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Performance evaluations of Concentrated Solar Thermal Power Technology

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Abstract

This review work consists of detailed description on various types of research in the field of solar thermal systems and various methods to improve the performance of the collector systems. Concentrated solar thermal systems are the highly advanced and large scale technology, which is used to generate the thermal energy and converted it in to electric energy through the application of power producing device coupled with the collector systems, therefore from the research point of view improvement in the working performance of the solar thermal system is highly important to achieve the better efficient device.

1. Introduction

Solar energy is a renewable and green resource of energy. Solar energy has several advantages over other alternative or renewable energy sources. All the primary or conventional energy resources are continuously depleting the environment of earth and are giving harmful effect to human health. Among all alternative sources of energies solar energy has great potential and India receives great amount of solar energy as compare to many other developed countries throughout the year. Concentrated solar thermal power is the most prominent and highly proven technology, which is used to generate electric power on large basis. Concentrating collectors are also known by focusing type collectors. Radiations coming from sun are falling on the collector and concentrating on the absorber area by reflected through mirrors. Continuous falling of radiations on receive per unit area can increase the temperature of receiver or absorber surface of collector. There are some losses which also accounts in the working mechanism of concentrating solar collectors and those losses are reflection losses from mirror and energy absorption losses on concentrating surface i.e. absorber copper tube. There are some advantages of concentrating collector over flat plate collector like achievement of higher temperature in receiver tube, which results in higher thermodynamic efficiency and further requirement of material in concentrating collectors are also less as compare to non concentrating collector due to which cost reduction in fabrication of solar concentrating collector can be achieved. Solar concentrators can be classified in different ways or methods. Solar concentrators can have reflecting surface or refracting type surface and it completely depends upon the concentrating device used to concentrate the sun's radiation on the absorber surface, reflecting surface are further classified into flat, spherical or parabolic type. Solar concentrators can be of imaging and non-imaging concentrators and further imaging type can be classified into line or point focussing solar concentrators. Concentrator's classification also depends upon the amount of temperature requirement for various applications. High concentration ratio means achievement of high temperature. Efficient working of concentrating collector also depends upon adopted tracking mechanism. Tracking can be done on intermittent and on continuous basis. Further tracking can be possible about one axis and two axes also. Flat plate collector along with mirror adjusted at edges has a capability to reflect and concentrated solar radiation on collector's absorber plate. It has low concentration ratio approximately unity, can achieve higher temperature as compare to flat plate collector alone. Compound parabolic concentrating collector have curved parts of two parabolas, it is also a type of non-imaging collector. This type collector possess moderate concentration ratio for e.g. 3 to 10. Apart from these advantage of compound parabolic collector having higher acceptance angle, which means that collector are adjusted on occasional basis. Another important type of collector known by cylindrical parabolic collector, sun rays are concentrated or image formation on the focal axis of the parabolic collector. Lenses are also used to concentrate sun light like Fresnel lens. Line concentrating collector like cylindrical, Fresnel lens having concentration ratio vary from 10 to 80 and range of temperature achieved between $150°C$ to $400°C$. Point focussing collector like parabolic dish collector can achieve higher concentration ratio and temperature as compare to line focussing collector and point focussing collector can achieve concentration ratio from 100 to 1000 and temperature up to approximately $2000°C$. For concentration of high amount of energy on a point, a new concept called as central receiver has been used on a large scale in the world. In this type of concentrating system a large number of mirrors also known as heliostats are used to concentrate the sun light on the central receiver which is situated at the top of tower [16].

