance spectra of all four fluids exhibits strong absorption bands at 950-1000nm and at 1200 nm for water, EG and PG. A significant amount of solar energy is concentrated in the visible band (300-700nm). In addition it has been observed experimentally that water as base fluid is the strongest solar energy absorber, still not strong enough to absorb more than 13% of incident solar energy. According to researchers findings to increase solar –weighted absorption coefficient to more than 90%, the fluid depth should increase to 1 m or larger.

Based on the literature survey, absorption of the incident radiation increases within the fluid by mixing small particle into the base fluid [13]. If small paricles are nanoparticle, optical properties of base fluid enormously increases[14].

IV REVIEW OF APPLICATIONS OF NANOFLUIDS IN SOLAR COLLECTORS

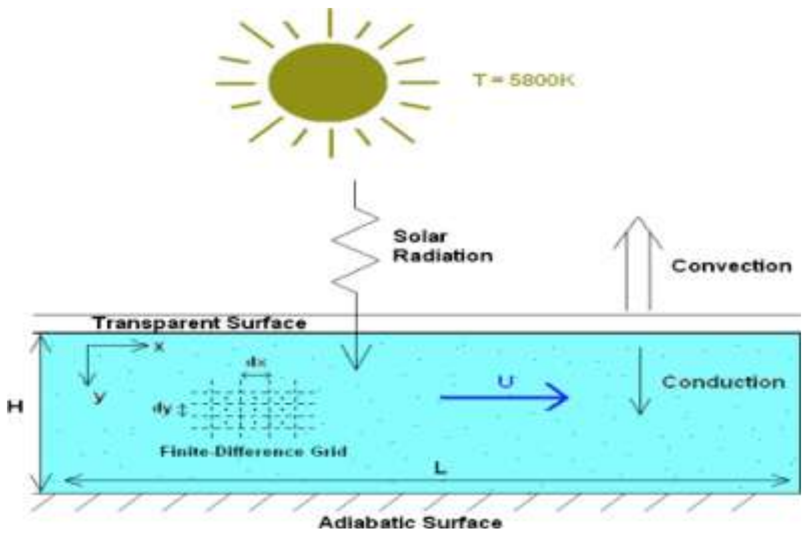

Fig:1 schematic of DASC based on nanofluid Tyagi et al.[9]

Thermal performance of the solar collector is determined by getting values of instantaneous efficiency for various combinations of incident radiation, ambient temperature and inlet fluid temperature.

Tyagi et al.[9].performed model study of DASC using two dimensional heat transfer analysis. He selected mixture of aluminum nanoparticles and water. Various parameters which affect thermal efficiency are size, volume fraction, and collector form studied by authors. On the basis of numerical modeling results shows 10% increase in thermal efficiency of nanofluid based DASC compare to conventional solar collectors of same type.

Spectral efficiency decreases as we go from top to bottom of nanofluid as shown in fig below

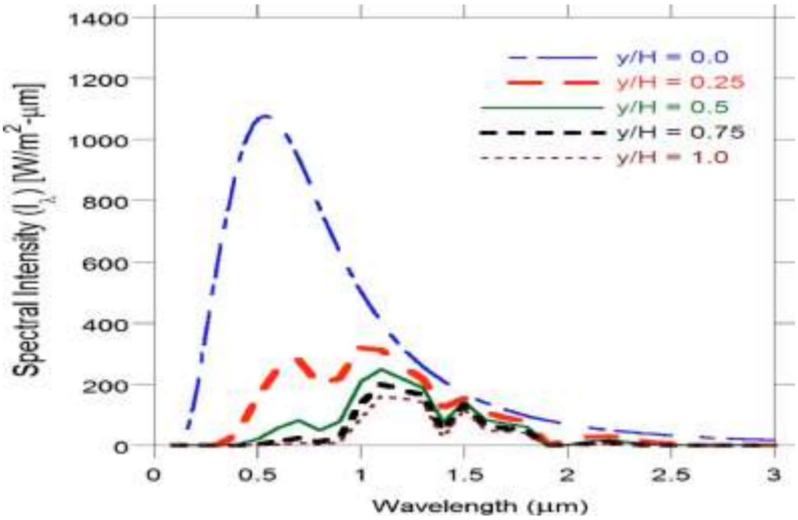

Fig: 2spectral efficiency v/s depth of nanofluid filled in collector. Tyagi et al.[9]

Collector efficiency increases with volume fraction Φ up to optimum level around 1% then become saturated.

