A Dissertation on

Performance Analysis of Parabolic Trough Collector Using Nanofluid

Submitted In the Partial Fulfilment of the Requirement for the Award of the Degree

Master of Technology

IN

Renewable Energy Technology

Submitted By

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DECLARATION

This is to certify that the work presented in this dissertation entitled "**Performance Analysis of Parabolic Trough Collector Using Nanofuid**" towards the partial fulfilment of the requirements for the award of the degree of **Master of Engineering** with specialization in **Renewable Energy Technology**, from Delhi Technological University, Delhi is an authentic record of my own work carried out under the supervision of **Dr. Pushpendra Singh**, associate professor, Department of Mechanical Engineering at Delhi Technological University, Delhi.

To the best of my knowledge, the content of this dissertation report has not been submitted by me for the award of any previous degree to anyone else.

Harwinder Singh

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Place: Delhi

This is to certify that the above statement made by the candidate is true to the best of my knowledge.

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CERTIFICATE OF APPROVAL

It is certified that the contents and form of the project entitled **"Perormance Analysis of Parabolic Trough Collector Using Nanofluid"** submitted by Harwinder Singh (2K13/RET/15) is hereby approved as a creditable study of research topic and has been submitted in a satisfactory manner for its acceptance as prerequisite to the degree for which it has been submitted.

It is understood that by this approval, the under signed do not necessarily endorse any conclusion drawn or opinion expressed there, but approve the Submission for the purpose for which it is submitted.

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Harwinder Singh

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Nomenclature and Abbreviation

C_{nf} = Specific heat of nanofluid, J kg-^{1} K^{-1}

C_f = Specific heat of base fluid, J kg-^{1} K^{-1}

C_{np} = Specific heat of nanoparticles, J kg^{-1} K^{-1}

K = Thermal conductivity of water, W m^{-1} K^{-1}

K_{mix} = Thermal conductivity of MWCNT based nanofluid, W m^{-1} K^{-1}

ρ = Density of water (1000 Kg/m^3)

ρ_{mix} = Density of mixture, Kg/m^3

Q_u = Useful heat gain, W

$\dot{m}$ = Mass flow rate of working fluid, kg s^{-1}

T = Temperature of working fluid

A_{aper} = Aperture area, m^2

G_T = Incident solar flux W m^{-2}

m = Mass of working fluid

W = Width of the reflector

D = Diameter of receiver tube

L = length of receiver tube

h_f = Convective heat transfer coefficient

N_u = Nusselt number

Re = Reynold number

Pr = Prandtl number

F_R = Collector heat removal factor

F = Collector efficiency factor

U_l = Overall heat transfer coefficient, W m^{-2} K^{-1}

L/h = Litre per hour

φ_p = Volumetric concentration of nanoparticles

μ = Dynamic viscosity, kg m^{-1} s^{-1}

ν = Kinematic viscosity, m^2/s

k = Capillary constant, 0.02672 mm^2/s^2

V = Volume

v = Volume flow rate

U_L= Overall heat loss coefficient, 1328W/m^2k

Abstract

Energy demand increasing day by day in the world due to rapid increase in developments, which results in conventional resources are continuously depleting from many decades. Renewable energy is the green energy source, which help us to minimize the use of conventional source of fuel like fossil fuel. Solar energy is the better way to meet the need of world's energy demand and India have large amount of solar energy or solar flux. To extract the energy from sun in the form of electricity we can use existing technology like solar photovoltaic and solar thermal system like concentrated solar power systems. Solar thermal is the best way to generate the electricity on the large basis and use the solar collector to extract the solar energy. Use of conventional fluids in the solar collector as a heat transfer medium suffer from some natural problems like poor heat gain or heat carrying property, Which results in decrease down the performance of solar collector. It has been seen that use of nano particles in conventional fluid can help to increase the thermal properties of the fluids, which in turn increase the performance of collector. Parabolic trough collector system is the way to generate the electricity on both small and large basis. This type of collector uses the mirror strips to reflect the rays of sun from collector and concentrate radiation on receiver tube, which is located on the focus point of the parabolic collector. In this project an experimental study has to be carried out to find the performance of solar parabolic trough collector. There are many types of method physically available today to enhance the performance of the PTC System like heat transfer analysis, double parabolic trough solar concentrator, parabolic trough receiver with outer vacuum shell, solar parabolic concentrator with multiple curved surfaces. But in this project the main concentration to evaluate the Performance of collector through nanofluids instead of conventional fluid. It has been seen that the performance evaluation with the use of nano fluid in parabolic trough technology is quite costly. But nanofluids show better thermo physical properties as compare to other conventional fluid so it is possible to increase the performance through nano particles in base fluid. Generally the efficiency of the solar parabolic collector is affected by the volume concentration of nano particles and due to mass flow rate of nano fluid. This project is based upon the use of water and MWCNT based nano fluids at different concentration i.e. 0.01% and 0.02% and also at different volume flow rates i.e. 160L/h and 100L/h in solar parabolic trough collector for evaluation and compares the performance of collector system.

Chapter-1

Introduction

1.1 Solar Energy

Solar energy is a renewable and green resource of energy. Sun is the big source of high grade solar energy and 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. Amount of solar irradiation received by earth's surface is around 1000W/m^2 in a whole day [1]. Solar energy can fulfil the world's present and future energy demand for both industrial and commercial use. Solar radiations which are incident on the earth's atmosphere are in the form of beam, diffuse and total radiation. Sun is the renewable and unconventional energy source for fulfilling the energy requirement on the earth. Some type of fusion reactions are continuously going on the surface of sun, which results in a large amount of heat generation and this heat has became an energy source for the other planets of solar system like earth. Diameter of sun is 1.36×10^6 Km and its surface contain large amount of gases. Diameter of earth is 1.27×10^4 Km, which is far less than diameter of sun. Further sun and earth distance is approximately 1.496×10^8 Km. Solar radiations that directly comes to the surface of earth is known by beam and direct radiations. Apart from this, scattered radiations coming to the surface of earth are known by diffuse radiations. The combination of both beam and diffuse or scattered radiations coming on the surface of earth is known as total and global radiations. Total energy received by earth from sun per unit time, on a surface of unit area kept perpendicular to the coming radiation on outside the earth's atmosphere (i.e. space) is known as solar constant and its value is 1350W/m^2 [2]. Energy sources are categorised in two forms like renewable or alternative and conventional or non renewable sources of energy. There are different conventional energy sources like petroleum, coal and natural gas also and their use in excess amount is associated with dangerous problem like pollution. There are also many advantages of green energy sources among conventional source of energy like green energy resource include wind, small hydro, geothermal and solar which does not pollute the environment and does not contribute to emission of green house gases to the earth's environment and these alternative sources help us to decrease down the effect of global warming, which is due to use of conventional fuel in excess throughout the world. Apart from this, conventional energy sources are in limited amount on the earth and their use generates dangerous waste, harmful gases in the living environment. So it is necessary for us to use renewable energy sources for generation of power or electricity to fulfil the need of world's energy or electricity demand on continuous basis. Solar energy harnessed from sun with the use of different technologies like solar heating, solar photovoltaic and solar thermal power for different purposes. Solar photovoltaic can be used for direct conversion of solar light or incident heat into electricity with the help of solar photovoltaic cells. Solar thermal power technology is used to harness the thermal energy (i.e. heat) from incident light or solar rays with the use of solar thermal collector. Among other highly concentrated solar thermal power (CSP) systems, parabolic trough solar thermal technology is the most proven technology, which has a capability to generate the electric power for both commercial and industrial use.

1.2 Solar Energy Scenario in India

Man has used energy at very fast rate from million years, primarily people required energy only for his basic need i.e. food. But people's demand increased due to the discovery of fire. In the beginning sun was the only source to fulfil the energy demand of human and it has been seen that people were using renewable or green energy resources from many past decades. After industrial revolution people discovered a new conventional source i.e. coal and during the invention of internal combustion engine, some other conventional resources like fossil fuels (oil and natural gas) came into use widely. Along with the discovery of all these conventional resources, a new energy source i.e. nuclear energy came into existence during the time of Second World War. Nuclear and thermal energy are using even today on a large scale for generation of electricity or power, which is done by set up of nuclear or thermal plants. Nuclear energy's contribution in fulfilling the energy need of people is not so much high because of limited quantity of uranium present on earth, but its contribution is very significant for human life because it does not create any disturbance to the environment as compare to thermal plants. From the past few year, depletion rates for fossil fuel like oil and natural gas has rise extremely high. So there is a great need to replace conventional resources from sustainable resources or alternative source of energy to prevent the degradation of fossil fuels and to decrease down the effect of harmful gases or waste. Based on the use of energy sources, these can be classified into two important types like commercial and non commercial. Further commercial includes hydroelectric, wind, fossil fuel along with nuclear power also, while non commercial sources include wood, agriculture & animal waste also fall in this category. Requirement and application of commercial sources is very high as comparison to non commercial sources and mostly in developed countries like in USA, Europe and in other developing countries like in India both the sources are used almost in same amount [3].

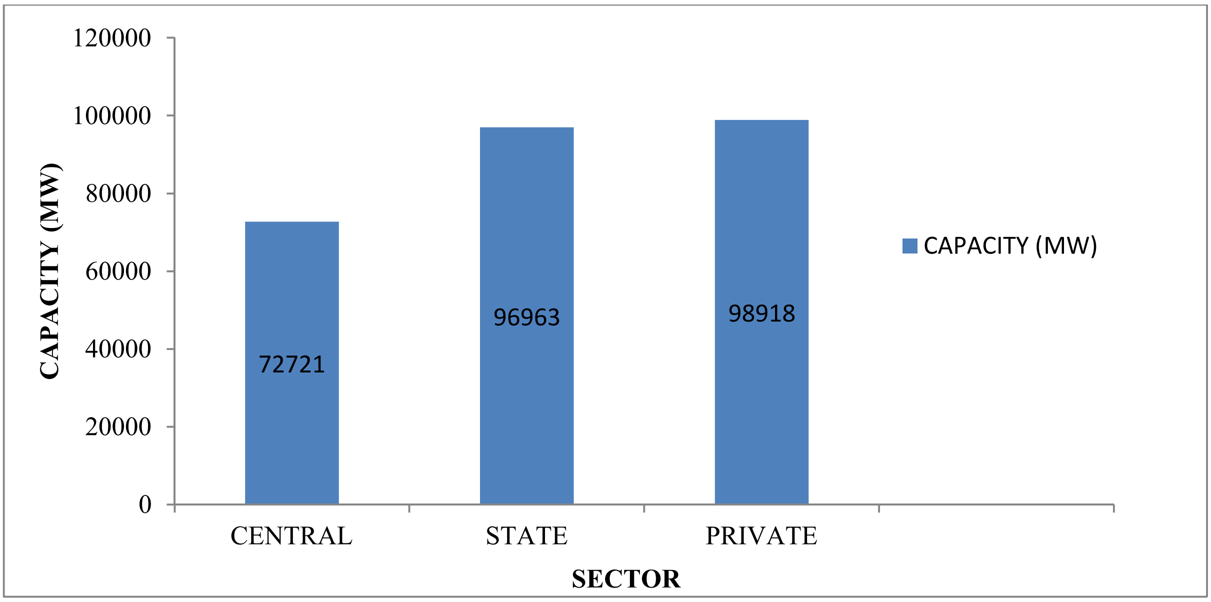


Figure: 1(a) Total Installed Capacity Sector Wise in India (30/4/2015)

Source: power sector at a glance all India, Ministry of Power (Government of India)

http://powermin.nic.in/power-sector-glance-all-india, access on 25/6/2015 (11:53am)

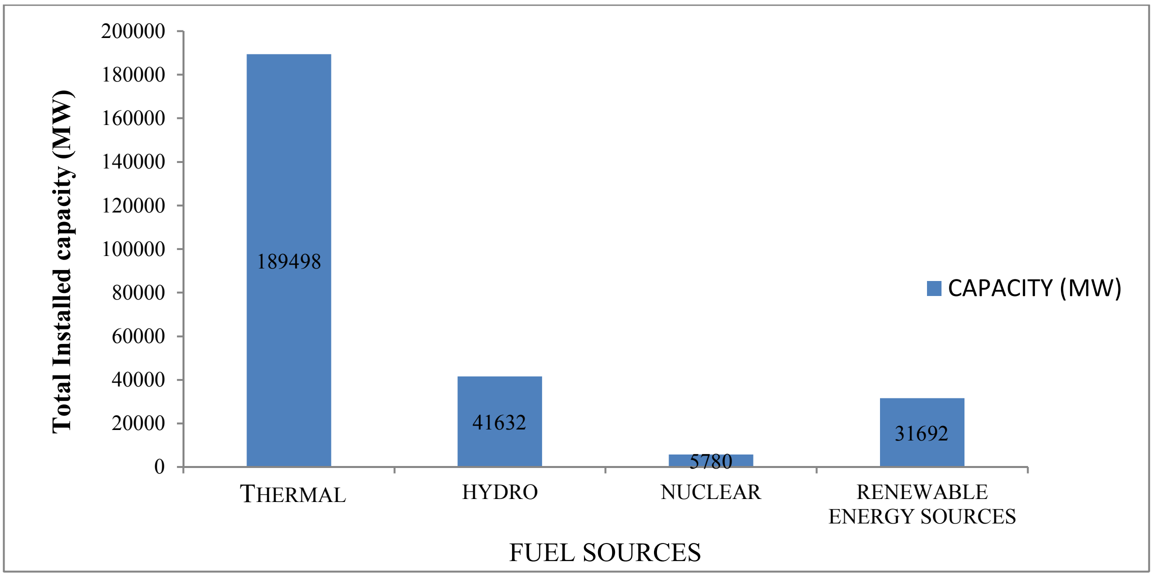


Figure: 1(b) Total Installed Capacity Fuel Wise (30/4/2015)

Sources: power sector at a glance all India, Ministry of Power (Government of India)

http://powermin.nic.in/power-sector-glance-all-india, access on 25/6/2015 (11:53am)

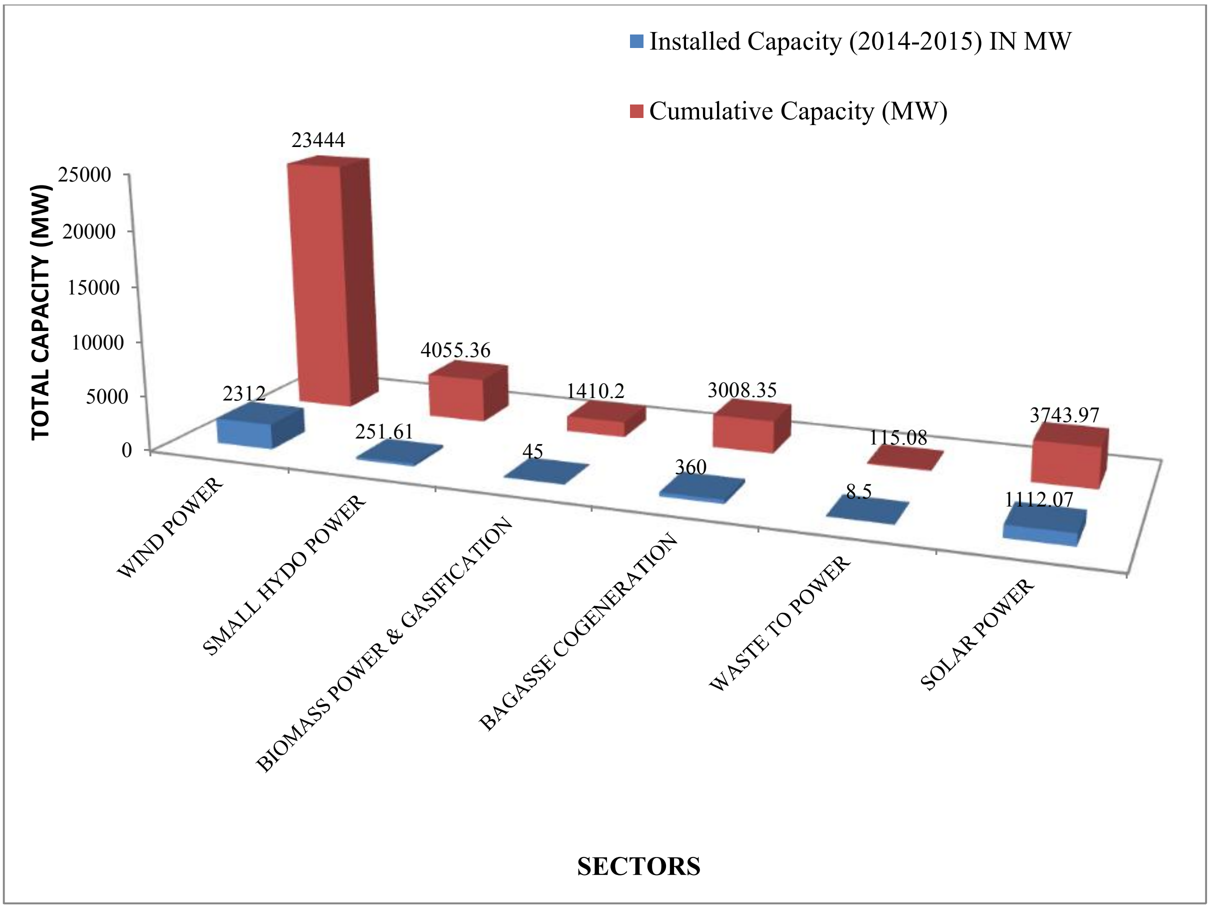


Figure: 1(c) Total Grid-Interactive Renewable Power from Various Sectors for 2014-2015 and Cumulative Installed Capacity (31/3/2015)

Source: physical progress (achievements) Ministry of New & Renewable Energy (Government of India)

http://mnre.gov.in/mission-and-vision-2/achievements/ access on 25/6/2015 (11:56am)

1.3 Solar Collector

Solar collector system is used to convert the sun's thermal energy into heat or in other useful form electricity. Collected solar energy or radiations can be transferred to fluid passing through tubes or pipes in contact with it and with the help of solar collector [4]. So it is necessary for solar collector to convert the solar energy into thermal energy in regular and efficient way to achieve the maximum electrical output from the device. Further solar collector can be classified in to two ways i.e., Concentrating and Non concentrating or flat plate collector.