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2. Literature Review

[1] Jan Fabian feldoff et al. (2012) conclude that Level zed Electricity Cost of a Direct Solar Generation plant

could be higher than that of synthetic oil plant and both the power generation systems have a 100 MWe gross turbine and a 9 hours storage capacity. They also conclude that without the application of thermal storage system, the Direct Solar Generation plant could show lower Level zed Electricity Cost. They analyze both synthetic oil power plant with molten salt two tank storage system and Direct Solar Generation system uses phase change material. It has been seen that application of Thermal Energy Storage influence the cost of Direct Solar Generation plant up to very high level. Therefore investment cost is higher about 10% and efficiency is about 8% better and finally they concluded that direct solar generation have higher levelized electricity costs are about 6%, which is due to the specific solar field costs and thermal storage costs. [2]Xiang-Qi Wang et al. (2007) conclude that with the change in geometry of flow, boundary conditions and by enhancing thermal conductivity of fluid, convective heat transfer can be increased. They describe that nano fluids also has capability to enhance heat transfer or thermal characteristics as compare to liquids, base or conventional fluids and superior in thermo physical properties as compare to mixture containing micro particles with base fluid. They also conclude that due to suspension of any type of nano particles, surface area can be enhanced and results in increase in amount of thermal conductivity of working fluid. Wang et al use the method of steady state parallel plate for measurement of the thermal conductivity of nano fluids. Suspension of Al_2O_3 and CuO nano particles with average diameter of 28 and 23nm in base or conventional fluids (like H_2O and ethylene glycol ($C_2H_6O_2$)), they evaluate from experimental results that nano fluids posses' higher amount of thermal conductivity than base fluids and also evaluate that thermal conductivity can be increased with decreasing of particle size. It has been seen that thermal conductivity of suspended carbon nano tubes can show higher thermal conductivity among all other nano particles and CNT also have very high aspect ratio. [3] Soteris A. Kalogirou et al. (2004) They discussed about different type of solar thermal collectors like flat plate, compound parabolic solar thermal, cylindrical parabolic or parabolic trough (PTC), Fresnel lens reflector system (LFR), parabolic dish and heliostats for different applications like water and space heating and cooling also, industrial heat process and also in thermal power plants. Further they also analyze the effect of using conventional fuel sources on environment of earth, which is associated with the Problem (like pollution), they also analyze that Industrialization is also a big cause for degradation of environment. They gave the brief description on solar energy collectors and its different types. Solar collector is an instrument used to extract the sun's energy from incoming solar radiations, this energy convert directly into heat or thermal energy and further this heat or thermal energy transfer to fluid like water following through collector system. Basically two type of solar collector are available like Non concentrating and concentrating collector, apart from this solar collectors are further classified according to motion like stationary collector, single axis collector and two axis collector. [4]T. Yousefi et al. (2012) they examine the effect of variation in pH of MWCNT-H_2O based nanofluid on the flat plate collector's efficiency experimentally and they take volume concentration 0.2 wt. % MWCNT with the application of Triton X-100 and also with various pH values, 3.5, 6.5, and 9.5. They concluded from the ASHRAE standard that increasing or decreasing the pH values with respect to the pH of isoelectric point, the efficiency of solar collector can be increased. [5]R. Saidur et al. (2012) they examine the effect of nanofluid on the performance of direct solar collector by using nanofluid as a working fluid. They investigate about extinction coefficient of Al-H_2O nanofluid has been experimentally and they found that particle size has minute effect on the optical properties of nanofluid. They observed enhancement in optical and thermal properties due to the use of nanofluids as volumetric absorber in Direct Solar Generation system. They finally conclude that water behaves like a transparent for incoming visible light but it has a greater absorption capacity at longer wavelength and Aluminum nanoparticle showed high extinction coefficient at small wavelength. On the contrary a lower extinction coefficient possessed longer wavelength, therefore for this reason aluminum nanoparticle can be used to increase absorption ability of water at the visible and small wavelength of light. [6]Alibakhsh Kasaeian et al. (2015) they describes the ways to enhance the working performance of solar parabolic trough collector system. For the purpose of investigation or inspection they employed four different types of receivers like evacuated steel tube with painted black, bare copper tube with painted black, non evacuated copper tube with glass envelop along with painted black and evacuated copper tube with painted black to examine and compare the optical and thermal efficiency of solar parabolic trough collector system. They take Volume concentration of nano particles is decided as 0.2% and 0.3% in oil base fluid for preparation of the working fluid for testing of these four different types of receiver. Finally they conclude from research work that efficiency of evacuated tube shows 11% higher than the bare tube efficiency due to convection losses and also conclude that time response is an important factor for evaluation of performance because it tells us that how much time needed by the system to stabilize it. It has been seen that evacuated copper tube showed greater time response due to minimum heat loss as compare to heat losses in evacuated steel tube with painted black due to radiations. They observed that efficiency of solar trough collector system with volume concentration 0.2% and 0.3% can be enhanced 4-5% and 6-7% with the help of MWCNT and mineral oil based nano fluid as comparison to efficiency achieved from pure oil only. It has also been found that black coated copper tube possesses high absorptive and thermal conductivity. [7]Nor Azwadi Che Sidik et al. (2014) this paper is review study, which is concentrated on methods to prepare the nano fluids along with challenges due to nano fluids. They describe all methods of preparation given by different investigators or researchers. They conclude that metallic and non metallic particles can be used to fabricate nano particles. They also describe the synthesis process for nano fluids along with characterization of nano fluids. They also includes some challenges comes in the synthesis process. Further they found that non metallic particles like silicon dioxides, titanium dioxides, aluminium oxide, iron oxide, aluminium nitride and carbon nano tubes. Further metallic