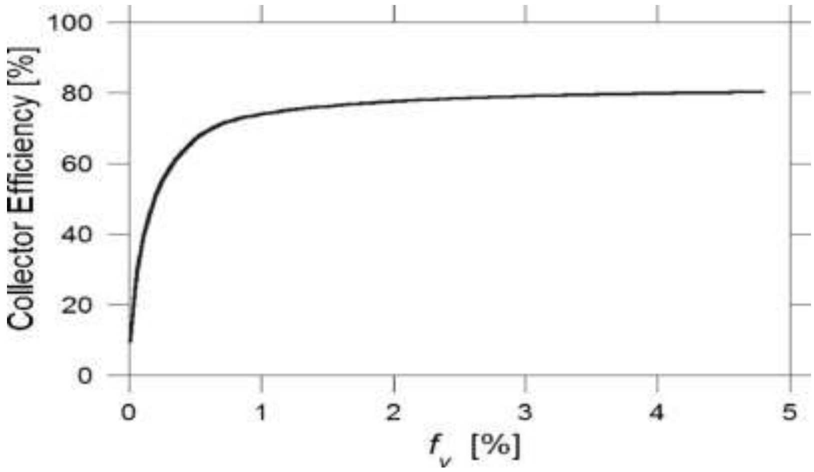

Fig: 3 graph between volume fraction and collector efficiency. Tyagi et al.[9]

Taylor et al.[15].Performed both experimental (design of dish collector system) and model study of nanofluid in high flux dish collector. Representative nanofluid selected is Therminol based graphite nanoparticles. (φ=0.125% to 0.25%). CR for dish collector is 400.Results shows that nanofluid dish collector attained 34% solar-to-thermal conversion efficiency at outlet temperature 250°C, which is 20% higher than when Therminol alone used as heat transfer fluid.

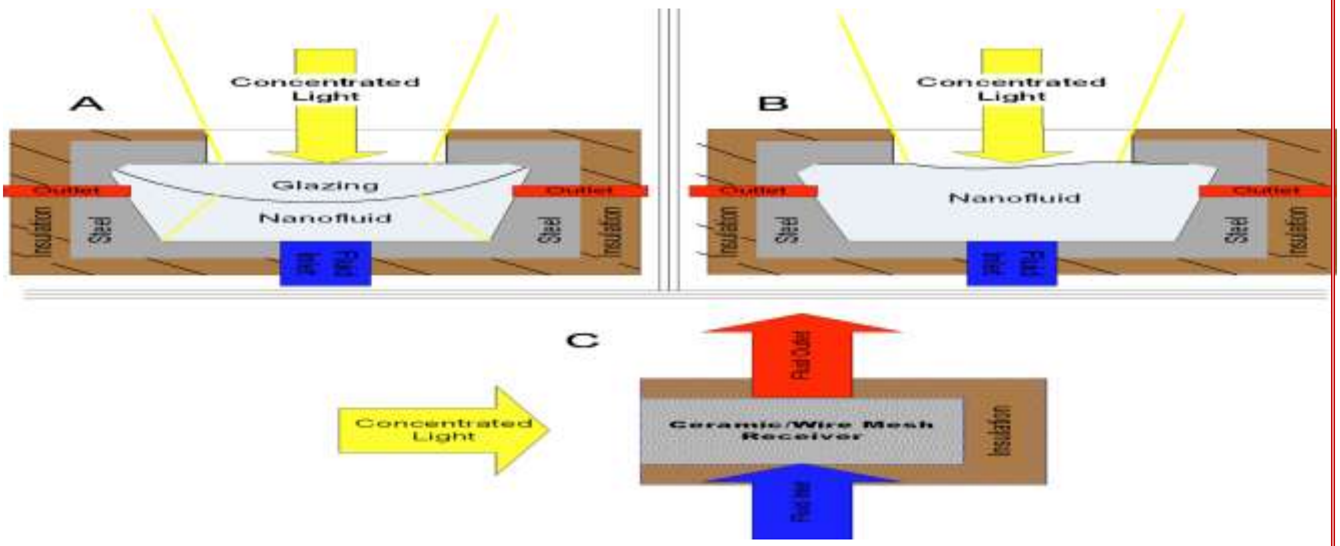

Fig: 4 A and B conceptual design of solar concentrating collector with glazing and without glazing. C conceptual power tower drawing with solid surface absorber. Taylor et al.[15]