Non concentrating collector's have same area of both collector and absorber. This type of collector generally used to water heating purposes (i.e. low temperature applications) and also possess capability to generate high temperature. Heat loss from collector is directly proportional to absorber area that's why these collectors cannot be used for high temperature devices and also due to cost of absorber, which become very high as comparison to mirror's cost. The most important classification of non concentrating collector is flat plate collector and these type of collectors are used to heat water for various domestic applications. There are different types of flat plate collectors like liquid flat plate collector and air heater which are used according to need. Flat plate collector is simply operated, very reliable and also requires very low inspection and maintenance also. Absorber tubes are the essential component of solar collector which absorbs all the solar energy and also take part in conversion of the solar energy in to working form like heat and electricity or power.

Concentrating collectors are also known by focussing 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. There are various important terms of concentrating collector and these are discussed as below [4]:

1. **Aperture area**, which is denoted by 'A_a' and solar radiation are incident on collector through this area.
2. **Acceptance angle**, which is denoted by '$2\theta_a$' and is the angle upon which incident beam radiation can deviate from normal to the aperture plane and still reach to the absorber or receiver surface. If acceptance angle is very large, collector requires only occasional adjustments. Further if acceptance angle is small then collector has to be adjusted on continuous basis.

3. **Absorber area**, which is denoted by 'A_{abs}' is the total surface area of absorber tube upon which solar radiation are concentrated. Useful energy can be obtained from this area of collector.
4. **Geometrical or area concentration ratio**, which is denoted by 'C' and is defined by the ratio of collector aperture's area to the area of absorber, its value can vary from unity to thousands for different type of collectors.
5. **Intercept factor (γ)** is defined by the ratio of energy achieved from solar radiations intercepted through absorber of certain width to the total energy of radiations redirected through focussing device and its value is almost unity.

1.4 Solar Concentrator's Classification

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 [3].

There are basically four important type of concentrating collector and they all are discussed as below:

(a) Parabolic trough concentrating solar collector
(b) Linear Fresnel reflector (LFR) system
(c) Parabolic dish solar system
(d) Heliostat/central receiver concentrated solar system

(a) Parabolic Trough Concentrating Solar Collector

This is the most impressive type of solar concentrating collectors and its use can be possible both on small or large scale. It consists of a reflecting surface in the form of parabolic structure and situated on the support structure of collector system. This collector has a line focussing receiver or absorber tube on its focal axis, which is made up of copper material. Receiver tube is evacuated with the help of concentric glass envelope so that conductive and convective heat losses can be minimized. A manual and automatic tracking system can be used to track the sun in the direction east to west during whole day so that it can maintain concentration of the solar radiation on the receiver tube effectively; it can possible around one and two axis. Solar radiation incident on the absorber surface provide the energy to working fluid like water or oil, which is circulated through the receiver tube. Parabolic collector can produce heat at high temperature like between $50°C\ to\ 400°C$ for electricity generation or heat treatment applications.

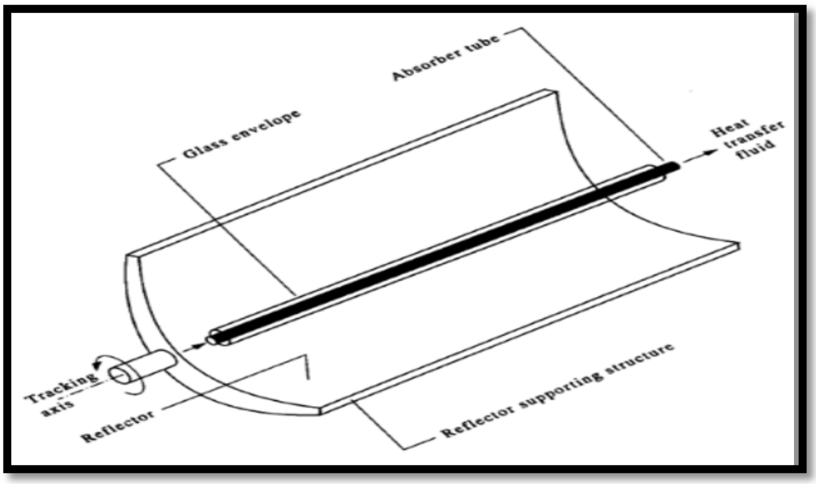


Fig 2(a): Parabolic Trough Collector

Source: A.Thomas and H.M.Guven (1993), "Parabolic Trough Concentrator- Design, Construction and Evaluation," Energy Conversion and Management, vol. 34, pp. 401-416[5]

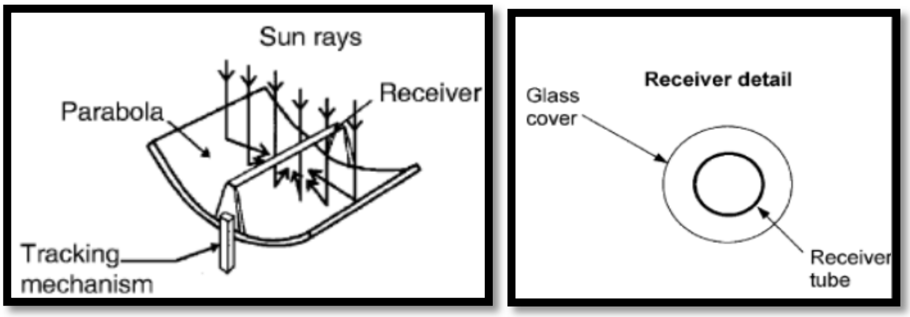


Fig. 2(b): Receiver of parabolic trough collector

Source: A.Thomas and H.M.Guven (1993), "Parabolic Trough Concentrator- Design, Construction and Evaluation," Energy Conversion and Management, vol. 34, pp. 401-416[5]

(b) Linear Fresnel Reflector (LFR) System

It includes large number of linear mirror strips that all together concentrate the sun light on the receiver, which is mounted over the linear tower. The main advantage of linear Fresnel reflector over parabolic trough collector that it uses reflector of flat shape not of parabolic shape, which make it cheaper as comparison to parabolic glass reflector system. Apart from this linear Fresnel reflectors are mounted very close to ground, which minimize the structural and repairing cost. Due to the application of Fresnel reflector, Linear Fresnel Reflector has more advantages as compare to parabolic trough mirror. This type of reflector system uses Fresnel lens effect, which have large aperture and long focal length and also acquire less cost as compare to conventional lens.

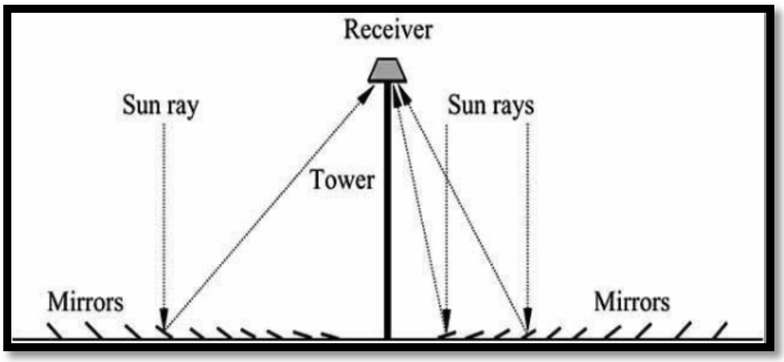


Fig. 3: Diagram of a Linear Fresnel Reflector field associated with receiver

Source: Soteris A. Kalogirou (2004), "Solar thermal collectors and applications," Progress in Energy and Combustion science, vol. 30: pp 231–295 [6]

(c) Parabolic Dish Solar System

It is a point focussing device, which means its concentration ratio and temperature achieved both are high as compare to line focussing devices. In this type of device solar energy is concentrated on the receiver, which is situated on the point of the focus of the parabolic dish solar system. Circulating working fluid in receiver absorbs the solar radiations and converts it into thermal energy or heat. This heat or thermal energy can be used to generate the power or electricity with the help of turbine generator system coupled with the receiver.

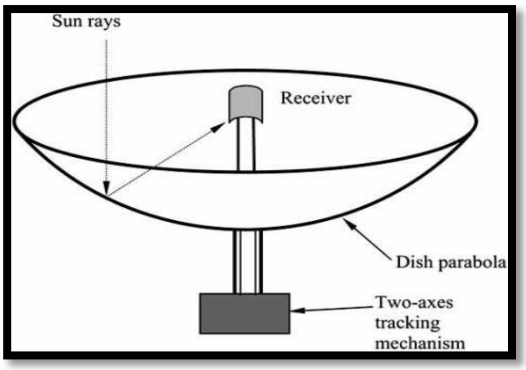


Fig.4: Diagram of a parabolic dish solar collector

Source: Soteris A. Kalogirou (2004), "Solar thermal collectors and applications," Progress in Energy and Combustion science, vol. 30: pp 231–295 [6]

(d) Heliostats/Central Receiver System

In this device solar radiation is concentrated on the central receiver after getting reflected through a large number of mirrors also known as heliostats. All the mirrors are placed on the ground around the central receiver or power tower system. Their tracking or orientation is controlled individually during the whole day, so that they reflect the direct beam radiation towards the top of the tower. Receiver containing working fluid absorbs solar radiations, which are concentrated on the receiver through heliostats. Thermal energy or heat from receiver transported toward ground from receiver, where this energy is used to run the conventional turbine and generator system for generation of power or electricity. Most commonly or widely used working heat transfer fluids are molten salt, water and air. Central receiver can be used to produce high temperature steam or electricity production on a large scale. This type of central receiver system is also known by power tower system.

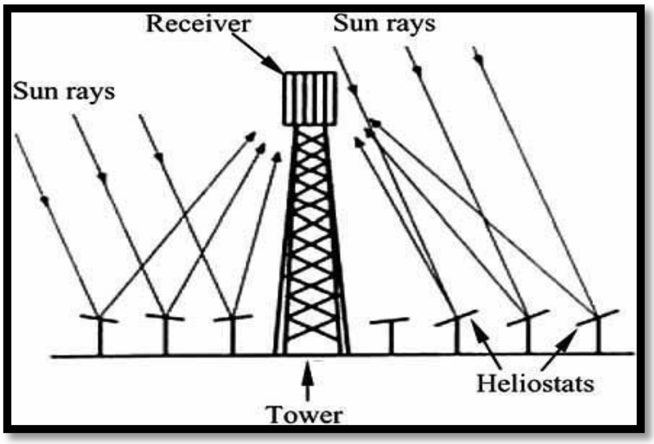


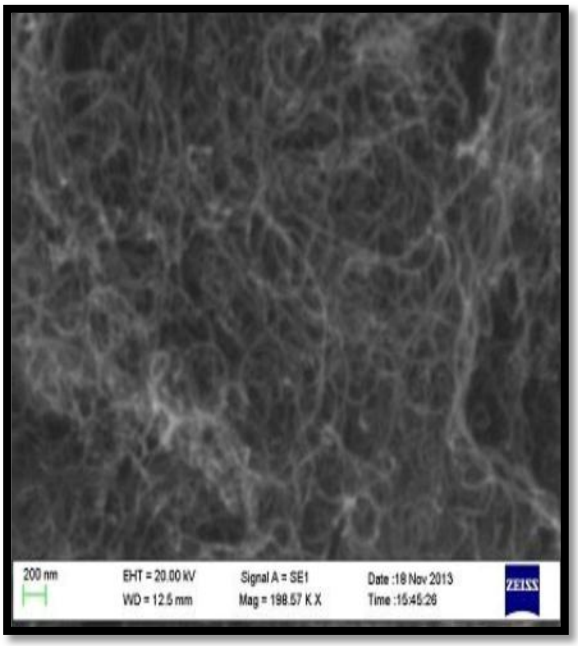
Fig. 5: Diagram of central receiver tower

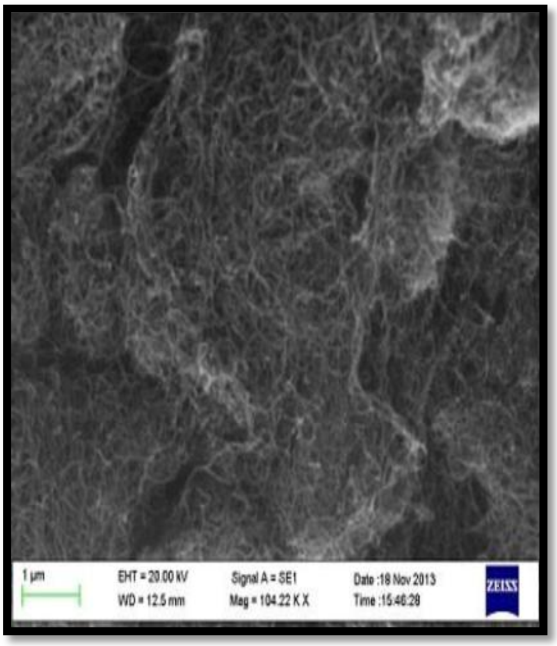
Source: Soteris A. Kalogirou (2004), "Solar thermal collectors and applications," Progress in Energy and Combustion science, vol. 30: pp 231–295 [6]

1.5 Preparation of Nano fluids

Formation of nano fluids are due to suspension of nano particles into base fluid and the term nano fluid is discovered by choi in the Argonne national laboratory of America (USA) in 1995 [10]. When nano particles are mixed with base fluid, it can increase the thermal property of the base or conventional fluid like water, oil and ethylene glycol [7].

There are various type of materials used for fabrication of nano particles like oxide ceramic, nitride ceramic, metals, semiconductors and carbon nanotubes etc. nano particles are generally described by the radius of less than100nm, in which atoms or molecules are bonded with each other. Commonly used method for fabrication of Nano particles is laser evaporation in which laser beam with high intensity is incident on the metal rod, which results in evaporation of atoms starts from the metal surface, these atoms of metal are cooled and convert into nano particles. Other methods to synthesize the nano particles are RF plasma, chemical methods, thermolysis and pulsed laser methods. Formation process of the nanofluids with improved thermal/heat transport properties has a requirement of both heat transfer fluid and nano particles. Heat transfer fluids can be water, ethylene glycol and hydrocarbons etc with or without the use of surfactants. Mainly two methods used to fabricate the nano particles i.e. physical and chemical process. Physical process are further divided into inert gas condensation and mechanical grinding process, while catalyst chemical vapour deposition and chemical precipitation is a type of chemical processes. For suspension of nano particles into base fluids two methods i.e. single and two step methods are generally employed. Further in the single step method both the fabrication and dispersion of nano particles in base fluid have done simultaneously and in two step method both first fabrication of nano particles and after fabrication, nano particles are dispersed into conventional base fluid with or without application of surfactants through stirring and sonication process. Generally two step method is used to fabrication of nano fluids as comparison to one step method because of complex mechanism of one step method along with cost of preparation of nano fluids on a large scale is comparatively higher than two step method [8]. Mixing of nano particles into base fluid can enhance the density of conventional fluids, which results in increase the heat absorbing capacity of conventional fluids and this property can increase the efficiency of energy storage device. In this experimental work MWCNTs used to prepare nano fluid by mixing with base fluid i.e. water and MWCNTs are manufactured by process of chemical catalyst vapour deposition method and structural characterization techniques like SEM, TEM, Raman spectroscopy and XRD is necessary to know about the structural arrangement of the nano particles and detailed description on experimentally evaluated SEM and XRD techniques for MWCNTs are discussed in chapter 8 and section 8.4. Further this section includes SEM, TEM, Raman spectroscopy and XRD image for MWCNTs, which is provided by Nano Green Technological Limited as shown below:





6(A) *6(B)*

Figure 6(A) & 6(B) SEM image of MWCNTs

Source: Nano Green Technologies Private Limited

Transmission Electron Microscopy (TEM), in this method a more powerful electron beam is used for generation of image. This technique is generally used for evaluation of more geometrical features of CNT on atomic scale as comparison to geometrical features of SEM image. TEM is used to evaluate information regarding diameter and defects in CNT nano particles. TEM is a powerful imaging technique and when it coupled with energy dispersive x-ray (EDX) with it, then TEM techniques can be used to measure some additional properties of CNT nano particles.