particles like gold, silver and copper can be use for fabrication of nano fluids. They also concluded that effect on properties like thermal conductivity of nano particles, Brownian motion of particles, thermo physical properties along with change in temperature are due to factors like poor dispersion or suspension of nano particles and lack of knowledge in understanding of mechanism that all are responsible. They also observed that increasing concentration of nano particles results in viscosity increases; this became also a challenge due to more requirement of pumping power to operate the system. They noticed that thermal conductivity of pure metallic particle based nano fluids will be higher as comparison to nano fluid containing oxide nano particles and also noticed that nano fluids posses less specific heat as comparison to base fluids. Further they observed that viscosity of nano fluids generally higher than the base fluids and it depends upon type of particles and also depends upon particle volume concentration. They also evaluate that homogeneous and stable dispersion of nano particles in conventional fluid are always a challenge for investigators. They conclude in his review study that preparation of nano fluids is followed by three common methods like sonication, PH control and surfactants. Cost comes on synthesis of nano particles and stability of nano particle in base fluid; both are the major factors that prevent the use of nano fluid on commercial basis. [8]Zhongyang Luo et al. (2014) they construct a simulation model of solar collector using nanofluid based on concept of Direct absorption collector by understanding the radiative transfer equations of particulate media and by combining both conduction and convection heat transfer. They concluded from the results of simulation model that nanofluids improved the outlet temperature by 30–100 K and system efficiency by 2–25% than the base fluid flowing through the system. They also found that photo thermal efficiency of graphite based nanofluid with 0.01wt% flowing through a coating absorbing collector is measured 122.7% and they finally conclude that nanofluids with in small concentration have a good ability to absorb the solar radiation, and also has an ability to improve the outlet temperatures and efficiency of system. [9]John Philip et al. (2012) they describe the developments and advances in the field of nano fluids applications and also they found their effect on the thermal characteristics of nano fluids. They gave an approach to achieve better thermal conductivity of nano fluids or heat transfer fluid. Enhancement in k is due to weight fraction of nano particles in base fluid like in water and ethylene glycol/MWCNT based nano fluid showed an increase in 'k' with an increment in $'\varphi'$. Water based CNT describe a non linear behavior between k and φ. They also found that thermal conductivity also affected by size of nano particles like dispersion of Al_2O_3 nano particles in water with different diameter i.e. 20, 50 and 100nm determine an increment in thermal conductivity with the reduction in the size of nano particles. It has been seen that 'k' for Al_2O_3 in water and E.G. based nano fluid increases with the reduction of size of nano particles. Apart from this some kind of nano fluids showed different characteristics and behaviour like SiC and water based nano fluid with different diameters of 16, 29, 66 and 99nm determine an increment in 'k' with an enhancement in size of particle. It has also been seen that in metallic dispersion like gold nano particle in water based nano fluids determine a decrement in 'k' with decrease in size of particle within the range of 2 to 40nm. Metal nano fluids like Cu with particle diameter 80nm dispersed in water and E.G also show an incremental change in 'k' with an enhancement in temperature. Ag in water based nano fluid show an incremental change in 'k' approximately 3.2% at 30℃ temperature and increment of 4.5% at temperature 60 ℃ at volume concentration 0.001%. Water based Al_2O_3 with diameter 36nm showed an increment in 'k' at temperature range between 2 to 50℃. For MWCNT and water based nano fluid showed an enhancement in 'k' is independent on the temperature at low concentration of MWCNT. Some nano fluid like TiO_2 with diameter 21nm and water based nano fluid show and decrement in 'k' with increment in temperature over a range of 15-35℃. In CNT and water based nano fluids an increment in 'k' with length of the nano tubes like at $0.5\mu m$ length of nano tube increment in 'k' was estimated to 14% and 45% increment was estimated in 'k' with length of 5 μm. The incremental behaviour of 'k' was found to be increased with increase of aspect ratio of nanotubes in water based CNT nano fluids. Water based nano fluid also show less enhancement in k as compare to E.G based nano fluids. To maintain the stability of nano particles, there is a requirement of surfactants, because they prevent the agglomeration of nano particles. SEM results show that water based CNT show reduction in 'k' with increase in ultra sonication time due to the reduction in the length of the nano tubes, while in E.G based CNT show an incremental change in 'k' with increase in ultra sonication time. They described that some change in temperature can become a cause of large error in thermal conductivity, apart from this agglomeration and settle down of nano particles in base fluid can affect to the results of experiment. [10]G.C. Bakos et al. (2001) They concluded from Simulation results that variations of parabolic trough collector's efficiency is a function of some important parameters like heat transfer fluid, pipe diameter, intensity of solar radiations as well as exposed area of the collector and it has also been seen from the results that with increase of flux of heat transfer fluid, there is a noticed incremental change in efficiency. However they also noticed that flux of flowing fluid cannot increase continuously because of decreasing solar flux with the change in time due to this decrement shown in temperature of fluid. Further with the increment in pipe length there is an effective decrease in efficiency value. [11]Tooraj Yousefi et al. (2012) they performed an experimental study with Al_2O_3-H_2O nano fluid as working fluid is used for investigate the efficiency of flat plate collector. They decided to take Volume fraction or concentration of nano particles as 0.2wt% and 0.4wt% with the particle diameter of 15nm along with the application of surfactant Triton X-100. Selective mass flow rates are 1, 2 and 3Lit/min. they found from results that nano fluid show an enhancement in efficiency as comparison to water. They concluded that heat removal factor (F_R) value for nano fluid is 0.6194 and 0.6086 with and without surfactant. They also concluded that adding surfactant into nano fluid has a positive effect seen on the efficiency of flat plate collector. It has also been seen that efficiency of flat plate collector increasing