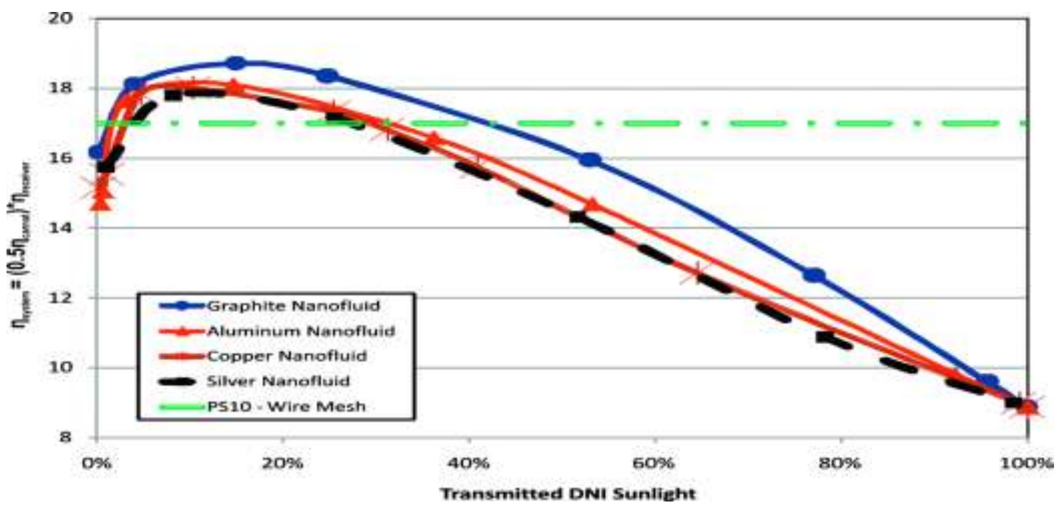

Fig:5 modeled system efficiencies with graphite,aluminium,copper and silver nanofluid in comparision with PS10 wire mesh.[15]

Said et al.[16] experimentally analyzed thremophysical properties of Al_2O_3 nanofluid and concluded that thermal conductivity significantly enhanced at very small volume fraction and viscosity marginally increased which is not desirable. For low concentration pumping power enhancement and pressure drop have insignificant effect on thermal efficiency. Authors suggest further research to establish thermal conductivity behavior at low temperature range.

Han et al.[17]. Performed experimental study on carbon black nanofluid for solar energy absorption. Results shows that nanofluid of high volume fraction had improved photo- thermal properties in the whole wavelength range from 2000 to25000 A°

Alim et al.[18] analytically applied second law of thermodynamics to analyze formation of entropy due to application of nanofluid in solar collectors. Investigators reported decrease in entropy formation by 4.34% and enhancement of heat transfer coefficient by 22.15%. There also small penalty in terms of pressure drop by 1.58%.

Ladjevardi et al.[19]performed analytical study on effect of particle size and volume fraction on efficiency of DASC.It has been observed that increase in particle size from 50nm to 300 nm enhances extinction coefficient from 0.4-to 10 in UV and visible ranges. At =0.00025 outlet dimensionless temperature increases from 0.27 to 0.915 compare to pure water.