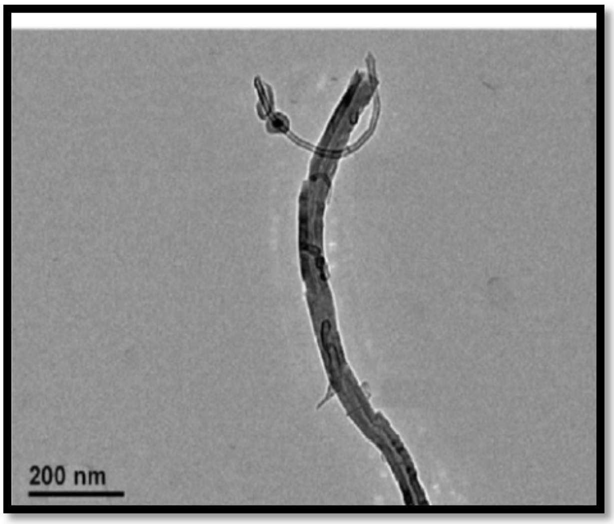


Figure 7: TEM image of MWCNTs

Source: Nano Green Technologies Private Limited

Raman Spectroscopy is an important technique used for characterization of CNTs structure in a very fast and precise way. This technique is use to find out the diameter of nano particles, configuration, number of walls present in CNTs and also about presence of crystalline or amorphous carbon in CNT.

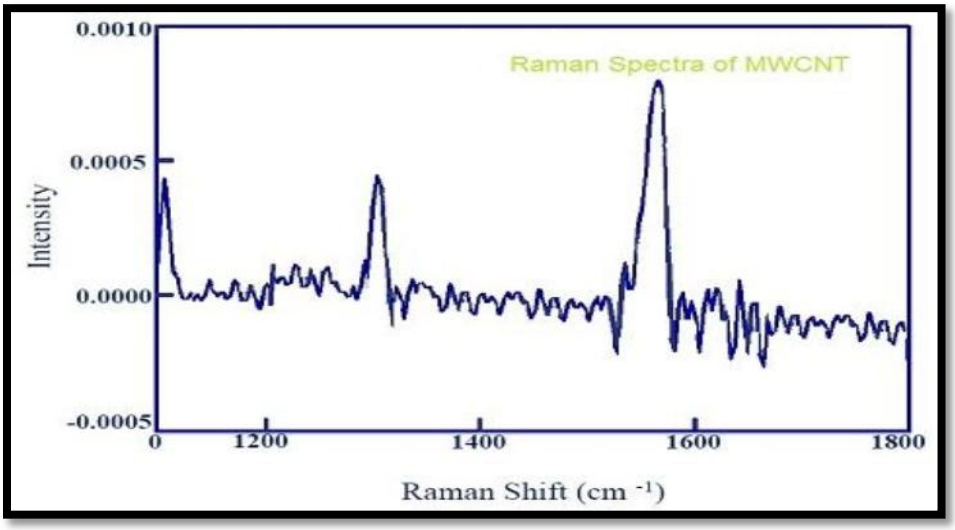


Figure 8: Raman Shift for MWCNTs

Source: Nano Green Technologies Private Limited

X- Ray Diffraction is a prominent technique to determine the crystal structure and atomic spacing in nanoparticles. Cathode ray tube generate X-Ray by using heating filament, which produce electrons and with applying voltage these electrons are accelerated toward target and start to bombard on target material. Electrons have an sufficient energy to displace or shift the electron of target material from the inner shell, which produce an X-Ray spectra of material.

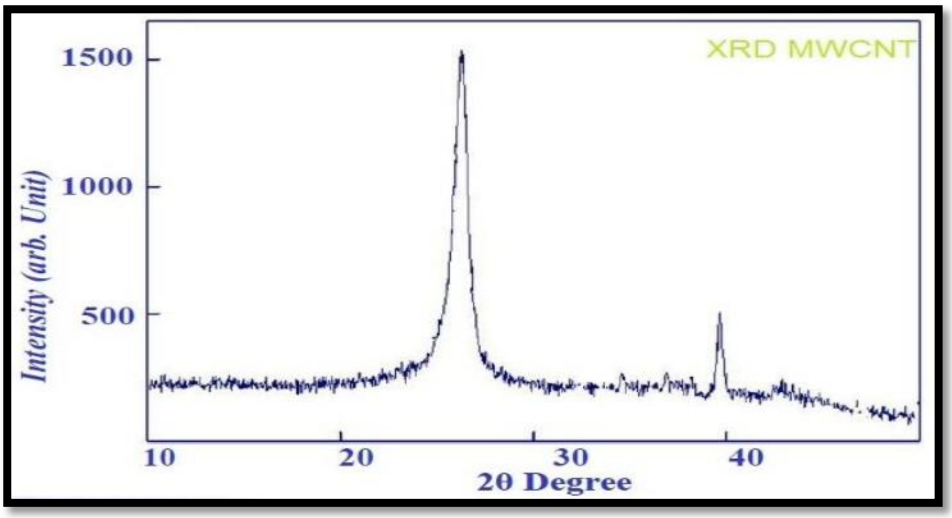


Figure 9: X-Ray Diffraction of MWCNTs

Source: Nano Green Technologies Private Limited

Chapter-2

Research Methodology

2.1 Literature Review

The literature review consists of research papers associated mainly with discussion on past research held both in the area of solar thermal technology and nanotechnology like nano fluids. There are lot of research work already have done relative to the use of nano fluids in the solar collectors like flat plate non concentrated collector and parabolic trough solar concentrated collector to achieve the high performance and high efficiency from solar collectors and including the fact that how we can enhance or maximize the efficiency of solar parabolic concentrated collector due to the variation in size of nano particles, volumetric concentration of nano particles in base fluid at different volume flow rates and corresponding mass flow rates and in how much extent these all factors affect to the performance of device. It has been seen from past experimental study, which has done already in this field that nano fluids has capability to enhance the heat absorbing capability of heat transfer fluids. Efficiency of solar power plant and heat exchanger greatly affected by the phenomenon of the thermal conduction in heat transfer fluids, it has been seen that nano fluids has a capability of high thermal conductivity and high mass diffusivity [9] and apart from this application of nano fluids found in the solar water heating systems, solar ponds, solar cooling system and in solar absorption refrigeration systems etc. Further this section of literature review describe all the experimental and theoretical research work with their concluded results, which has already done or going on and discussion on all that of research work related to improvement in the efficiency of solar parabolic concentrated collector due to the application of various nano fluids are discussed later in the different chapter of literature review.

2.2 Outcome of Literature Review

After study about all past research which is discussed in literature review already, now I would like to discuss important outcome of the research study. It has been seen that enhancement in efficiency or performance of solar collector highly depend upon the thermo physical properties of the fluid, which tells us that how efficiently heat transfer fluids absorb the heat from sun radiations and how efficiently heat can transfer from working fluid during working in heat exchanger, which is further used in power plant to generate electricity. It is also seen that some limitations come in the way to absorb the heat by conventional fluids flowing through the solar collector. The conventional collector can absorb the heat up to a certain limit so concept of using nano fluid with in base fluid comes out, which help us to increase the capability of base fluid or conventional fluid to absorb or extract the maximum amount of solar thermal energy or heat from sun radiations and by which an increment and improvement in performance of solar collector is achieved. There are also some challenges comes out during the working on solar collector technology with nano fluids, that are discussed later in different section. It has been seen that very few research held or going on in the area of improvement in performance of parabolic trough collector, which is due to cost constraint of both of parabolic trough collector and also of nano fluids.

2.3 Problem Formulation

From the section of outcome of literature review, there are some problems associated with the project research work comes out. The main problem is cost which comes out on overall project. The cost of project includes the cost of both nano fluids instead the use of conventional fluid and cost of parabolic trough collector, which is a costly collector system. The cost of parabolic trough collector increases due to cost of copper absorber pipe, mirror strips, pumping system and also due to insulation used. Further cost comes on reduction of heat losses due to radiation, convection, conduction etc, for this purpose a evacuated glass cover also provided to reduce or minimize the loss of heat. Further nano fluid preparation uses sonication and stirring devices that are too costly and time consuming devices in their working. The detailed discussion on problems is discussed in separate chapter.

2.4 Objective of Study

After study about all the past research in the field of solar energy collectors and nono fluids applications that really help me out to decide the objective of my research work. Now I would like to describe my project objective i.e. “To analyse the performance of parabolic trough based solar collector with the use of nano fluid" and also comparison between the different results comes out during the working of solar collector.

2.5 Proposed Experimental Set-up

This section consists of a working parabolic trough collector system, whose performance is analysed with the help of working heat transfer fluid. But from the past research it has already seen that conventional fluid like water losses his heat quickly, heat losses are due to radiation, conduction, convection etc. so the concept of nano fluids comes here and become effective in almost all type of collector systems because nano fluids enhance the heat absorbing capability of base fluid and also an increment come in efficient heat transfer during working in heat exchanger. So I would like to do experimental work on prototype of the solar parabolic trough concentrated collector with the use of water as working conventional fluid and proposed nano fluids like MWCNT and distilled water based mixture. The experimental work includes a flow chart of complete process with use of nano fluids in solar parabolic trough collector, which is discussed later in different chapter.

2.6 Experimentation & Data collection

Parabolic trough collector in which parabolic trough consists of a parabolic shape can made with a material of high strength. A tube provided in the middle of parabolic structure also known by copper receiver tube and tube also carries a heat transfer fluid. Receiver can be painted black from outside surface to absorb the maximum solar radiations. Receiver can also evacuate through a glass cover to reduce the loss of heat due to conduction, convection and radiation.

For experimental work, I would like to use prototype of solar thermal collector (parabolic trough collector) in which high temperature can be achieved with the use of water and proposed nano fluid i.e. MWCNT and distilled water based mixture, which are used to increase the heat absorbing and heat carrying capability of base or conventional fluids(i.e. distilled water). This section mainly consists of experimental and theoretical properties of MWCNT based nano fluid and water, experimental readings related to inlet and outlet temperatures, solar intensity and variations in experimental data with the use of water, MWCNT and distilled water based nano fluid with different concentrations i.e. 0.01wt% and 0.02wt% and at different volume flow rates i.e. 160L/h and 100L/h in solar parabolic trough collector at existing environmental conditions like heat flux and wind speed. Different results obtained with different experiments, which help us to analyse that how the performance can improve of parabolic trough collector system with the effective cost reduction. Further this chapter also include structural characterization techniques, which are discussed in different chapter in detail.

2.7 Comparative Analysis

This project is strictly based upon the comparison between the performance parameters of parabolic trough collector evaluated from this current experimental study and also performance parameter of other type collector system, which are already available from previous research work. Tooraj Yousefi (2012) was found efficiency parameters for flat plate collector with the application of working fluid like water and MWCNT nanofluid. This comparative analysis concluded that how a parabolic trough solar collector better in working as comparison to flat plate collector almost at same type of conditions of mass flow rates and discussed in detail later.

2.8 Results and Discussions

Results showed graphically that an improvement in performance of solar parabolic trough collector through MWCNT based nano fluid at 0.01% and 0.02% vol. concentration with different volume flow rates i.e. 160L/h and 100L/h and also this section include graphical comparison between efficiency comes through MWCNT nanofluid and water. Particle size of MWCNTs and proper mixing of MWCNTs in base fluid also affects the efficiency of solar collector. It has also been find out from past research work that MWCNT possess higher amount of thermal conductivity, which is very effective to improve the thermo physical properties like thermal conductivity of base fluids. Therefore use of MWCNTs with the base fluids i.e. distilled water to analyse the performance of solar parabolic collector, which results in improvement in efficiency from collector can be achieved through incremental change in heat absorbing capability of conventional fluid and further detailed discussion on enhancement in performance of collector is described in separate chapter.

2.9 Conclusion

The all study of existing past research work and comparative analysis help us to conclude that use of nano fluids showed an increment in performance of solar parabolic collector as comparison to performance achieved from base fluid i.e. water. Parabolic trough collector is a costly system so use of nanofluids in this system becomes effective to increase the efficiency and cost reduction of collector system, which uses only conventional fluid like water. But some points are also concluded from the past research that are use of nano fluids carry some challenges in working of system like high cost of nano particle, pressure drop in system and pumping power requirement, instability and agglomeration and also of erosion and corrosion of component of system. The results outcome of this study helps us to decide suitable nano fluid as a working fluid according to performance requirement from collector system.

2.10 Future Scope of Work

Both technical and economical developments in nanofluids are still going on and strong potential to deployment of nanofluids to improve the performance of various systems based upon working of fluids. It has been seen that nano fluids can be used to improve the performance of different types of solar thermal collectors and other application of nano fluids are also observed in the area of Solar cooling and refrigeration system. It has been seen in the previous research study that adding more MWCNTs in paraffin has a capability to enhance the thermal storage characteristics of phase changing materials and this application can be used in the enhancement of the thermal performance of system [41].

Chapter-3

Literature Review

3.1 Introduction

In this section our main aim to study all the past research, which have already done in the field of our area of interest. The literature review consists of different research papers related to area of interest i.e. improvement in performance of solar parabolic collector. After reviewing all research paper we are capable to indentify the research gap and problem formulation. After analysing all the technical factor and economic factor, we can define our objective, which is basically an outcome of literature review. So with respect to research work this is the most important section or area of study.

3.2 Scope of Literature Review

The review help us to decide what has already done in the past and what we have to do further for improvement in existing technology. The review also helps us to find out problems in present research work and to analyse different economic and environmental factor on which system is working. The detailed study of review creates a mind setup about our area of research and provides a direction to our study, which helps us to reach our objective and to decide a methodology to achieve this objective or goal. The literature review is the basic building block of every research work.

3.3 Reviews in Area of Parabolic Trough Collector

Parabolic trough collector system is a concentrating thermal power technology. This is a high temperature technology and can be used of water and thermal oil as the working base fluid. It can be used for the purpose of water heating and generation of electricity both on major and small scale. Parabolic trough collector has also affordable cost of construction as comparison to other concentrated solar thermal power systems for electricity production also with effective thermal storage. Parabolic solar trough technology is the most prominent solar thermal electric technology. The first parabolic trough collector based solar thermal power plant was situated in America 1984, which has been operating in California Mojave desert and plant has a capacity of 14 to 80MW[6].

The parabolic trough collectors (PTC) consist of solar collectors with reflected surfaces i.e. mirrors, receiver tube and support structures. The parabolic-shaped mirrors are manufactured into a parabolic shape that concentrates incoming sunlight onto a central receiver tube, which is situated at the focal line of the collector and evacuated through glass cover. Selection of parabolic trough collector system for research work is due to easy availability of this technology on reasonable basis among other solar thermal systems.

3.4 Significant Contribution in Proposed Area of Research

This section includes all the previous research work related to parabolic trough concentrating collector system and nanotechnology (area of nanofluids) which has already done in the past and it will be combination of theoretical and experimental study work and results outcome of the past research study is being described.

3.4.1 Heat Transfer Characteristics of Nano Fluids: A Review

Source: Xiang-Qi Wang, Arun S. Mujumdar, heat trabsfer characteristic of nano fluids: a review, international journal of thermal science; 46 (2007), pp 1-19

This research is a complete study of heat exchange and fluid flow characteristics of nano fluids in forced and free convection. With the change in geometry of flow, boundary conditions and by enhancing thermal conductivity of fluid, convective heat transfer can be increased. 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. 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 ($C_2H_6O_2$)), experimental results shows 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.

3.4.2 Solar Thermal Collectors and Applications

Source: Soteris A. Kalogirou, solar thermal collector and applications, Progress in Energy and Combustion Science; 30(2004), pp 231–295 [6]

This research is a complete overview of different 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 and also discussion on their applications like water and space heating and cooling also, industrial heat process and also in thermal power plants. Further this paper also analyse the effect of using conventional fuel sources on environment of earth. Problem (like pollution) related to environment growing continuously due to increasing world's population, therefore consumption and demand of energy both are increasing on continuous basis. Industrialization is also a big cause for degradation of environment, apart from this concentration on some hazardous pollutants like sulphur dioxide, nitrogen oxides, particulates and carbon monoxides is necessary to analyse the actual condition of environment. This section also includes the description of solar energy collectors and its different types. Solar collector is a 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. This paper also describes the optical and thermal analysis of collector system and the method that how we can evaluate the performance of different solar collector along with their applications for different purposes.

3.4.3 Performance Evaluation and Nanofluid Using Capability Study of A Solar Parabolic Trough Collector

Source: 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), pp 368–375 [31]

This research work describes the ways to enhance the working performance of solar parabolic trough collector system. For the purpose of investigation or inspection 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 are used to examine and compare the optical and thermal efficiency of solar parabolic trough collector system. 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. Results comes out from research work that efficiency of evacuated tube shows 11% higher than the bare tube efficiency due to convection losses. Also 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. 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. Black coated copper tube possesses high absorptive and thermal conductivity.

3.4.4 A Review Paper on Preparation Methods and Challenges of Nanofluids

Source: 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), pp 115–125 [32]

This paper is review study, which is concentrated on methods to prepare the nano fluids along with challenges due to nano fluids. This paper includes the all methods of preparation given by different investigators or researchers. Metallic and non metallic particles can be used to fabricate nano particles. The aim of review paper is to describe the synthesis process for nano fluids along with characterization of nano fluids. This review paper also includes some challenges comes in the synthesis process. 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. This paper 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 for change in properties. All these issues are need to greater attention in future for achievements of better results from application of nano fluids in different technical fields. 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. It has been noticed that thermal conductivity of pure metallic particle based nano fluids acquire higher thermal conductivity as comparison to nano fluid containing oxide nano particles [12] and also nano fluids posses less specific heat as comparison to base fluids. Further viscosity of nano fluids generally higher than the base fluids and it depends upon type of particles and also depends upon particle volume concentration. This review paper also evaluate that homogeneous and stable dispersion of nano particles in conventional fluid is always a challenge for investigators. 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.