by increase in mass flow rate. Results from performed experiments concluded that efficiency enhancement in collector is 28.3% at 0.2% weight fraction of nano particles along with the 15.63% efficiency enhancement with the application of surfactant due to enhancement in heat transfer. [12]K. Vignarooban et al. (2015) they found the effect of different types of heat transfer fluids available like air, water and thermal Oils, organic fluids, molten-salts and liquid metals etc on solar thermal collector system components. They concluded in his review study that it is highly important to evaluate the stability of used stainless steels and nickel based alloys for piping and container materials because heat transfer fluids, while flowing through the piping system show high impact on these materials and stability of these material while in contact with heat transfer fluids is very important from research point of view for the long life of concentrating solar power systems. [13]Gianluca Coccia et al. (2015) they found that industrial process heat applications ranging from 70 to 250DegC has been possible by the manufacture of low-cost parabolic trough collectors (PTCs), therefore in this construct a prototype of PTC with a 90Deg rim angle and a small concentration ratio of 9.25 built along with Fiberglass is used as the external shell and polystyrene used for inside fill component. They used receiver is of circular cross section and made up of aluminum, which is covered or evacuated with glass envelope. They also used the application automatic tracking system, which is based on a solar-position computer program. They evaluate the main features of prototype are its less cost, low weight and ease of manufacture. [14] J. Paetzold et al. (2014) they concluded that flowing wind is greatly affect to performance of parabolic trough collector system. They also concluded that increasing concentration ratio, results in higher temperature achieved from receiver tube and concentration ratio is also increased due to increment in aperture area. They found that heat losses by convection increased due to high wind speed flowing over the collector. They evaluated data from the series of test performed in wind tunnel and also from previous research work related to PTC. They performed total 17 types of simulation for every geometry of parabolic trough by using CFD program with variable parameter i.e. depth of trough system with the variation in pitch angle i.e. -90° to 90° also with an increment of 15°. They evaluate that high quantity of aerodynamic forces and larger vortex are formed on backside of of trough, when pitch angle posses higher value above 15° and smaller from -60°. Forces exerts on PTC collector affect to the working performance of solar PTC system. It has been seen that with incremental change in depth of trough, results in incremental change in aerodynamic forces also measured in the PTC system. [15]Harwinder singh (2015) performed an experimental study on the prototype of parabolic trough collector using MWCNT based nanofluid. He takes different volume concentrations of 0.01% and 0.02% along with different volume flow rates i.e. 160L/h and 100L/h. He also evaluates the thermo physical properties of MWCNT based nanofluid theoretically and he compared the thermal performance due to water and MWCNT based nanofluid, while used as working fluid in parabolic trough collector system. Finally he concluded that MWCNT based nanofluid at 0.02wt% and at 160L/h showed higher thermal performance as comparison to other fluids at various concentrations and volume flow rates.