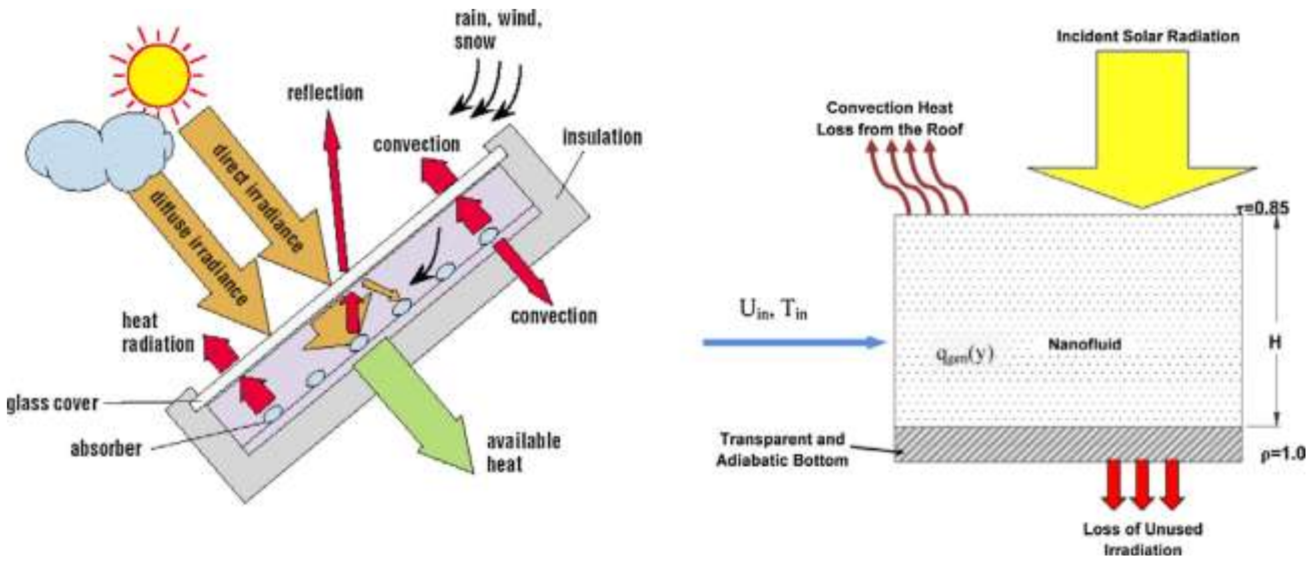

Fig: 6 conventional (left) and volumetric (right) solar collectors. Ladjevardi et al. [19]

Parvin et al.[20] have done mathematical modeling and analysis on effect of Cu and Ag nanoparticles on entropy generation and thermal efficiency. Results reveals that Cu nanoparticles with highest R_e and φ=3% is the most effective fluid to enhance heat transfer rate. The collector efficiency enhances 2 times and more than two times for increasing Reynolds number and solid volume fraction with Ag and Cu nanoparticles.

Karami et al.[21] performed experimental research on application of CNT-fluid as energy absorbing fluid for low temperature DASCs. Nanofluid made of MWCNTs-10nm diameter and 5-10µm length properly dispersed in distilled water. Research findings established that improvement in thermal conductivity is 32.2% for 150ppm of f-CNT.

Lu et al.[22].experimentally performed an open thermosyphon using nanofluid. Nanofluid was based on demonized water and Cu nanoparticles (size mean dia 50 nm).optimum efficiency 30% in terms of heat transfer coefficient enhancement observed at evaporator filling ratio 60% for Φ=1.2%.

Said et al.[23]. Performed experimental analysis on application of SWCNTs base nanofluid on exergy efficiency and pumping power for conventional flat plate solar collectors. Material chosen in experiment is (90% CNT with 60% SWCNTs, 99.5% TiO_2, SiO_2 99.5%, and Al2O3 99.8%). Experimental results confirm that SWCNTs may be a good option in laminar flow condition. Analytical results confirm that SWCNT based fluid can arrest entropy generation by 4.34% and augment heat transfer coefficient by 15.53 % theoretically with compare to water. He et al.[24] Experimentally investigated on photo thermal properties of nanofluids for direct absorption solar thermal energy systems. For Cu-H_2O based absorbing fluid, experimental results shows that small addition of nanoparticle in base fluid can widen solar energy absorption spectrum. Nanoparticles exhibit excellent absorption characteristics. It makes the transmittance of nanofluid lower in the range of 250-1350nm wavelength. The transmittance of Cu-H_2O nanofluid (0.1%) is closer to zero and temperature increase observed 25.3% higher than de-ionized water. Luo et al.[25] performed analytical simulated study on performance improvement of a nanofluid solar collector based on DAC concept. Based on results of simulated study authors concluded increase in outlet temperature 30-100k and efficiency by 2-25%.Filho et al.[26]. Experimentally investigated effect of Ag/water nanofluid in direct absorption solar collectors. Stable formulation of Ag/water was prepared by high pressure homogenizer. Results established that up to 144% enhancement in stored thermal energy can be achieved for an extremely low concentration (6.5ppm). Size of Silver nanoparticle taken 10- 80 nm, average 20nm. Specific absorption rate up to 0.6kw/g obtained during initial heating period for 6.5ppm, but decreases to 0.01 kw/g at 650 ppm due to enhanced particle-particle interaction. Tiwari et al.[27] reported 31.64% enhancement in thermal efficiency when Al_2O_3/H_2O nanofluid used as heat absorbing fluid in place of pure water at $\varphi =$1.5%. Rahman et al.[28].Investigators has tried to introduce innovative design of quarter circular plate DASC with variable tilt angle and solid volume fraction of CNT nanofluids. Further research needed to establish compatibility of CNT based nanofluid with new design. Rahman et al.[29]performed theoretical model based study of impact of triangular collector design and Φ on convective heat transfer coefficient (h). Nanofluids are based on Cu/Water, Al_2O_3/Water and TiO_2/Water. Model mathematical solution shows that convective heat transfer increases up to a certain optimum value of φ (0.05 to 0.08). h also increases with increase of G_r.