3.4.5 Thermal Properties of Nano Fluids

Source: John Philip, P.D. Shima, Thermal properties of nanofluids, Advances in Colloid and Interface Science; 183–184 (2012), pp 30–45 [33]

This review paper is a complete overview of developments and advances in the field of nano fluids applications and also their effect on the thermal characteristics of nano fluids. This paper is 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 behaviour between k and φ. Thermal conductivity also effected 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 [13]. 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 [14]. 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 [15]. 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 [16]. 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 [14]. 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% [18]. Water based Al_2O_3 with diameter 36nm showed an increment in 'k' at temperature range between 2 to 50℃ [19]. For MWCNT and water based nano fluid showed an enhancement in 'k' is independent on the temperature at low concentration of MWCNT [20]. 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℃ [21]. 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 $5\ \mu m$[20]. The incremental behaviour of 'k' was found to be increased with increase of aspect ratio of nanotubes in water based CNT nano fluids [23]. Water based nano fluid also show less enhancement in k as compare to E.G based nano fluids [24]. To maintain the stability of nano particles, there is a requirement of surfactants, because they prevent the agglomeration of nano particles [25]. 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[23]. This review also describe 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 effect to the results of experiment.

3.4.6 Radiative Properties of Nano Fluids

Source: Z. Said, M.H. Sajid, R. Saidur, M. Kamalisarvestani, N.A. Rahim, Radiative properties of nanofluids, International Communications in Heat and Mass Transfer, 82 (2015); pp 236–249 [34]

A Nano fluid has better thermo physical properties as compare to conventional fluids. This review paper is an complete overview about radiative properties of nano fluid, which have received less attentions or interest from all investigators as compare to thermal conductivity and convective properties of nanofluids along with the detailed description on optical properties like absorption coefficient and scattering coefficient of nano fluids. At very low concentration of particles, nano fluids showed greater enhancement in the thermal and optical properties [26]. It has been seen that MWCNT based nano fluids has more potential to absorb the solar radiation as comparison to aluminium due to very less energy was scattered away [27]. Otanicar et al performed an experiment related to energy absorption capabilities of different fluids like simple water, ethylene glycol ($C_2H_6O_2$), propylene glycol and also therminol VP-1. It has been seen from experimental results that among all other the fluids water showed high capability to store energy from solar radiations, which absorb 13% of the energy. This paper is also an overview of improvements in the research area of nano fluids, which includes the preparation methods for nano fluids like single and two step methods and also includes the study about stability of nano fluids, it means that proper dispersion of nano particles in base fluids is necessary. It has also been seen that properties of nano fluids are strongly dependent upon the size, shape and also on the structure of nano particles with the properties of additives, all which are used in experimental work. Further this paper includes optical properties of nano fluids along with the specific evaluation method to find these properties and light scattering theory which are further divided into two types i.e. Rayleigh theory and Mie scattering theory.

3.4.7 An Experimental Investigation on the Effect of Al_2O_3-H_2O Nanofluid on the Efficiency of Flat-Plate Solar Collectors

Source: 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), pp 293-298 [35]

In this experimental study Al_2O_3-H_2O nano fluid as working fluid is used for investigate the efficiency of flat plate collector. Volume fraction or concentration of nano particles are taken 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. Results evaluate that nano fluid show an enhancement in efficiency as comparison to water. Heat removal factor (F_R) value for nano fluid is 0.6194 and 0.6086 with and without surfactant. Adding surfactant into nano fluid has a positive effect seen on the efficiency of flat plate collector. It has also been concluded that efficiency of flat plate collector increasing by increase in mass flow rate. The results concluded from this paper 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.

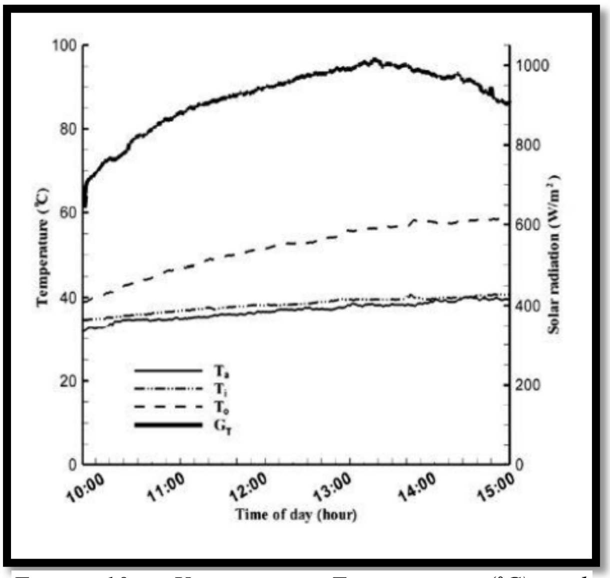


Figure 10: Variation in Temperature (˚C) with respect. to Time and Solar radiation (W/m^2) with change in day time

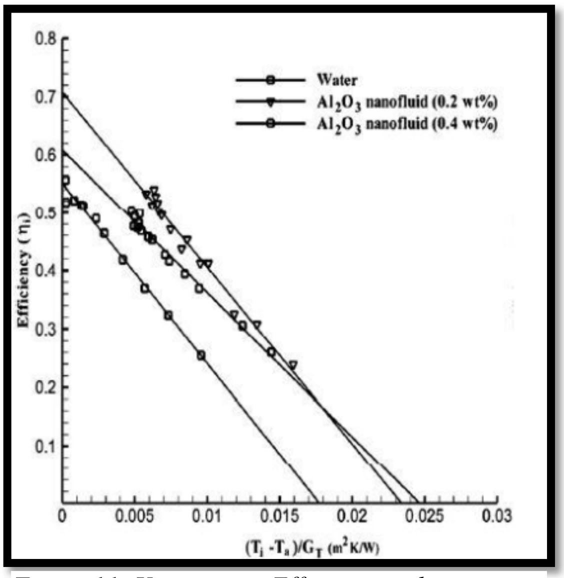


Figure 11: Variation in Efficiency with respect. to water and Al2O3 nanofluids at different volume concentrations

Source: Yousefi.T, Veysi.F, Shojaeizadeh.E, Zinadini.S (2012), "An experimental investigation on the effect of Al_2O_3 – H_2O nanofluid on the efficiency of flat plate solar collectors," Renewable Energy [35]

Figure 10 showed typical observed data of temperatures and solar radiations for base fluid i.e. water at mass flow rate 1Lit/min and Figure 11 represent the variations in efficiency of solar flat plate collector with respect to the reduced temperature parameters for different mass flow rate (Ti -Ta)/G_T. the slope of lines in the given figure is F_RU_L and is used to evaluate that how energy is removed or energy loss from the solar collector. Intersection of the slope lines on (Ti -Ta)/G_T i.e. efficiency of collector is zero and this point is also known by stagnation and is occur only when no fluid is flowing through the collector.

3.4.8 Performance Analysis of Parabolic Trough Solar Collector with Non Uniform Solar Flux Conditions

Source: Yanjuan Wang, Qibin Liu, Jing Lei, Hongguang Jin, Performance analysis of parabolic trough solar collector with non uniform solar flux conditions, International Journal of Heat and Mass Transfer; 82 (2015), pp 236–249 [36]

In this research paper numerical simulation has done, which is based upon solar ray trace method and finite element method. In this paper circumferential temperature difference of absorber achieve up to 22-94k with inlet temperature 373-673k along with direct normal irradiance 500-1250W/m^2 at inlet velocity range of 1-4m/s. in this work solar ray trace software is employed to compare the solar energy flux. It has been seen that non uniform distribution of solar energy flux results in non uniform distribution of temperature circumferentially, which is cause of mechanical stress in the absorber or receiver tube. In this paper discussion on heat transfer process in parabolic collector is included like convection heat transfer from working fluid to absorber, conduction heat transfer in absorber material and further transfer of heat from absorber to glass cover by radiations. All factors in this work are investigated numerically and results evaluate that non uniform flux distribution in circumferential direction and incremental change measured in temperature distribution on absorber circumferentially with the increment in DNI. Further circumferential temperature difference decrease with increase in velocity of heat transfer fluid and also increase in inlet temperature. In this paper stress distributions and deformations are calculated for the receiver only when end of receiver is allowed to be expanding along the axial direction. Also displacement measured in receiver tube is larger as comparison to displacement in glass cover.

3.4.9 Nanofluids with Enhanced Thermal Transport Properties

Source: Zenghu Han, Nanofluids with enhanced thermal transport Properties, Department of Mechanical Engineering, University of Maryland at College Park, Maryland; 2008 [8]

Conventional fluids have a low value of thermal conductivity, which directly effect to the heat exchange efficiency of the working thermal device. Some necessary changes are required to increase the effectiveness of the device like changes in design of the equipments of heat exchange and also use of extending surfaces like fins to enhance the heat transfer. To improve the heat transfer properties of fluid by mixing of solid particles into liquid, Also dispersion of solid particles in to base fluid or liquid is known by nano fluids. It has seen the investigators that nano fluids exhibit greater thermal conductivity value as compare to the conventional base fluids. In this research work a technique is used to synthesize the nano fluid i.e. nano emulsification along with the measurement of thermal properties of nano fluid, it has also been seen from experimental results that thermal conductivity enhancement was found 52% in water in FC72 nano fluids and increment in heat capacity 126% in water in FC72 nano emulsions, further viscosity of nano fluids is increased due to addition of nano particles in base fluid. It has been seen that due to increase of thermal conductivity, an enhancement is measured in heat transfer coefficient in water-in FC72 based nano fluids. All the experimental results evaluate that nano fluids acquire improved thermophysical properties like thermal conductivity.

3.4.10. Wind Engineering Analysis of Parabolic Trough Solar Collectors: The Effects of Varying the Trough Depth

Source: 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); pp 118–128 [37]

Flowing wind is greatly affect to parabolic trough collector system. Increasing concentration ratio, results in higher temperature achieved from receiver tube and concentration ratio is also increased due to increment in aperture area. Heat losses by convection increased due to high wind speed flowing over the collector. In this study airflow is measured with the aim of reduction in wind loads and also corresponding thermal heat losses from receiver, which results in higher concentration ratio is achieved from the system and incremental change in performance of efficiency of parabolic trough collector can be measured. Data evaluated from the series of test performed in wind tunnel and also from previous research work related to PTC. In this study simulation has done using CFD program with variable parameter i.e. depth of trough system. For every geometry of parabolic trough, total 17 types of simulation performed in this research work with the variation in pitch angle i.e. -90° to 90° with an increment of 15°. 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.

3.4.11 Performance Study on Evacuated Tube Solar Collector Using Therminol D-12 as Heat Transfer Fluid Coupled With Parabolic Trough

Source: P. Selvakumar, P. Somasundaram, P. Thangavel, Performance study on evacuated tube solar collector using therminol D-12 as heat transfer fluid coupled with parabolic trough, energy conversion and management, 85 (2014); pp 505–510 [38]

In this experimental work a parabolic work a parabolic trough based solar collector with evacuated tube using synthetic oil as a working fluid is developed for water heating purpose in low solar irradiance conditions. Evacuated tube with parabolic trough is used for the purpose of incremental change in heating characteristic of therminol D-12. The production of hot water is possible at around 60℃ in case of low solar irradiance. The experimental study is conducted in the morning time 6:00am to 9:00am, in which solar radiations is varied from 200W/m^2 to 600W/m^2. Experimental study has done with and without the application of parabolic trough and mass flow rate is decided also i.e. 0.05 and 0.08Kg/sec. the maximum temperature measured in case of evacuated tube without parabolic trough is 40°C, which is at 540W/m^2 solar irradiance and it is less than temperature attained from evacuated tube with parabolic trough by amount of 28°C, it means that evacuated tube with parabolic trough possess 68°C temperature under the low solar irradiance conditions. An enhancement in heating efficiency is also measured i.e. 30% for purpose of instant hot water generation.

3.4.12 Design, Fabrication and Experimental Analysis of a Parabolic Trough Collector Using Different Reflecting Material for Hot Water Generation

Source: Sanjay and Devender Kumar, design fabrication and experimental analysis of a parabolic trough collector using different reflecting materials for hot water generation- a thesis, mechanical engineering department, thaper university (2012) [39]

In this experimental thesis work design, fabrication and experimental analysis of PTC prototype along with feasibility study of manufactured prototype are discussed in detail. An experimental set up of parabolic trough collector is fabricated for thermal analysis with different reflecting materials for the purpose of comparison b/w performance or efficiency, which is different for various reflecting materials like stainless steel, aluminium foil and also glass mirror. Maximum value of temperature achieved 81.2°C and average value of temperature measured 65°C. Results come out for improved efficiency 5 to 40% through application of glass as a reflecting material instead of stainless steel and aluminium foil. This study also conducted that reduction in mass flow rate results in improvement in efficiency comes out from the thermal analysis of PTC. A steady state thermal analysis has done with proper understanding of heat transfer concept b/w glass cover and absorber tube and also b/w absorber tube to working fluid. Improvement in instantaneous efficiency 4 to 40% measured with the help of glass mirror as comparison to instantaneous efficiency comes out from stainless steel and improvement 5 to 35% is measured as comparison to aluminium foil’s instantaneous efficiency. Improvement in overall system efficiency 40% is measured through glass mirror. Further an improvement in optical efficiency is also measured using glass mirror instead of other reflecting materials.

CHAPTER-4

Research Gap

After study about past research in the field of performance improvement of collector system I found out that efficiency of solar collector mainly depends on the thermo physical properties of the working fluid, which is absorbing or extracting the heat. So it has been found that the thermal properties (thermal conductivity, heat capacity, viscosity, etc.) of the flowing fluid, which are used to absorb the energy plays an important role to make the system more effective.

By study and reviewing the past research, it has been seen that conventional fluids can absorb heat up to a certain limit, which in turn limits the efficiency of solar collector. Therefore application of nano fluid comes in to existence because it nano fluid has a capability to extract high quantity of thermal energy from incoming sun rays. So these nanofluids can be used in solar collectors in order to improve its performance. There are also some challenges in the application of nonofluids and all that are discussed as below:

(1) High Cost of MWCNTs

Cost of manufacturing for MWCNTs is very high due to costlier mechanism to manufacture MWCNTs by CVD method and further formation of nano fluid is not so easy because it require some finite method like sonicator and stirring device. In this project MWCNTs used to prepare nano fluid, which is very costlier among other nano particles. MWCNTs used in this experimental study are manufactured in green nanotechnology limited with the method of catalyst chemical vapour deposition. Fabrication of PTC also acquires high cost due to copper absorber tube; pump required, employed tracking mechanism and insulation used on piping system.

(2) Problem of Instability and Agglomeration

Instability and agglomeration problem came during the working of nano fluid in solar parabolic trough collector. Improper sonication and stirring results in agglomeration of nano particles starts in base fluid during working as a working fluid and affect to the performance of the collector system badly. In natural circulation of fluid flow this problem has more chance arise and this is due to higher density of nanoparticles generally, while in forced circulation of fluid flow i.e. with the help of pumping system problem of instability and agglomeration can be minimized. Further MWCNTs possess less density as comparison to base fluid, so there are fewer chances to problem of MWCNTs and it is completely depends upon volume concentration of MWCNTs.

(3) Pumping Power and Pressure Drop in Solar Collector

With the use of nano particles in base fluid, viscosity starts increasing of the nano fluid mixture. Increasing viscosity can become a cause for decreasing pressure in the piping system; therefore system required more pumping power to pump the working nano fluid mixture through the receiver and piping system for efficient and proper working of solar collector on continuous basis. Further MWCNTs used in this experimental study at higher concentration in water has an ability to increase the viscosity of nanofluid. This problem can arise at lower volume flow rate and higher concentration of nanoparticles during the experimentation.

(4) Erosion and Corrosion of System Components

Nano particles used in base fluid also have a capability to enhance some problem like erosion and corrosion of collector components. Some research work related to erosion and corrosion effect of metallic nano particles is going on continuous basis to prevent these bad effects of the nano particles on collector receiver and pump system. Regarding the problem of erosion and corrosion of metallic structure due to presence of carbon nano tubes in the working fluid (water) may increase or decrease depending upon the material of construction, which can be investigated in further studies.

Some other important outcomes of literature review are discussed in detail as below:

1. Increasing volume concentration of nano particles in base fluid results in incremental change in viscosity, which have some positive and negative effects on system performance like incremental change in viscosity corresponding an increment change is measure in heat absorbing capacity of nano fluid and increasing viscosity also possess some negative affect like pressure drop is increased.
2. Thermo physical properties like thermal conductivity can be increased with the use of nano particles. MWCNTs possess higher thermal conductivity among other nano

particles, so its use in base fluid can increase the thermal conductivity of nano fluid mixture. After reviewing through past research work in the area of MWCNTs, it has been seen that MWCNTs and ethylene glycol based mixture showed greater increment in thermal conductivity value as comparison to enhancement comes in MWCNTs and water based mixture. Thermal conductivity also depends upon aspect ratio or length of nano tubes.