3. Outcome from Literature/ Research Gap

1 Nano fluid has an ability to show higher efficiency along with high outlet temperature, while working as a working fluid in solar thermal collector.
2 Phase change material can be used for thermal storage for a long period.
3 Agglomeration of nano particles can be avoided by using surfactants and by sonication method.
4 pH value of nanofluid highly affect to the efficiency of collector system.
5 Top covered along with different receiver materials and selective receiver coating has an ability to increase the life of reflecting surfaces and also help to minimize the heat losses from the receivers.
6 It has been studied that low cost parabolic trough collector system can be used for industrial process heat applications.
7 Efficiency of solar thermal collector highly depend upon various kind of working fluid used like conventional, micro fluid as well as nano fluid and further efficiency also depend upon the parameter of the collector design along with tracking mechanism i.e. automatic or manual. It has also been seen that size of nanoparticles, viscosity of fluid and thermo physical properties if nanofluid has a high impact on the collector performance.

4. Objective of Research Work

1. Evaluation of the performance of concentrated solar thermal collector on commercial basis with the help of various types of fluids with different volume flow rates and at different concentration and further comparison between the results outcome from the collector system theoretically and experimentally later.
2. Evaluation and comparison of the performance by using different receiver material and different glazing materials for solar concentrator.
3. Storage capability of the solar thermal power plant for the storage of heat for the usage of non sun shine hours can be increased by the phase change materials.
4. Various types of evacuation tubes around receiver and metal glass seal at the end of the receiver can be used for the prevention of heat loss from the receiver. Further insulated material can be used to prevent the heat loss from the pipes in which fluid is flowing.
5. Evaluation of the various thermal properties of various fluids used as a working fluid like thermal conductivity, viscosity, density along with the evaluation of various flow parameters, which are responsible for better thermal performance of collector during their working in the system