Zhang et al.[30].performed experimental study on radiative properties of [HMIM] [NTf2] as base fluid and Cu and Ni nanoparticles (D mean 40nm).observation revealed that for φ=40ppm, only about 3% of light transmitted in whole wavelength range. Excellent radio property of Ni/C Ionanofluid qualifies it for promising heat absorbing material for medium to high temperature DASCs.

Table:1 Research perspective of use of Nanofluids as heat transporting and absorbing medium in DASCs for improvement in thermal efficiency

S. No	References	Types of nanoparicles	Size (nm)	Base fluid	Applications	Findings
1	Tyagi et.al [9]	Al	10 -20	Water	Direct absorption solar collector	10% higher absolute efficiency for 0.8% volume fraction than conventional flat plate collector
2	Lenert et al.[31]	Co	28	VP-1 Therminol	Volumetric receiver(DASC)	With increase in nanofluid height and solar insolence efficiency of receiver increases. Optimum increase in system efficiency achieved is 35% for H>5cm and c-100
3	Otanicar et al.[15]	CNT,Graphite and Silver	Graphite 30,CNT(6 -20),Silver	H_2O	Direct absorption solar collector	Increase in efficiency of solar collector recorded is 5%

			(20-40)			
4	Taylor et al.[15]	Any nanoparticle	Nano range	Common base fluid i.e. water, molten salt, oil	Modeling and experimental study for commercial application of nanofluids(10-100MWe)	10% increase in efficiency of high flux solar collector is achievable at very small concentration of nano-particles in base fluid without any adverse change in capital cost
5	Lazdevardi et al. [19]	graphite	50-300	Pure water	Volumetric receiver(direct absorbing) collector	For 0.000025% volume concentration, increase in solar radiation absorbance from 27% to 50%
6	Parvin et al.[20]	Cu	Not given	Water	Direct absorber collector	Simulation study, collector efficiency increases about two fold with increase of Reynolds no from 200 to 1000 at volume fraction 0.03
7	Filho et al.[26]	Ag	10-80 nm	H_2O	DASC	SAR achieved 0.6kw/g for 6.5ppm and decreases to 0.01kw/g at 650ppm, probably due to enhanced particle to particle interaction
8	Zhang et al.[30]	Carbon coated Ni nanoparticle	40 mean dia	Ionic liquid(HMIM)	Direct absorption solar collector to study radiation absorption ability	Volume fraction varied from 10ppm to 40ppm, radiation absorption reaches up to 100% for 1cm deep penetration of solar radiation. Recommended as absorber especially in medium-high-temperature DACs.
9	Qinbo et al. [24]	Cu	H_2O	30 mean dia	Transmittance analyses of nanofluid	Experimental results shows that transmittance of Cu-H_2O nanofluid is much less than that of demonized water and also decreases with increasing particle size, mass fraction and depth of penetration. highly suitable for DASCs

V CONCLUDING REMARKS

Review based on previous works establishes that by applications of nanofluids in solar energy systems, thermal conductivity, heat transfer rate, and optical absorption characteristics can be enhanced. Large number of experimental and mathematical model based studies has been performed. It is unanimously accepted that nanofluids have ability to enhance overall thermal efficiency of solar and thermal energy systems.

It is desirable to do further research work to find nanomaterials to increase surface absorption capability of absorbing plate of flat plate collector in order to further increase thermal efficiency of collector.

Lot of mathematical model studies has been performed in application of nanofluids for volumetric receivers working as DASCs. More experimental work still required along with focus on optical property of nanofluids. Nanofluids having higher extinction coefficient are preferable for DASCs.

More focused research work is needed in field of Brownian motion of particles, dynamic properties of nanofluids, mechanism of agglomeration and methods to increase stability.

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