3. Specific heat can be increased or decreased of nano fluid mixture because it dependent upon specific heat of nano particles. Further nano particles size, variation in temperature and sonication time for nano fluid mixture affect to thermal properties of nano fluid mixture and corresponding changes in system performance.
4. Proper dispersion of nanoparticles in base fluid also necessary to avoid the problem of agglomeration and instability of nanoparticles and proper dispersion of nano particles can be possible with the help of functionalize nanoparicles and application of suitable surfactant with in nanofluid.
5. Performance evaluation process also depends upon proper tracking or way of tracking and continuous solar flux coming on solar collector.
6. Multiphase fluid flow model is required to analyse the problem of phase change during the working in parabolic trough collector system. When working fluid gains heat so much that it undergo the phase change i.e. from liquid state to gaseous state with the increasing solar intensity and corresponding increasing temperature of inlet and outlet temperature. In general nanofluid possesses higher density in comparison to base fluid due to the presence of MWCNT based nanoparticles and nanoparticles do not undergoes under phase change condition. Therefore it is necessary to find the solution for this kind of problem to avoid the agglomeration and instability of nanofluid. One method to avoid the problem of agglomeration during phase change with the help of phase change material and it is the important area for research point of view for further investigation in the field of varying thermo physical properties of nanofluid.
7. To analyse the fluid flow problem in receiver theoretically computational fluid dynamics can be used under natural boundary condition. CFD is a complex method to analyse the multiphase fluid flow and effect on varying thermophysical properties under varying environmental condition throughout the research time i.e. changing solar flux and wind speed and this method is also helpful to analyse the total heat losses from solar receiver and throughout the collector system and support structure.

Chapter-5

Problems Formulation

The detailed study of literature review helps us to evaluate the outcome of the review which associated with some problems also. This section describes the all problems associated with the technology (parabolic trough collector) and also with that of working fluid like nano fluids i.e. which is the combination of nanoparticle and base or conventional fluid used.

Some problems arise in all previous research study is as discussed below:

1. Cost of both nanofluid, which is used as a working fluid in the system and also the cost of parabolic trough collector system, which has a receiver tube that accounts maximum cost in overall cost of system.
2. Nano fluid with high viscosity produces pressure drop in the system so here more requirement of pumping power to pump the fluid so here cost of pumping also become a problem of cost increment. Further increment change in volume concentration of nano particles results in problem of agglomeration and instability of nano particles arise in the working system.
3. Structural characterization techniques of nano particles are necessary to find crystal structure and particle dimensions such as XRD, SEM and TEM. All these characterization techniques account big cost in the research work.
4. Heat loss from receiver due to convection, radiation and conduction can't be eliminated permanently. Also leakage problem, power failure and discontinuous solar flux greatly affect to the system performance.
5. While working of Nano fluid in solar collector, some erosion and corrosion problems come in to account.
6. Improper tracking and high wind speed has a capability to decrease down system performance and badly affect to inlet and outlet temperature of collector.
7. Use of nano fluid for increase the efficiency of the collector becomes common. Increased particle size and sonication time also have a capability to increase or decrease the performance of collector system.

Chapter-6

Objective of the Study

After going through all the past research and challenges coming in the path of my research I decided about the complete objective of my project work study i.e. Performance Analysis of Parabolic Trough Collector using Nanofluid.

(a) Technology used for project work Parabolic Trough Collector

(b) Proposed Nanofluid for my project work are MWCNT and distilled water based nanofluid mixture

Some important objectives related to project work are as follows:

- Variation in inlet and outlet temperatures, solar intensity and wind speed measured with change in day time through both MWCNT nanofluid (0.01wt% & 0.02wt %) and water at different volume flow rates 160L/h and 100L/h.
- Further variation in useful heat gain, thermal efficiency, instantaneous efficiency and overall thermal efficiency of the collector system measured with change in day time.

Chapter-7

Proposed Experimental Set-up

7.1 Introduction

This chapter deals with complete overview of research proposal along with flow chart of research work, which describe the way to do research study and also discussion have done on requirement of necessary instrument used in the experimental study.

7.2 Proposal of Research Work

Concentrated solar power systems are used to generate electricity on large scale and improvement in their working performance is also important from research point of view. In this research work most prominent technology parabolic trough collector system, which is a medium temperature collector system is used to complete the objective of research work. Parabolic trough collector system is the only system among other CSP systems, which can be used to generate power on both commercial and industrial basis. There are lot of research already held relative to design improvement of collector system and also with the use of different working fluid for enhancement of thermal performance of collector.

Nano fluids are the new approach, which can be used to enhance the thermal performance of solar thermal collectors. There are many researches going on all around the world with the use of different nanofluid in different system to improve the working performance. This research study also based upon use of nanofluid in parabolic trough collector for the purpose of efficiency improvement. It has been seen from previous research study that multiwalled carbon nanotubes acquire better thermophysical properties among other nanoparticles like thermal conductivity is very high. So after study about all research parameter, I would like to decide the use of MWCNTs in water to manufacture the nanofluid, which can be used as working fluid for parabolic trough solar collector and after going through many research papers related to field of nanofluids applications, I decided to take the MWCNTs concentration in 6 litre water 0.01wt% and 0.02wt% and MWCNT nanofluid is used as working fluid for the receiver of solar parabolic collector to flow at different volume flow rates. Less concentration of MWCNTs in water is due to higher cost and very less density of MWCNTs. The complete steps of proposed research work are discussed in flow chart as discussed below:

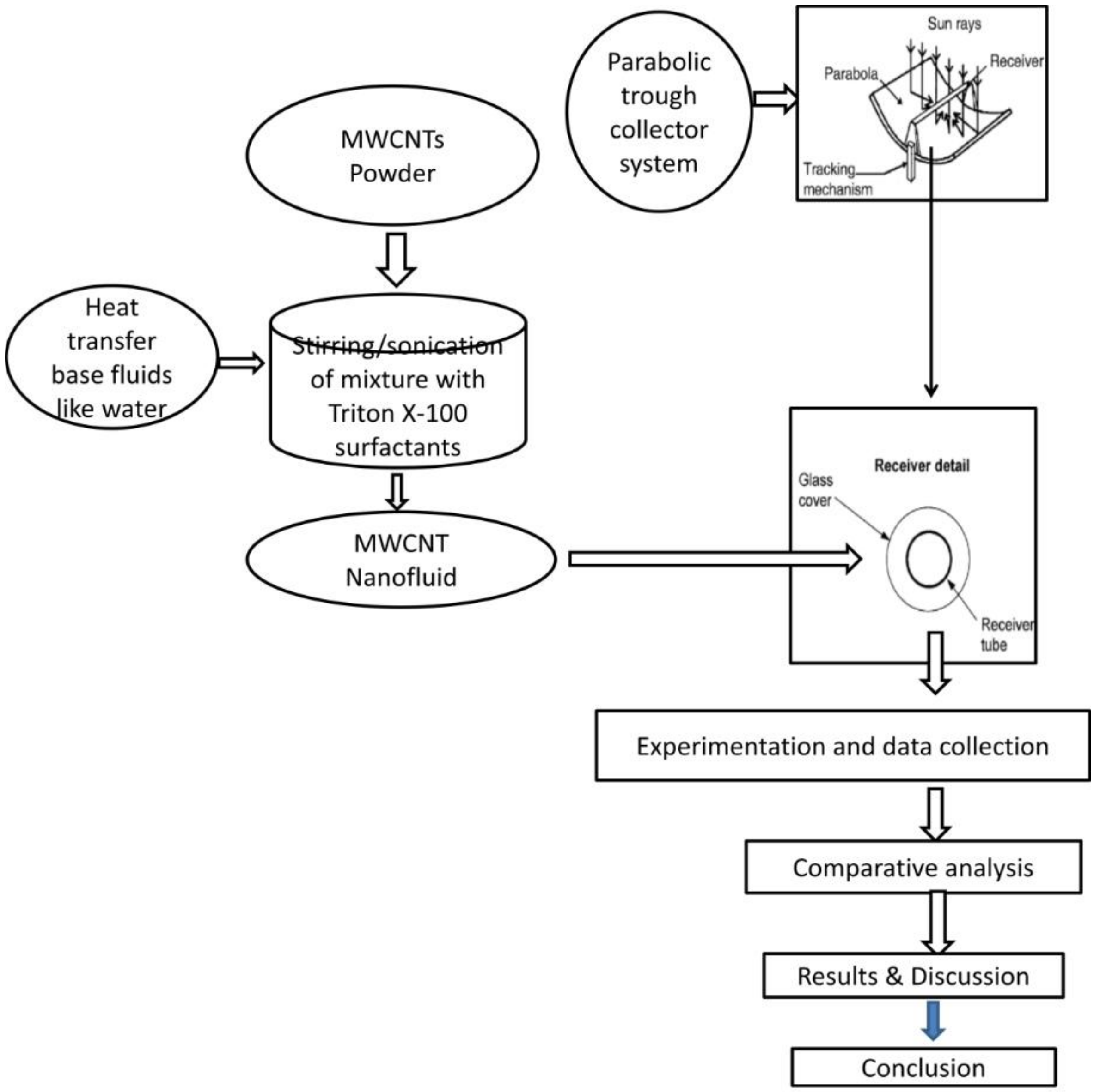


Figure 12: shows the complete flow chart of proposed experimental work

Important steps of research work are discussed as below:

1. MWCNTs powder of diameter 20-40nm used for the preparation of nano fluid, in which water is used as a base fluid. To prepare MWCNT nanofluid an ultra sonication device is used. Hot plate stirrer is also required before the process of sonication for proper dispersion of MWCNTs in water.
2. Proper dispersion of MWCNTs in water is necessary from research point of view to avoid the problem of agglomeration and instability occurs during the experimental

study. Therefore an application of Triton X-100 surfactant is used for better dispersion behaviour.

3. After preparation of nanofluid, now it is ready to flow inside the collector receiver tube for certain time period. Copper receiver with outside painted black is used for solar parabolic trough collector and a Pump is used inside a storage tank for forced continuous flow of fluid.
4. Inlet and outlet temperatures measured after an interval of half an hour through thermometers. Solar power meter is used to measure the global solar flux at an instant and anemometer is also used to measure the wind speed over the solar collector. Detailed descriptions on instruments, which are used in experimental research work, are discussed in next section of instruments and devices.
5. Manual tracking system is used to track the movement of sun in east to west direction and also in north south direction during the experimental study from 9:00am to 3:30pm.
6. After the completion of experimental work, all temperatures and solar intensity data is used for evaluation of thermal, instantaneous efficiency and overall thermal efficiency. Further comparative analysis includes the comparison between the efficiency parameters comes out from this research study and also from previous research work through the same MWCNT-H_2O nanofluid. All results are shown graphically in separate chapter of results and discussion, which is discussed in detail later.

7.3 Experimental Set up

For compare and analyse the performance, first we have to prepare a model of parabolic trough collector with manual tracking system are used to complete our aim and to carry out the different experiments. A parabolic trough collector consist of a parabolic shape, a stainless steel can be employed for this structure the reason behind it gives mechanical strength and a tube carry heat transfer fluid is also employed and manufactured from copper material, also known by receiver tube and its outside surface painted black to absorb the maximum solar radiation and can also it covered with glass to reduce the losses which is due to conduction, convection and radiation. Storage tank also provided to store the fluid and necessary insulation is used to reduce heat loss from receiver, piping system and storage tank.

Figure 13: Front view of experimental set up of PTC system (Thapar University)

Figure 14: Rear view of PTC system

Figure 15: Side view of PTC system

Specification of solar parabolic trough collector[47]:

1. Length of the collector = 1.2m
2. Breadth of the collector = 0.915m
3. Area of the aperture = 1.0188m^2
4. Rim angle = 90°

5. Focal length = 0.30m
6. Inside diameter of the receiver = 0.027m
7. Outside diameter of the receiver = 0.028m
8. Length of the receiver = 1m
9. Inside diameter of the glass cover = 0.064m
10. Outside diameter of the glass cover = 0.066m
11. Insulation used on storage tank and pipes = glass wool and aluminium foil
12. Pump for fluid circulation = 18W
13. Nano material used = MWCNTs
14. Basefluid used = Distilled water
15. Volume flow rates = 160L/h & 100L/h
16. Weight fraction of MWCNTs = 0.01% & 0.02%

7.3 Instruments and Devices

There are various type of instruments required to achieve the objective of our project like solar power meter, anemometer, sonication, structural characterization techniques for nanoparticles, magnetic stirrer and thermometers etc can be used. Some important of all these instruments are discussed in below:

7.3.1 Solar Power Meter

This device is used to measure heat flux directly coming on the solar collector throughout the day time and is measured in W/m^2. Solar power meter have a sensor inside with it, which observes solar intensity and display the reading on the screen of device.

Specifications of Solar Power Meter:

Display = $3\frac{1}{2}$ digits, 2000 readings

Range = 2000W/m^2, 634 BTU/ (ft2×h)

Resolution = 0.1W/m^2, 0.1BTU/ (ft2×h)

Accuracy of soalr power meter = within +/- 10W/m2 [+/-3 BTU/ (ft2xh)] or +/- 5% whichever is greater in sunlight. Temperature included error +/- 0.38 W/m2 / ºC [+/-0.12 BTU/

Figure 16: Solar Power Meter (Tenmars TM-207)

(ft2xh)] / ºC] deviation from 25 ºC

Angular accuracy = Cosine corrected

Drift = < +/- 2% per year

Over input = Display "OL"

Sampling time = 0.25 second

Operating Temperature and Humidity = 0C~50ºC below 80% RH

Power supply in solar power meter = 9V battery x1

Length of sensor wire = 1.5M

Size of Solar power meter = 130x 55x 39mm (LxWxH)

Weight of Power meter = 150g

7.3.2 Anemometer

Anemometer is used to measure wind flow or wind speed during experimental work and is measured in 'm/s'. Fan of device can stack in the direction of flowing wind, which in turn fan rotated and digital reading for velocity of wind displayed on screen of the device. Measurement of wind speed is necessary with respect to performance evaluation of solar collector system because an increase in wind flow, there is a chance for heavy convective heat losses from the collector device and decrease down the working performance of solar collector.

Figure 17: CFM/CMM Vane Anemometer (PRECISE AM804)

7.3.5 Sonication Process

Sonication process is done to improve the behaviour of dispersion of nano particles in base fluid. Sonication has a capability to increase the thermal conductivity of nano fluids. Time of sonication also gives an effect on zeta potential and nano particle size.

Sonication is a technique to disperse the aggregated nano particles or to avoid agglomeration. Water based MWCNT showed different dispersion behaviour due to ultra sonication time. It means below the optimum sonication time MWCNT and distilled water based nano fluid showed better dispersion quality. But beyond the limit of optimum sonication time results in breakage of length of nano tubes starts, which in turn decreased the aspect ratio [28]. A surfactant Triton X-100 is used is almost in same amount as that of MWCNTs used to avoid the quick sedimentation of MWCNTs in base fluid and also help to reduce the tendency for agglomeration of MWCNTs. To prepare the MWCNT and distilled water based nano fluid there is necessary to evaluate the weight of the MWCNTs required for different concentration. The weight of MWCNTs can be evaluated by using the formula of volume concentration as discussed below:

Figure 18: BRANSON Sonication device

Volume concentration of nano particle is denoted by 'φ_v'

$$\varphi_v = \frac{V_P}{V_{EFF}} \text{ [46].................. (1)}$$

Here

$$V_P = \frac{W_P}{\rho_P} \text{ .... (2)}$$

&

$$V_{EFF} = V_P + V_F \text{ ....(3)}$$

Assume data for experimentation

Quantity of base fluid taken = 6 liters

Density of MWCNT nano particles = $0.25\frac{gm}{cm^3}$

Standard density of water or base fluid (ρ_F) = $1000\ \frac{kg}{m^3}$

φ_v	0.01%	0.02%
W_p (gm)	0.15	0.35

Table 1: Calculated weight of MWCNT nano particles for different concentration

18(i) 18(ii)

Figure 18(i) & 18(ii) shows weight measurement instrument for nano particles in grams

A calculated amount of MWCNT put into container with of Triton X-100 surfactant and mixed with distilled water as per decided amount 6 liters. First stirring the the mixture for a certain time for the achievement of homogeneous mixture and then is mixture has put on the sonication device for the total time 3:30 hours.

18(iii) 18(iv) 18(v)

Figure 18(iii), 18(iv) & 18(v) shows sample of mixture (φ_v= 0.01%) and bucket of MWCNT and water based nano fluids at 0.01% and 0.02% volume concentration

7.3.6 Magnetic Stirrer

Magnetic stirrer is a device that created a rotating magnetic field due to rotating magnets or with the help of stationary magnets, which is cause of stir bar immersed in a liquid to spin very fast and result in stirring it. A Glass vessel does not have any effect on the magnetic field, when glass vessel used in stirring purpose. Use of magnetic field in mainly in the areas of chemistry and biology and it is better than gear driven motorized stirrer, because it posses less wear and tear due to in presence of any moving parts and quieter in operation or working. It also includes a hot plate to heat the liquid containing in glass vessel.

Figure 19: Magnetic stirrer with hot plate

7.3.7 Thermometers

Thermometer can be used to measure the temperature of working fluid flowing through the parabolic collector and these thermometers are placed on inlet and outlet edge of the receiver tube. Thermometer contain mercury, which senses the temperature of working fluid at inlet and outlet side of the collector absorber tube and its range vary from 10-110℃ .

Figure 20: Thermometer

Chapter-8

Experimentation and Data collection

8.1 Introduction

This section deals with experimental readings or data of inlet and outlet temperatures, heat flux and wind speed measured throughout the day along with the detailed description of different thermo physical properties of water and MWCNT & distilled water based nano fluid. Further this area include all performance evaluation related equations and structural characterization techniques for MWCNTs also discussed.

8.2 Mathematical Equations for Evaluation of Performance of Parabolic Solar Collector

The working performance of the PTC system is determined by calculating useful heat gain, thermal efficiency (per half an hour), instantaneous efficiency and overall thermal efficiency. Following are the equations which are generally used to investigate the performance of solar collectors.