5. Experimentation & Data Collection

This section is deals with the experimental as well as theoretical data, which comes out from the evaluation of performance of solar thermal collector system by using different fluids and different collector receiver material along with different type concentrator glazing. Further this section also contains the experimental results for the

different types of storage medium used for increasing the heat storage capability of the thermal power plant and it will be discussed later in brief. This section includes the results of experimental study, which is based upon the analysis of parabolic trough collector system using nanofluid [15].

1. Some results are concluded during the experimental study, which was held on PTC prototype in Thapar university and finally evaluates that thermo physical properties of MWCNTs based nano fluid far expressive than base or conventional fluids like water, ethylene glycol. Further it has also been seen in this study that MWCNT and water based nano fluid with volume concentration i.e. 0.01% and 0.02% showed less value of important thermo physical properties specific heat and density. While thermal conductivity of MWCNT based nano fluids is always seems to be higher than water at the decided concentration.
2. It has also been seen that useful heat gain by nano fluid and water, while used as working fluid in collector system is fully dependent upon the volume flow rate, specific heat and also upon temperature difference measured during experimental working. It has also been observed by the author of thesis that in case of nano fluid mixture highest dominant factor is temperature difference, which is dependent upon incoming solar intensity throughout the experimental time and higher solar intensity results in higher amount of temperature difference. It has been concluded from figure that nano fluid mixture with 0.02% volume concentration and at 160L/h volume flow rate showed maximum useful heat gain overall among other fluids [15].

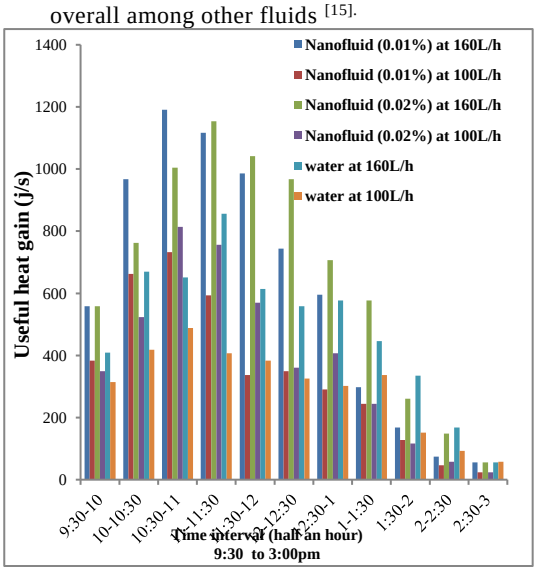

Fig: 1. Experimental variation in useful heat gain by nano fluid and water at different conc and volume flow rates [15]

3. Experimental work concluded that obtained maximum value of instantaneous efficiency for MWCNT based nano fluid mixture at 0.01% and 0.02% vol. concentration and at 160L/h volume flow rate is 96.49% and 96.46%[15]. It has been observed during experimental work maximum instantaneous efficiency possessed by nano fluid mixture with 0.01% and 0.02wt% at 160L/h volume flow rate among other fluids. It has been also been observed from experimentation that water at 160L/h also showed highest value of instantaneous efficiency at some points as compare to other fluids like water at 100L/h and nano fluid with different volume flow rates i.e. 160L/h & 100L/h[15]. It has been concluded from experimental work that maximum thermal efficiency for nano fluid mixture with at 100L/h volume flow rate is 11.36% and 10.31% measured. It has been also concluded that nano fluid mixture with 0.01% volume concentration at 100L/h possessed higher value of overall thermal efficiency as comparison to nano fluid mixture with same concentration and at 160L/h. Further nano fluid mixture 0.02% vol. concentration showed different behaviour, it means that nano fluid mixture at 160L/h showed higher value of overall thermal efficiency as comparison to thermal efficiency possessed by nano fluid mixture with same concentration (0.02%) at 100L/h and thermal efficiency achieved by nano fluid mixture with 0.01% vol. concentration at different volume flow rates. Thermal efficiency dependent upon the important parameters like temperature difference, total mass of liquid fluid through receiver collector system, specific heat of the fluid and most important total solar global radiation comes on the collector system. The changes come in all these parameters results in the changes come out in the performance of thermal efficiency.