(a) The density of the nanofluid is determined by using eq. (4)

$\rho_{nf} = (1 - \varphi_p)\, \rho_f + \varphi_p\, \rho_{np}$ ………………………..................(4)

Source: 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); pp 293-298

(b) The specific heat of the nanofluid is determined by using eq. (5).

$c_{nf} = \{(1 - \varphi_p)\, \rho_f\, c_f + \varphi_p\, \rho_{np}\, c_{np}\} / \rho_{nf}$…………………..........(5)

Source: 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); pp 293-298

(c) Thermal conductivity of the nanofluid is determined by using eq. (6).

$k_{nf} = \frac{k_f\, [k_{np} + 2\, k_f + 2\, \varphi_p\, (k_{np} - k_f)]}{[k_{np} + 2\, k_f - \varphi_p (k_{np} - k_f)]}$...(6)

Source: Shaker M., Birgersson E., Mujumdar A.S. (2014), "Extended Maxwell model for the thermal conductivity of nanofluids that accounts for nonlocal heat transfer," International Journal of Thermal Sciences, vol. 84, pp. 260-266 [22]

(d) Viscosity of the nanofluid is determined by using eq. (7).

$\mu_{nf} = \mu_f / (1 - \varphi_p)^{2.5}$ ....(7)

Source: Purna Chandra Mishra, Sayantan Mukherjee, Santosh Kumar Nayak, Arabind Panda (2014), "A brief review on viscosity of nanofluids," Int Nano Lett, vol. 4: pp. 109–120 [45]

(e) Useful heat gain of the system is determined by the using equation (8).

$Q_u = \dot{m}C_{nf}(T_{out}-T_{in})$………...(8)

Source: S.P. Sukhatme, J.K. Nayak, Solar Energy principles of thermal collection and storage, Mc Graw Hill, ISBN 0-07-026064-8, (2012) [3]

(f) Thermal efficiency of the system is determined by the applying equation (9).

$\eta th = mC_{nf}(T_{out}-T_{in})/A_{aper}G_T t$………......................................(9)

Source: S.P. Sukhatme, J.K. Nayak, Solar Energy principles of thermal collection and storage, Mc Graw Hill, ISBN 0-07-026064-8, (2012) [3]

Here

G_T is incident solar flux in W/m^2

T is correction factor

(g) Instantaneous efficiency of the system is determined by applying eq. (10).

$\eta_i = q_u / G_T R_b W L$ ……..(10)

Source: S.P. Sukhatme, J.K. Nayak, Solar Energy principles of thermal collection and storage, Mc Graw Hill, ISBN 0-07-026064-8, (2012) [3]

(h) Overall thermal efficiency is determined by the following eq.(11)

$\eta_{ot} = mC_{nf}(T_{max}-T_{mini})/A_{aper}G_{av}t$……..................................(11)

Source: S.P. Sukhatme, J.K. Nayak, Solar Energy principles of thermal collection and storage, Mc Graw Hill, ISBN 0-07-026064-8, (2012) [3]

(i) Convective heat transfer coefficient is determined by applying eq. (12)

$h_f = N_u \times k / D_i$ ………………..(12)

Source: S.P. Sukhatme, J.K. Nayak, Solar Energy principles of thermal collection and storage, Mc Graw Hill, ISBN 0-07-026064-8, (2012) [3]

8.3 Properties of Nanofluid Mixture & Water

In this section available properties of MWCNTs, thermo physical properties of MWCNT and distilled water based nano fluid mixture and experimentally measured thermo physical of distilled water and some other important properties of distilled water are also discussed.

8.3.1 Properties of MWCNT Nano particles

This section includes the thermo physical properties of MWCNTs powder. MWCNT Sample provided by 'Green nano technological limited' and complete description about properties is discussed below;

(1) Diameter of nano particles = 20-40nm

(2) Length of nano particles = 1-10micrometer

(3) No of walls of nano particles = 3 to 15

(4) Density of nano particles = 0.25 $\frac{gm}{cm^3}$

(5) Surface area = 350 $\frac{m^2}{gm}$

(6) Thermal conductivity of nano particles = 1500$\frac{W}{m-k}$ [40]

(7) Specific heat capacity of nano particles = 630$\frac{J}{kg-k}$ [40]

8.3.2 Properties for MWCNT based Nano fluid Mixture

Thermo physical Properties of nano fluid mixture are calculated through formula as discussed before. To calculate the thermal conductivity and viscosity of MWCNTs based nano fluid mixture, experimentally measured viscosity and thermal conductivity for distilled water can be used in the formula of nano fluid mixture, while standard density value is used for distilled water and calculated value of all other properties are shown in table below:

Thermo physical Properties		Mixture I (φ_p = 0.01%) (MWCNT+ Distilled Water)	Mixture II (φ_p = 0.02%) (MWCNT + Distilled water)
Thermal Conductivity (K_{mix})		0.61718489 $\frac{W}{m-k}$	0.617369817 $\frac{W}{m-k}$
Dynamic viscosity (μ_{mix})		0.000854213 $\frac{Kg}{m-sec}$	0.000854427 $\frac{Kg}{m-sec}$
Kinematic viscosity (ν_{mix})		$0.854 * 10^{-6} \frac{m^2}{sec}$	$0.854 * 10^{-6} \frac{m^2}{sec}$
Specific heat (C_{Pmix})		4186.91 $\frac{J}{kg-k}$	4186.82 $\frac{J}{kg-k}$
Density (ρ_{mix})		999.925 $\frac{kg}{m^3}$	999.85 $\frac{kg}{m^3}$
Mass flow rate ($\dot{m}_{mix}$)	Vol. flow Rate	Mixture I (φ_p = 0.01%)	Mixture II (φ_p = 0.02%)
	160L/h	0.04444 $\frac{Kg}{sec}$	0.044437$\frac{Kg}{sec}$
	100L/h	0.027775 $\frac{Kg}{sec}$	0.0277736 $\frac{Kg}{sec}$
Mass of mixture (m_{mix})		5.99955 Kg	5.9991Kg
Average Velocity(V_{avgmix})	Vol. flow Rate	Mixture I (φ_p = 0.01%)	Mixture II (φ_p = 0.02%)
	160L/h	0.077622m/s	0.077623m/s
	100L/h	0.048514m/s	0.048449m/s
Reynold No. (Re_{mix})	Vol. flow Rate	Mixture I (φ_p = 0.01%)	Mixture II (φ_p = 0.02%)
	160L/h	2454.091335	2454.122951
	100L/h	1533.814988	1531.759953
Prandtl No. (Pr_{mix})		5.794880934	5.794471893
Nusselt No. (Nu_{mix})	Vol. flow Rate	Mixture I (φ_p = 0.01%)	Mixture II (φ_p = 0.02%)
	160L/h	23.92534563	23.92491667
	100L/h	3.66 [3]	3.66 [3]

Convective heat Transfer coefficient (h_{Fmix})	Vol. flow Rate	Mixture I (φ_p = 0.01%)	Mixture II (φ_p = 0.02%)
	160L/h	546.9022893	547.0563491
	100L/h	83.66284064	83.68790853
Collector efficiency factor ($F^{'}$)	Vol. flow rate	Mixture I (φ_p = 0.01%)	Mixture II (φ_p = 0.02%)
	160L/h	0.9754369	0.9754437
	100L/h	0.8586555	0.8586919
Heat removal factor (F_r)	Vol. flow Rate	Mixture I (φ_p = 0.01%)	Mixture II (φ_p = 0.02%)
	160L/h	0.971861499	0.971781752
	100L/h	0.854227064	0.854262771

Table 2: Thermo Physical Properties of Nanofluid Mixture at Different Concentration 0.01% and 0.02%

8.3.3 Evaluation of Thermo Physical Properties of Distilled Water Experimentally and Theoretically

In this section thermo physical property of distilled water is discussed. Thermal conductivity, Density and specific heat are calculated experimentally as shown below:

(a) Thermal Conductivity of Distilled Water

Instrument used to calculate the thermal conductivity of distilled water is KDP Pro and it can also used to calculate the thermal diffusivity at different required temperatures after some interval. KDP PRO works on the principle of transient hot wire and it is a hand held device. It has a needle sensor, which is used to measure thermal conductivity

Figure 21: KD2 PRO Conductivity Meter

	Thermal Conductivity (W/m-k)	Room Temperature (℃)	Error Occured
Distilled Water	0.643	20.69	0.0077
	0.665	20.98	0.0068
	0.592	21.14	0.0072
	0.569	21.26	0.0074
	AVERAGE = 0.617W/m-k		

Table 3: Experimentally Calculated Thermal Conductivity of Distilled water

(b) Experimental Density of Distilled Water (16/3/2015)

ANTON PAAR Density meter is used to measure the density of distilled water and also known by U-tube oscillating apparatus. This device is used to calculate density as well as specific gravity of the liquid, which is injected into the device in amount approximately 4ml.

Figure 22: Density Meter (Anton Paar-DMA 4500)

Distilled water	Density (g/cm^3)	Specific Gravity	Temperature (°C)
	0.99911	1	15
	0.99690	0.9994	22.98
	0.99793	0.9999	21.03
	Average=0.99798		

Table 4: Experimentally Evaluated Density of Distilled Water

(c) Viscosity of Distilled water (17/3/2015)

Viscosity of distilled water can be determined by automated kinematic viscometer and this apparatus is known by Petrotest viscobath. Newtonian liquid's viscosity can be evaluated through viscometer. Kinematic viscosity of liquids can be calculated by using formula as given below:

Kinematic viscosity = k * T

here

k (capillary constant) = 0.02672 mm^2/s^2

&

T is flow time period of the liquid

Figure 23: kinematic viscometer (Petrotest Viscobath)

Sample	Kinematic viscosity ($\frac{mm^2}{sec}$)	Time period (sec)	Temperature (℃)
Distilled Water	0.000000774	29	38.8
	0.000000908	34	28.2
	0.000000881	33	30.3
	Average=0.000000854		

Table 5: Experimentally Evaluated Kinematic Viscosity of Distilled Water (17/3/2015)

Thermal conductivity (K)		$0.617\frac{W}{m-k}$
Density (ρ)		$1000\ \frac{kg}{m^3}$
Dynamic viscosity (μ)		$0.854 * 10^{-3}\frac{Kg}{m-sec}$
Kinematic viscosity (ν)		$0.854 * 10^{-6}\frac{m^2}{sec}$
Specific heat (C_P)		$4.187\ \frac{KJ}{kg-k}$
Reynold No. (Re)	160L/h	2453.901639
	100L/h	1533.814988
Nusselt No. (Nu)	160L/h	23.92455252
	100L/h	3.66 [3]
Prandtl No. (Pr)		5.795296596
Average velocity	160L/h	0.077616m/s

	100L/h	0.048514m/s
Convective heat transfer coefficient (h_F)	160L/h	546.7203298
	100L/h	83.63777778
Mass flow rate ($\dot{m}$)	160L/h	$0.04444\frac{Kg}{sec}$
	100L/h	$0.027777\frac{Kg}{sec}$
Collector efficiency factor ($F^{'}$)	160L/h	0.975429002
	100L/h	0.858619195
Heat removal factor (F_R)	160L/h	0.971853735
	100L/h	0.854191545
Mass of water ($\rho *$ Volume) (Here volume of water taken= 6 litres)		6 Kg

Table 6: Important Properties of Water

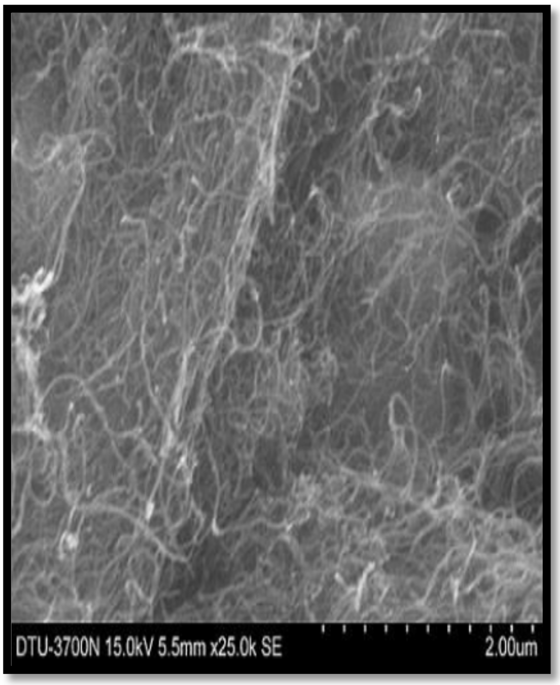
8.4 Structural Characterization Techniques

There are many type of structural characterization techniques used to obtain the information regarding the structure of MWCNTs. This section deals with the important structural techniques like Scanning Electron Microscopy (SEM), Transmission Electron Microscopy and Raman Spectroscopy. All these techniques are discussed in detail as below.

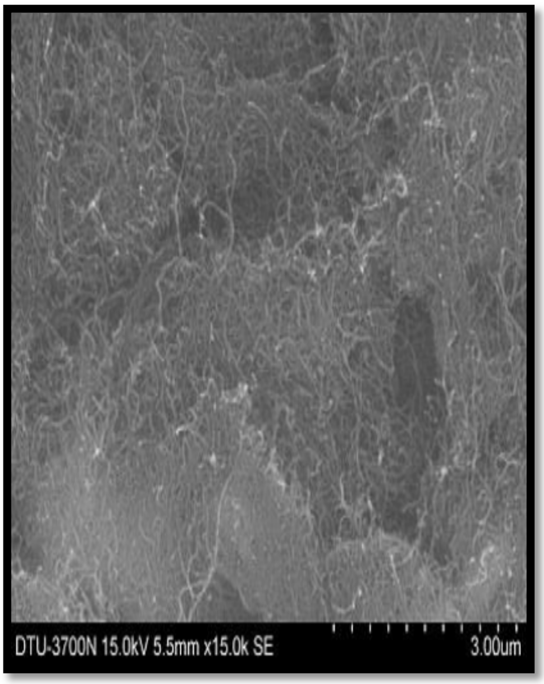
8.4.1 Scanning Electron Microscopy (SEM)

In this technique high energy electron are used to produce image of solid surfaces and also provide the necessary information about structural arrangement and geometrical features of

carbon nano tubes. In this method a topographical image of CNT sample formed due to the generation of secondary electron, when primary electron beam is used to scan the surface of CNT sample. SEM images for MWCNTs are shown in figure below,
SEM is provided by the nano science and technology department of DTU, New Delhi.



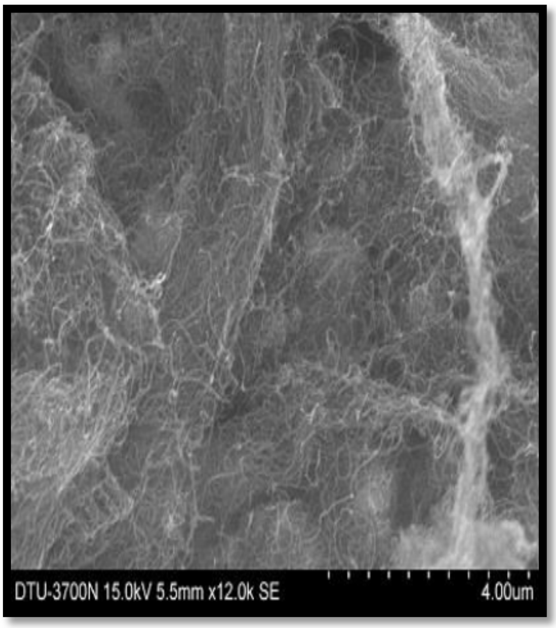
24(A)



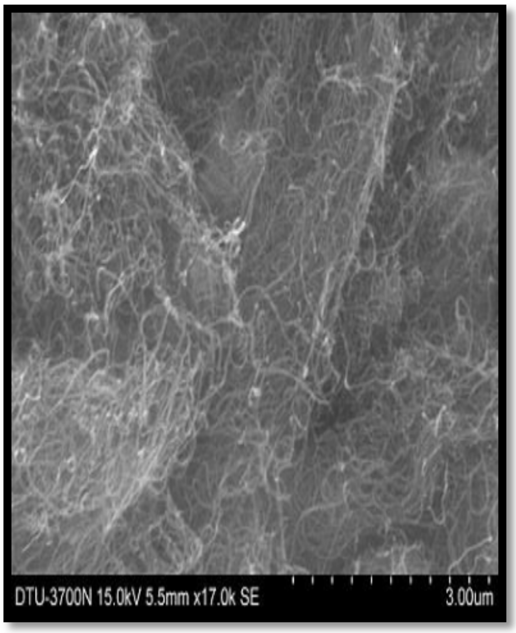
24(B)

Figure 24(A) & 24(B) SEM image of MWCNTs

Source: Department of Nano Science Technology, Delhi Technological University



24(C)



24(D)

Figure 24(C) & 24(D) SEM image of MWCNTs

Source: Department of Nano Science Technology, Delhi Technological University

- Significance of SEM

Figures of SEM for MWCNTs with 20-40nm diameter and length 1-10μm as shown upper side describe that morphology of nanotubes are randomly intertwine together and highly connect with each other, which can be probably due to vander wall's forces. All figures of SEM completely shows that primarily agglomerated carbon nanotubes and nanofibers are present in non uniform tubular structure and also possess large surface area by the nanotubes because of small diameter and large length of multiwalled carbon nanotubes and nanofibres. Generally properties of MWCNTs that influence the surface area are no of walls present, diameter of nanotube, length and impurities present in material sample. Large surface area possessed by multiwalled carbon nanotubes as completely understood by SEM image become a cause to provide a better media for thermal transport in nanofluid. Further SEM figure 24(c) completely shows that sample of MWCNT present in agglomerated form and formation of MWCNTs bundle starts at some places, which can give the negative effect on property of thermal conductivity of nanofluid and also it starts to decrease the heat transfer between nanotubes. To avoid the problem of agglomeration of nanotubes, use of sonication device along with magnetic stirrer is much necessary for this experimental study. Further SEM is also used for the evaluation of defects present in carbon nanotubes along with evaluation of any damage to CNTs, which has also an effect on mechanical properties, electrical and thermal properties of CNTs [44].

Important points related to SEM are discussed as under:

- All images of SEM as shown upper were taken with different resolution 2μm, 3μm and 4μm and magnification by the application of SEM to visualize the morphology of nanotubes and sample of nanotubes along with arrangement of nanotubes. MWCNTs produced by CVD method with diameter of 20-40nm, length 1-10micrometer and number of walls 3-15 used for experimental study. SEM image is an important tool to find out the purity of MWCNT sample and also for other different sample of nanoparticle. After find out unwanted material in all area of sample surface, it is helpful for us to estimate the degree of purity of MWCNTs sample.
- SEM is the important technique to visualize the outer morphology of the surface of MWCNTs sample and it can be coupled to TEM to find out the characteristics of internal surface morphology of MWCNTs sample.

- Tube diameter of MWCNTs can identify with the help of SEM technique and MWCNTs possess smaller diameter with the range of 1-20nm can be indentified at small resolution of SEM equipment [42].
- SEM technique is used to check the presence of MWCNTs in sample material, all figure of SEM shown above confirmed that nanotubes are present in the sample and shown in the form of fibres. SEM confirmed that sample is manufactured with 97-98% pure MWCNTs and approximately 2% amorphous carbon present in this sample material.

8.4.2 X- Ray Diffraction (XRD)

As discussed before XRD is the technique to indentify the crystal structure and atomic spacing in sample material and this technique is based upon the useful interface between monochromatic X-Rays, which are produced by cathode ray tube and crystalline sample material. Monochromatic radiations are generated and accelerated toward the sample in a collinear manner and concentrated on the sample. When incident ray interacted with sample, it produce diffracted ray and also satisfy the Bragg’s law. According to this relation wavelength of electromagnetic radiation is directly proportional to diffraction angle and also atomic or lattice spacing between the crystal structures of sample material. After that all diffracted rays are collected, detected and then counted.

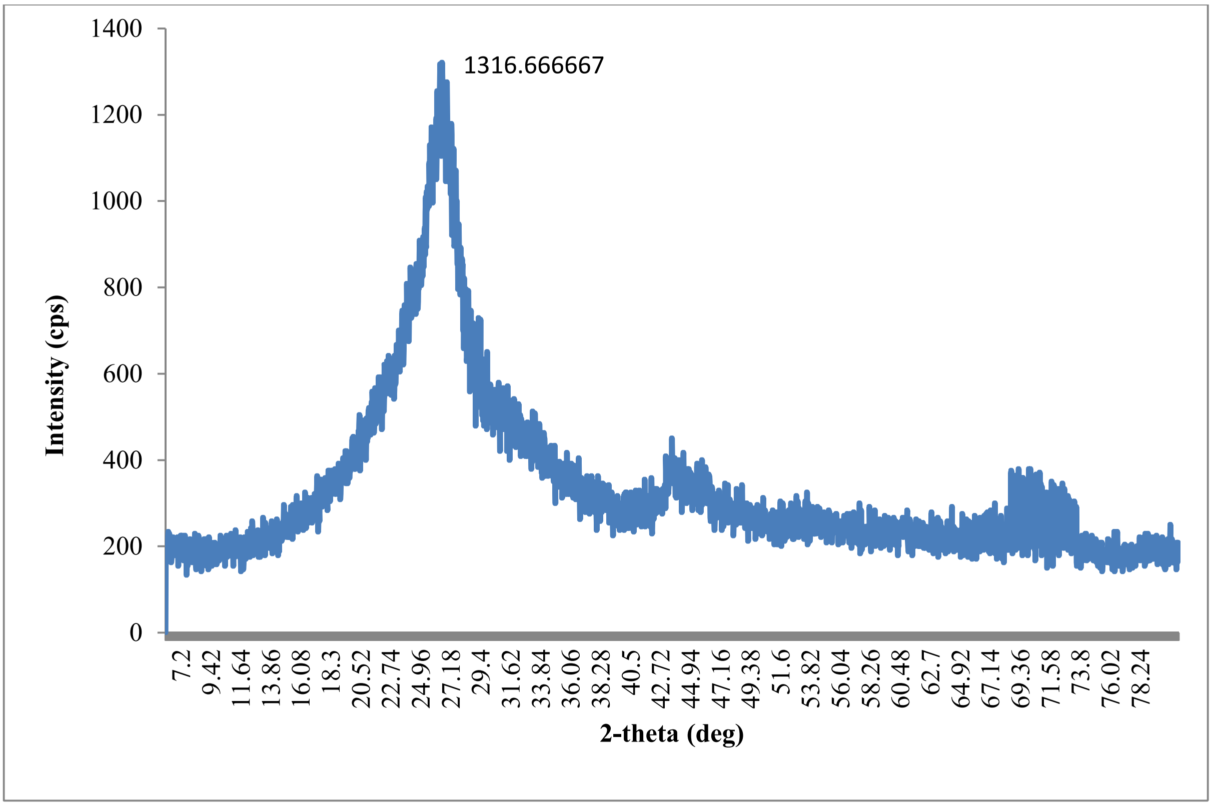


Figure 25: X-Ray Diffraction Graph for MWCNTs

- Significance of XRD

XRD pattern for MWCNTs as shown in figure 25 and XRD peak observed always at $2\theta \cong 26°$ and it is the technique to measure interlayer spacing using Bragg's law. XRD has a capability to investigate sample purity. It is completely clear from the figure of XRD that maximum intensity of peak is 1316.66 count per second for the MWCNTs with diameter of 20-40nm. XRD peak of MWCNTs shows that provided sample is present in the form of crystalline structure, apart from this it has also determined the degradation of physical properties due to defects formation in crystal structure of sample material. Width of the highest intensity peak 1316.66cps of X-Ray have been used to measure the size of crystal and if calculated crystalline size from XRD peak as in figure 25 showed smaller value than determined from manufacturers shown in fig.9 by measurement of surface area, then it can be only due to agglomeration of MWCNTs power and it has also been seen that increase in viscosity and thermal conductivity of nano powder monotonically depend on the actually measured XRD crystalline size rather than the nominal size of nano powder measured from surface area. Therefore difference in the structural measurement has a possible effect on heat transfer properties in nanofluids[43]. MWCNTs sample used without the attachment of functional group for this experimental work, XRD as shown upper also help us to analyze the functionality of carbon nanotubes, it is necessary because thermal conductivity of carbon nanotubes is governed by the transportation of phenons and it has been seen that any process of functionalization has an bad effect on phonon transportation, which can decrease the thermal conductivity. Functionalization of carbon nanotubes with hydrogen atoms also reduces their thermal conductivity and enhancement in degradation of thermal conductivity can be measured due to the reduction in the length of scattered phenons [44].

Important point related to XRD:

- XRD tool used to analyse the structure of MWCNTs at atomic and molecular level. The X-ray beam diffract in many direction due to presence of atoms. XRD crystallographer tool produce a 3D image for density of electron, which is based upon angles and diffracted beam intensity.
- Evaluated density of electrons describes the chemical bonding between the atoms of structure, position and atoms disordering of crystal structure. It is important technique to determine the length of nanotubes, size of MWCNTs, and also chemical bonding in material. It also used to measure atomic spacing between layers
- In figure 25, diffracted patterns are shown for MWCNTs to indentify the presence of Mutiwalled carbon nanotubes and also study of phase. From XRD figure, it is clear that MWCNT sample are crystalline in structure.
- Highest value of the peak of X-Ray 1316.66cps is formed at 26° value of 2-theta, which gives confirmation regarding the crystal structure of Multiwalled carbon nanotubes in sample material.
- In this technique d-spacing term is used to find out the distance between the crystal's atomic layers.

8.4 Experimental Data and Readings

This section includes the reading and data of experimental work. MWCNT and distilled water based nano fluid mixture and water is used as a working fluid in parabolic trough collector to find out results. A transient state thermal analysis has done on experimental system by assuming that piping and storage tank are properly insulated.

Experimental Day 24/3/2015

Time interval (half an hour)	Temperature Inlet (°C)	Temperature Outlet (°C)	Solar Intensity (W/m^2)	Wind Speed (m/s)
9:30-10	24.9	27.9	941.454	0.9
10-10:30	27.9	33.1	1008.504	1
10:30-11	33.1	39.5	1123.949	0.2
11-11:30	39.5	45.5	1085.224	0.9
11:30-12	45.5	50.8	974.809	1
12-12:30	50.8	54.8	960.654	0.95
12:30-1	54.8	58	956.929	0.8
1-1:30	58	59.6	942.029	0.9
1:30-2	59.6	60.5	893.604	1.2
2-2:30	60.5	60.9	887.644	2.2
2:30-3	60.9	61.2	874.239	2.3

Table 7: Variation in Inlet and Outlet Temperature, Solar intensity and Wind speed for MWCNTs and Distilled water based mixture at 160L/h Volume flow rate with 0.01% Volume concentration.

Time interval (half an hour).	Temp. Difference (°C)	Useful Heat Gain (J/s)	Thermal efficiency	Overall Thermal Efficiency	Instantaneous Efficiency	Absorbed Flux
9:30-10	3	558.19884	4.36%	4.66%	60.416%	598.87
10-10:30	5.2	967.54465	7.06%		87.375%	705.32
10:30-11	6.4	1190.82419	7.79%		96.4936%	786.46
11-11:30	6	1116.39768	7.57%		93.690%	759.36
11:30-12	5.3	986.151286	7.44%		92.134%	682.10
12-12:30	4	744.265121	5.70%		70.559%	672.20
12:30-1	3.2	595.412097	4.58%		56.667%	669.59
1-1:30	1.6	297.70604	2.32%		28.782%	659.16
1:30-2	0.9	167.45965	1.37%		17.0672%	625.28
2-2:30	0.4	74.426512	0.61%		7.6363%	621.11
2:30-3	0.3	55.819884	0.47%		5.81508%	611.73

Table 8: Variation in Useful heat gain, Thermal efficiency, Overall efficiency, Instantaneous efficiency, Absorbed flux with Temperature difference for MWCNT and Distilled water based mixture at 160L/h Volume flow rate with 0.01% Volume concentration.

Experimental Day 25/3/2015

Time interval (half an hour)	Temperature Inlet (°C)	Temperature Outlet (°C)	Solar Intensity (W/m^2)	Wind Speed (m/s)
9:30-10	26.6	29.9	690.964	0.4
10-10:30	29.9	35.6	725.234	0.6
10:30-11	35.6	41.9	759.504	0.8
11-11:30	41.9	47	834.749	0.7
11:30-12	47	49.9	860.079	0.55
12-12:30	49.9	52.9	854.864	0.7
12:30-1	52.9	55.4	881.684	1
1-1:30	55.4	57.5	883.919	1.15
1:30-2	57.5	58.6	868.274	1.45
2-2:30	58.6	59	865.294	3.55
2:30-3	59	59.2	712.569	1.3

Table 9: Variation in Inlet and Outlet temperature, Solar intensity and Wind speed for MWCNT and Distilled water based mixture at 100L/h Volume flow rate with 0.01% Volume concentration

Time interval (half an hour)	Temperature Difference (°C)	Useful Heat Gain (J/s)	Thermal Efficiency	Overall Thermal Efficiency	Instantaneous Efficiency	Absorbed Flux
9:30-10	3.3	383.41628	6.54%	4.99%	50.53738%	483.467
10-10:30	5.7	662.86112	10.76%		83.24191%	507.446
10:30-11	6.3	732.63597	11.36%		87.85284%	531.424
11-11:30	5.1	593.08626	8.36%		64.70824%	584.073
11:30-12	2.9	337.245	4.61%		35.71123%	601.797
12-12:30	3	348.8742	4.80%		37.168025 %	598.148
12:30-1	2.5	290.7285	3.88%		30.03117%	616.914
1-1:30	2.1	244.2119	3.25%		25.16239%	618.478
1:30-2	1.1	127.92056	1.73%		13.41779%	607.531
2-2:30	0.4	46.51657	0.63%		4.896%	605.446
2:30-3	0.2	23.260797	0.38%		2.973%	498.584

Table 10: Variation in Useful heat gain, Thermal efficiency, Overall efficiency, Instantaneous efficiency, Absorbed flux with Temperature difference for MWCNT and Distilled water based mixture at 100L/h Volume flow rate with 0.01% Volume concentration.

Experimental Day 27/3/2015

Time interval (Half an hour)	Temperature Inlet (°C)	Temperature Outlet(°C)	Solar Intensity (W/m^2)	Wind Speed (m/s)
9:30-10	26.2	29.2	755.779	0.2
10-10:30	29.2	33.3	881.109	0.8
10:30-11	33.3	38.7	971.884	0.8
11-11:30	38.7	44.9	1089.134	1.1
11:30-12	44.9	50.5	990.309	0.6
12-12:30	50.5	55.7	976.739	0.75
12:30-1	55.7	59.5	980.619	0.8
1-1:30	59.5	62.6	950.769	0.85
1:30-2	62.6	64	936.814	2.5
2-2:30	64	64.8	922.659	2.1
2:30-3	64.8	65.1	901.799	1.4

Table 11: Variation in Inlet and Outlet temperature, Solar intensity and Wind speed for MWCNT and Distilled water based mixture at 160L/h Volume flow rate with 0.02% Volume concentration

Time interval (half an hour)	Temp Difference (°C)	Useful Heat Gain (J/s)	Thermal Efficiency	Overall Thermal Efficiency	Instantaneous efficiency	Absorbed Flux
9:30-10	3	558.06123	5.43%	5.14%	67.2488%	528.84
10-10:30	4.1	762.80385	6.37%		78.8462%	616.54
10:30-11	5.4	1004.6684	7.61%		94.1468%	680.05
11-11:30	6.2	1153.5082	7.79%		96.4577%	762.10
11:30-12	5.6	1041.8784	7.74%		95.8173%	692.95
12-12:30	5.2	967.4585	7.29%		88.9732%	683.45
12:30-1	3.8	706.9889	5.30%		65.6613%	686.17
1-1:30	3.1	576.7541	4.46%		55.2475%	665.28
1:30-2	1.4	260.4696	2.04%		25.322%	655.51
2-2:30	0.8	148.8397	1.18%		14.691%	645.61
2:30-3	0.3	55.81491	0.45%		5.6368%	631.01

Table 12: Variation in Useful heat gain, Thermal efficiency, Overall efficiency, Instantaneous efficiency, Absorbed flux with Temperature difference for MWCNT and Distilled water based mixture at 160L/h Volume flow rate with 0.02% Volume concentration.

Experimental Day 28/3/2015

Time interval (half an hour)	Temperature Inlet (°C)	Temperature Outlet (°C)	Solar Intensity (W/m^2)	Wind Speed (m/s)
9:30-10	26.4	29.4	777.384	0.95
10-10:30	29.4	33.9	859.334	2.05
10:30-11	33.9	40.9	929.364	2.35
11-11:30	40.9	47.4	959.909	3.2
11:30-12	47.4	52.3	969.594	3.65
12-12:30	52.3	55.4	974.809	0.3
12:30-1	55.4	58.9	953.204	3.25
1-1:30	58.9	61	1003.119	2.1
1:30-2	61	62	1013.549	1.7
2-2:30	62	62.5	975.554	2
2:30-3	62.5	62.7	958.419	2.65

Table 13: Variation in Inlet and Outlet temperature, Solar intensity and Wind speed for MWCNT and Distilled water based mixture at 100L/h Volume flow rate with 0.02% Volume concentration.

Time interval (half an hour)	Temp. Difference (°C)	Useful Heat Gain (J/s)	Thermal Efficiency	Overall Thermal Efficiency	Instantaneous Efficiency	Absorbed flux
9:30-10	3	348.8491	5.28%	4.79%	40.8695%	543.935
10-10:30	4.5	523.2737	7.17%		55.458%	601.275
10:30-11	7	813.98144	10.31%		79.7675%	650.275
11-11:30	6.5	755.83991	9.27%		71.7129%	671.648
11:30-12	4.9	569.78701	6.92%		53.5205%	678.424
12-12:30	3.1	360.4774	4.35%		33.6787%	682.073
12:30-1	3.5	406.9907	5.02%		38.8862%	666.956
1-1:30	2.1	244.1944	2.86%		22.1707%	701.882
1:30-2	1	116.283	1.35%		10.4488%	709.1802
2-2:30	0.5	58.14153	0.70%		5.42791%	682.595
2:30-3	0.2	23.2566	0.48%		2.20998%	670.605

Table 14: Variation in Useful heat gain, Thermal efficiency, Overall efficiency, Instantaneous efficiency, Absorbed flux with Temperature difference for MWCNT and Distilled water based mixture at 100L/h Volume flow rate with 0.02% Volume concentration.