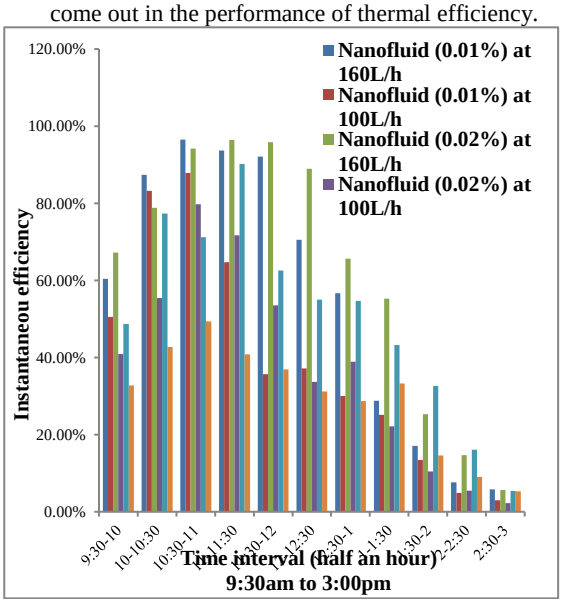

Fig: 2. Experimental variations of instantaneous efficiency [15]

6. Future Scope

Solar concentrating collectors can be used for the electricity generation on large scale and in various applications like industrial process heat. Therefore improvement in the solar thermal collector performance is highly important from research point of view so that an efficient solar thermal device can be developed. Further

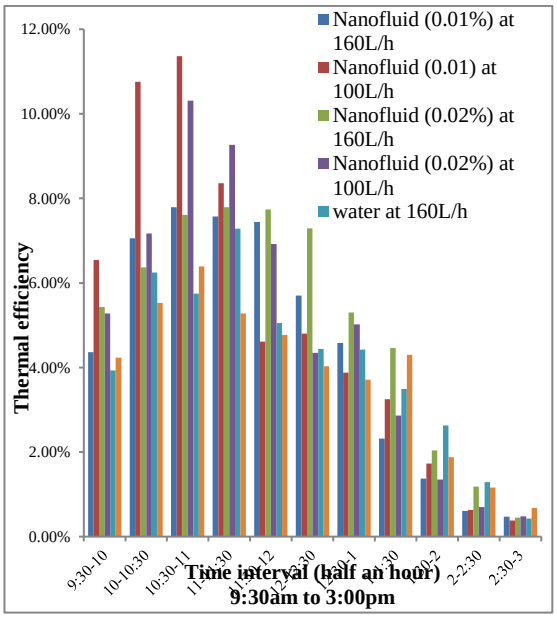

Fig: 3. Experimental variations in overall thermal efficiency for different fluids

Improvement in thermal storage device for the use in night or cloudy days also an important aspect for the construction of efficient solar thermal power plant in future. Nanofluids are the efficienct fluids, which have a capability to enhance the thermal performance of every solar thermal collector systems due to greater thermo physical properties of nanofluids like thermal conductivity so it is possible to enhance the efficiency of the hybrid as well as simple collector system by the combination of various types of nanofluids, which are made up of mixing the nano particles with different base fluids or conventional fluids like water, ethylene glycol, synthetic oil and combination of both water and ethylene glycol.

7. Conclusion

Concentrated solar thermal power is a highly prominent and proven technology to meet the current world's electricity demand, therefore advancements in the technology is greatest requirement for the better performance. Many aspects like different fluids conventional as well as nano fluid along with the improvement in thermal collector design parameters can show high thermal performance. Improvement in the thermal storage system by using phase change material is very important aspect from the research point of view because it has an ability to decrease down the cost of overall solar thermal power plant.

References

[1] Jan Fabian Feldhoff, Kai Schmitz, Markus Eck, Lars Schnatbaum-Laumann, Doerte Laing, Francisco Ortiz-Vives, Jan Schulte-Fischedick, Comparative system analysis of direct steam generation and synthetic oil parabolic trough power plants with integrated thermal storage, Solar Energy, 86, 2012, 520-530

[2] Xiang-Qi Wang, Arun S. Mujumdar, Heat trabsfer characteristic of nano fluids: a review, International Journal of Thermal Science, 46, 2007, 1-19

[3] Soteris A. Kalogirou, Solar thermal collector and applications, Progress in Energy and Combustion Science, 30, 2004, 231–295

[4] T. Yousefi, E. Shojaeizadeh, F. Veysi, S. Zinadini, An experimental investigation on the effect of pH variation of MWCNT–H_2O nanofluid on the efficiency of a flat-plate solar collector, Solar Energy, 86, 2012, 771-779

[5] R. Saidur, T. C. Meng, Z. Said, M. Hasanuzzaman, A. Kamyar, Evaluation of the effect of nanofluid-based absorbers on direct solar collector, International Journal of Heat and Mass Transfer, 55, 2012, 5899–5907

[6] Alibakhsh Kasaeian, Samaneh Daviran, Reza Danesh Azarian, Alimorad Rashidi, performance evaluation and nano fluid using capability study of a solar

parabolic trough collector, Energy Conversion and Management, 89, 2015 368–375

[7] Nor Azwadi Che Sidik, H.A. Mohammed, Omer A. Alawi, S. Samion, A review paper on preparation methods and challenges of nanoluids, International Communications in Heat and Mass Transfer, 54, 2014, 115–125

[8] Zhongyang Luo, Cheng Wang, Wei Wei, Gang Xiao, Mingjiang Ni, Performance improvement of a nanofluid solar collector based on direct absorption collection (DAC) concepts, 75, 2014, 262-271

[9] John Philip, P. D. Shima, Thermal properties of nanofluids, Advances in Colloid and Interface Science, 183–184, 2012, 30–45

[10] G. C. Bakos, I. Ioannidis, N. F. Tsagas, I. Seftelis, Design, optimisation and conversion-efficiency determination of a line-focus parabolic-trough solar-collector (PTC), Applied Energy, 68, 2001, 43-50

[11] Tooraj Yousefi, Farzad Veysi, Ehsan Shojaeizadeh, Sirus Zinadini, An experimental investigation on the effect of Al_2O_3-H_2O nanofluid on the efficiency of flat-plate solar collectors, Renewable Energy, 39, 2012, 293-298

[12] K. Vignarooban, Xinhai Xu, A. Arvay, K. Hsu, A.M. Kannan, Heat transfer fluids for concentrating solar power systems – A review, Applied Energy, 146, 2015, 383-396

[13] Gianluca Coccia, Giovanni Di Nicola, Marco Sotte, Design, manufacture, and test of a prototype for a parabolic trough collector for industrial process heat, 74, 2015, 727-736

[14] J. Paetzold, S. Cochard, A. Vassallo, D. F. Fletcher, Wind engineering analysis of parabolic trough solar collectors: the effects of varying the trough depth, journal of wind engineering and industrial aerodynamics, 135, 2014, 118–128

[15] Harwinder Singh, Pushpendra Singh, Performance Analysis of Parabolic Trough Collector System Using Nano fluid" Delhi Technological University Delhi, An Unpublished M.tech Thesis, 2015

[16] S. P. Sukhatme, J. K. Nayak, Solar Energy principles of thermal collection and storage, Mc Graw Hill,