Time interval (half an hour)	Temperature Inlet (°C)	Temperature Outlet (°C)	Solar Intensity (W/m^2)	Wind Speed (m/s)
9:30-10	17.6	19.8	765.464	0.5
10-10:30	19.8	23.4	788.559	0.25
10:30-11	23.4	26.9	833.259	1.15
11-11:30	26.9	31.5	864.549	0.5
11:30-12	31.5	34.8	893.604	0.65
12-12:30	34.8	37.8	924.149	1.1
12:30-1	37.8	40.9	960.654	0.4
1-1:30	40.9	43.3	940.539	0.65
1:30-2	43.3	45.1	934.579	1.1
2-2:30	45.1	46	948.734	0.7
2:30-3	46	46.3	946.499	1.9

Table 15: variation in Inlet and Outlet Temperature, solar intensity, Wind speed for water at 160L/h

Time interval (half an hour)	Temp. Difference (°C)	Useful Heat Gain (J/s)	Thermal Efficiency	Overall Thermal Efficiency	Instantaneous Efficiency	Absorbed Flux
9:30-10	2.2	409.354	3.93%	4.01%	48.7048%	535.595
10-10:30	3.6	669.853	6.25%		77.3647%	551.754
10:30-11	3.5	651.245	5.75%		71.1806%	583.031
11-11:30	4.6	855.923	7.28%		90.1659%	604.924
11:30-12	3.3	614.031	5.05%		62.5810%	625.254
12-12:30	3	558.21	4.44%		55.0114%	646.627
12:30-1	3.1	576.817	4.42%		54.6850%	672.169
1-1:30	2.4	446.568	3.49%		43.2422%	658.095
1:30-2	1.8	334.926	2.63%		32.6385%	653.924
2-2:30	0.9	167.463	1.29%		16.0757%	663.829
2:30-3	0.3	55.821	0.43%		5.37124%	662.265

Table 16: variation in useful heat gain, thermal efficiency, overall thermal efficiency, instantaneous efficiency and absorbed flux with temperature difference for water at 160L/h

Time interval (half an hour)	Temperature Inlet (°C)	Temperature Outlet(°C)	Solar Intensity (W/m^2)	Wind Speed (m/s)

9:30-10	15.3	18	873.489	1.65
10-10:30	18	21.6	891.369	0.8
10:30-11	21.6	25.8	900.309	0.7
11-11:30	25.8	29.3	907.759	1.45
11:30-12	29.3	32.6	946.499	1.55
12-12:30	32.6	35.4	950.969	2.5
12:30-1	35.4	38	959.164	1.4
1-1:30	38	40.9	922.659	0.55
1:30-2	40.9	42.2	944.264	2.65
2-2:30	42.2	43	940.539	1.05
2:30-3	43	43.5	999.394	1.4

Table 17: variation in Inlet and Outlet Temperature, solar intensity, Wind speed for water at 100L/h

Time interval (half an hour)	Temp. Difference (℃)	Useful Heat Gain (J/s)	Thermal Efficiency	Overall Thermal Efficiency	Instantaneous Efficiency	Absorbed Flux
9:30-10	2.7	314.025	4.23%	3.77%	32.7419%	611.18
10-10:30	3.6	418.582	5.53%		42.7681%	623.69
10:30-11	4.2	488.346	6.39%		49.4007%	629.946
11-11:30	3.5	406.955	5.28%		40.8294%	635.158
11:30-12	3.3	383.7	4.77%		36.9206%	662.265
12-12:30	2.8	325.564	4.03%		31.179%	665.393
12:30-1	2.6	302.309	3.71%		28.7048%	671.127
1-1:30	2.9	337.191	4.30%		33.2837%	645.584
1:30-2	1.3	151.154	1.88%		14.5788%	660.701
2-2:30	0.8	93.018	1.16%		9.00715%	658.095
2:30-3	0.5	58.136	0.68%		5.29792%	699.275

Table18: variation in useful heat gain, thermal efficiency, overall thermal efficiency, instantaneous efficiency and absorbed flux with temperature difference for water at 100L/h.

Chapter-9

Comparative Analysis

9.1 Introduction

This section include the comparison of efficiency parameters that comes out from this experimental research work through MWCNT nanofluids with 0.01wt% and 0.02wt% and further also from water at different mass flow rates and also between the efficiency parameters comes out from past research work held on flat plate collector through same MWCNT nanofluid and also from water at different mass flow rates, which was conducted by Tooraj Yousefi (2012).

9.2 Comparison b/w Efficiency parameter ($F_R U_L$) and F_R ($\tau\alpha$) for MWCNT nanofluid at different concentration 0.01% and 0.02% with different volume flow rates

This section includes theoretical comparison b/w evaluated results of $F_R U_L$ and F_R ($\tau\alpha$) with application of MWCNT 0.01wt% and 0.02wt% nanofluid in parabolic trough collector and also b/w same nanofluid at 0.2 wt% and 0.4wt% used in flat plate collector

$F_R U_L$ and F_R ($\tau\alpha$) both are positive and negative efficiency parameters and there is a considerable effect of mass flow rates on these efficiency factor. Calculated values of $F_R U_L$ and F_R ($\tau\alpha$) for MWCNT nanofluid with Surfactant Triton X-100 at different concentration 0.01% and 0.02% with different volume flow rates are shown in Table

Volume flow rates	Mass flow rates	MWCNT (0.01%) nanofluid	
		$F_R U_L$	F_R ($\tau\alpha$)
160L/h	0.04444 $\frac{Kg}{sec}$	12.90632071	0.769714307
100L/h	0.027775 $\frac{Kg}{sec}$	11.34413541	0.676547834

Table 19: Shows $F_R U_l$ and F_R ($\tau\alpha$) for MWCNT (0.01%) nanofluid at 160L/h and 100L/h

Volume flow rates	Mass flow rates	MWCNT (0.02%) nanofluid	
		$F_R U_L$	F_R ($\tau\alpha$)

160L/h	$0.044437\frac{Kg}{sec}$	12.90526167	0.769651147
100L/h	$0.0277736\ \frac{Kg}{sec}$	11.3446096	0.676576114

Table 20: Shows F_RU_l and $F_R\ (\tau\alpha)$ for MWCNT (0.02%) nanofluid at 160L/h and 100L/h

Volume flow rates	Mass flow rates	Water	
		F_RU_L	$F_R\ (\tau\alpha)$
160L/h	$0.04444\frac{Kg}{sec}$	12.9062176	0.769708158
100L/h	$0.027777\frac{Kg}{sec}$	11.34366372	0.676519703

Table 21: Shows F_RU_l and $F_R\ (\tau\alpha)$ for water at 160L/h and 100L/h in PTC system

Expression of collector heat removal factor is same for both flat plate collector and parabolic trough collector and way to find instantaneous efficiency from both types of technologies is also almost same. It has been seen that F_RU_l and $F_R\ (\tau\alpha)$ increases with increase in mass flow rate of working fluid in case of parabolic trough collector.

Tooraj Yousefi et al (2012) performed an experimental investigation related to the effect of MWCNT nanofluid on the performance of flat plate collector. He performed also an experiment through water at various flow rates and in quasi steady state conditions.

Mass flow rates	F_RU_l	$F_R\ (\tau\alpha)$
$0.0167\frac{Kg}{sec}$	44.19	0.51
$0.033\ \frac{Kg}{sec}$	36.95	0.5
$0.05\frac{Kg}{sec}$	31.04	0.551

Table 22: Shows F_RU_l and $F_R\ (\tau\alpha)$ for water at various mass flow rate in case of flat plat collector [17]

For 0.05 $\frac{Kg}{sec}$ mass flow rate F_RU_L and $F_R\ (\tau\alpha)$ values for MWCNT nanofluid is shown in table below:

Fluid	F_RU_L	$F_R\ (\tau\alpha)$
MWCNT nanofluid (0.2%)	39.53	0.549
MWCNT nanofluid (0.4%)	45.27	0.912

Table 23: Showed F_RU_L and $F_R\ (\tau\alpha)$ values for MWCNT nanofluid at 0.2wt% and 0.4wt% [17]

In this experimental study MWCNT nanofluid at 0.2% and 0.4% weight fraction in double distilled water without surfactant used to evaluate performance or efficiency of solar flat plate collector. From experimentation, it was concluded that 0.2% MWCNT showed poor results of efficiency as comparison to water because F_RU_L possess higher value in MWCNT 0.2 wt% nanofluid as comparison to water in case of flat plate collector. It has been also seen that heat transfer in nanofluid from absorber surface is directly proportional to thermal conductivity and inversely proportional to boundary layer thickness. Therefore it was concluded that 0.2 wt% MWCNT nanofluid showed less enhancement in thermal conductivity as comparison to enhancement in boundary layer thickness, while water showed more enhancement in thermal conductivity as comparison to thermal boundary layer thickness. Further experimentally calculated values of $F_R\ (\tau\alpha)$ is almost same for water and MWCNT 0.02wt%. It has been also seen that MWCNT 0.04wt% showed better results for efficiency because in this case energy removed parameter is compensated by energy absorbed parameter. So it was concluded in this experimental work that 0.4wt% MWCNT nanofluid showed better performance in flat plate collector as comparison to 0.2wt% MWCNT nanofluid without application of surfactant.

Tooraj Yousefi et al (2012) also conducted another experiments through MWCNT 0.2wt% nanofluid with the application of surfactant Triton X-100. It has been seen that using surfactant has a significant negative effect on efficiency because of reduction in heat transfer between water and nanotubes. But experimental results through MWCNT 0.2wt% with surfactant showed better results for efficiency as comparison to MWCNT 0.2wt% without surfactant.

Mass flow rates	F_RU_l	$F_R\ (\tau\alpha)$
$0.0167\frac{Kg}{sec}$	27.26	0.615
$0.033\ \frac{Kg}{sec}$	38.52	0.745
$0.05\frac{Kg}{sec}$	53.96	0.824

Table 24: Shows F_RU_l and $F_R\ (\tau\alpha)$ for MWCNT 0.2wt% with surfactant Triton X-100 [17]

It has been seen that F_RU_l and $F_R\ (\tau\alpha)$ increased with increase in mass low rate in both parabolic trough collector and flat plate collector system and this comparative analysis concluded that increment in F_RU_l negative efficiency parameter is smaller in case of parabolic trough collector than increment in F_R $(\tau\alpha)$ positive efficiency parameters relative to efficiency parameters evaluated from flat plate collector by Tooraj Yousefi. Therefore it is concluded that heat losses can be minimized and efficiency can be improved through the application of concentrating parabolic trough collector like parabolic trough collector, which is a high temperature line concentrating solar power system.

Basically collector heat removal factor is an important parameter in design and it is an actual useful heat gain rate to the thermal gain which would occur if the complete absorber surface was at the same inlet fluid temperature. Its value ranges from 0 to 1. During the research work on different days of working, collector heat removal factor evaluate at different volume flow rate i.e. 160L/h and 100L/h and also at different weight concentration 0.01% and 0.02%. heat removal factor also evaluate for water, which is used as a working fluid for the parabolic trough collector system.

Collector heat removal factor	Vol. flow Rate	Mixture I ($\varphi_p = 0.01\%$)	Mixture II ($\varphi_p = 0.02\%$)
	160L/h	0.971861499	0.971781752
	100L/h	0.854227064	0.854262771

Table 25: Collector heat removal factor for different mixture of MWCNT based nanofluid at different volume flow rates

Collector heat removal factor	Vol. flow Rate	Water
	160L/h	0.971853735
	100L/h	0.854191545

Table 25: Collector heat removal factor for water at different volume flow rates

Collector heat removal factor's value slighter less in case of water than from MWCNT based nanofluid mixture at different volume flow rates.

Chapter-10

Results and Discussions

10.1 Introduction

This is the important section of the experimental work because this section deals with the performance evaluation data for parabolic solar collector and further this section also include graphical representation of results outcomes from the performance analysis of parabolic trough collector through nano fluids and water. This section describes the variation in solar intensity, inlet & outlet temperatures. Difference between outlet and inlet temperatures with the change in time of the day, variations in the useful heat gain, thermal & overall thermal efficiency, instantaneous efficiency and also absorbed flux by the collector throughout the day time is discussed in detail for both MWCNT & distilled water based nano fluids and simple water, which are passing through the receiver of parabolic collector.

10.2 Evaluation of Performance of Solar Parabolic Collector using Nano Fluid and Water

In this work a mixture of MWCNT & Distilled water is prepared through the process of sonication with different concentrations of 0.01% and 0.02% and this mixture is flowing through the receiver or absorber tube at different volume flow rate of 160L/h and 100L/h. all the experimental results outcomes from the use of mixture and variation between those results are discussed graphically in this section.

10.2.1 Results of Experimental Work with the Use of Nanofluid at 0.01% Volume Concentration

(a). Experimental Variation in Total Solar Intensity, Inlet and Outlet Temperatures With The Change in Time for Nanofluid Mixture (Experimental Day 24/3/2015)

Figure shows complete graphical representation of data related to change in solar intensity, inlet & outlet temperatures with the change in time for mixture of MWCNT & distilled water, which is flowing through solar parabolic collector at 160L/h with concentration of 0.01%.

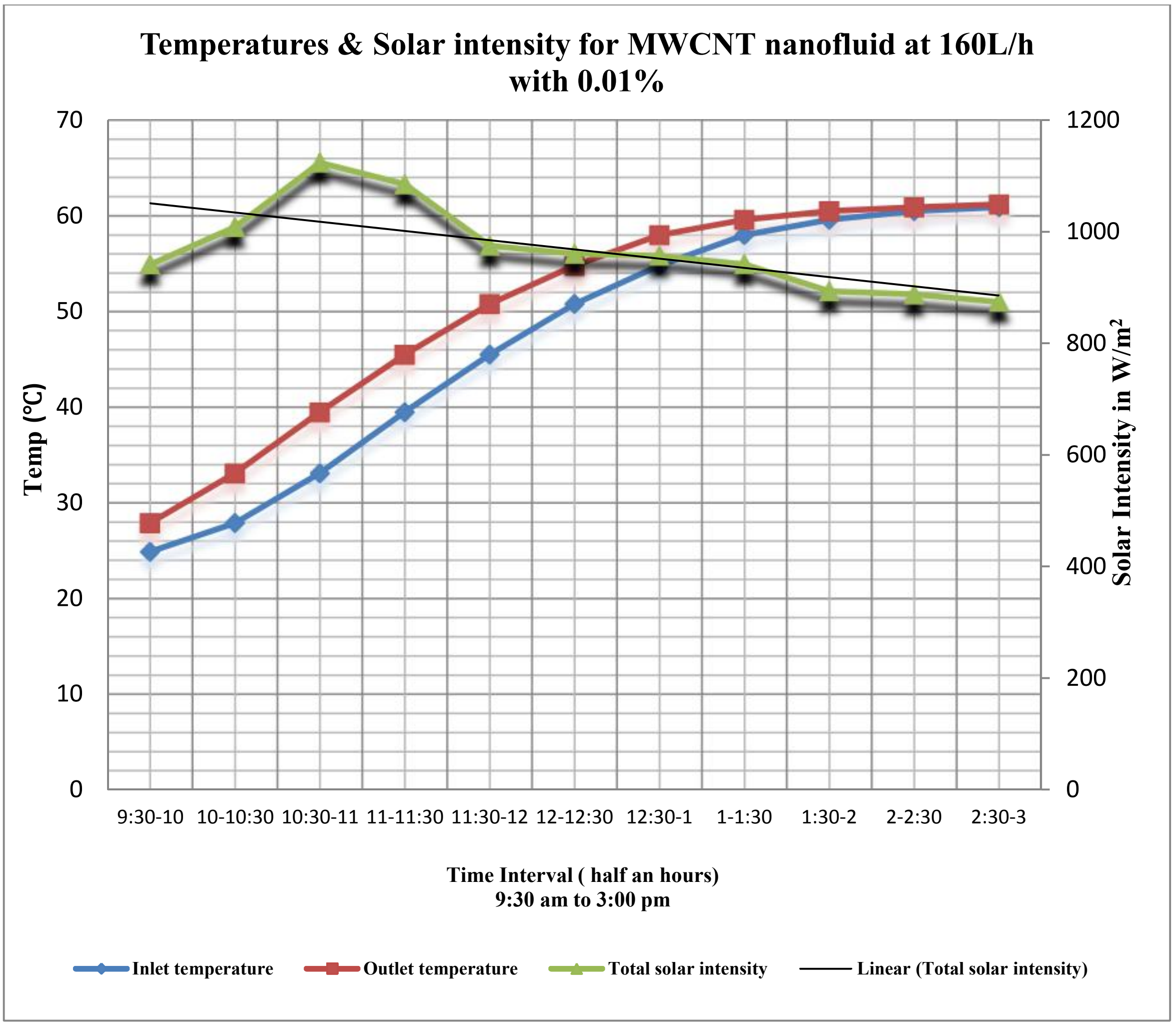


Figure 26: Shows Variation in temperatures and total solar intensity with change in day time for nano fluid at 160L/h with volume concentration 0.01%

Experimental readings taken from 9:00am to 3:30pm and it has been seen that maximum rise in solar intensity is 1123.949W/m^2 on around 12:00pm and also continuous increment in inlet and outlet temperatures is measured throughout the decided experimental day time. Initial starting temperature is 24.9°C and maximum outlet temperature is noticed around 61.2°C.

(b)Experimental Variation in Total Solar Intensity, Inlet and Outlet Temperatures With The Change in Time for Nanofluid Mixture (Experimental day 25/3/2015)

Figure shows complete graphical representation of data related to change in solar intensity, inlet & outlet temperatures with the change in time for mixture of MWCNT & distilled water, which is flowing through solar parabolic collector at 100L/h with concentration of 0.01%.

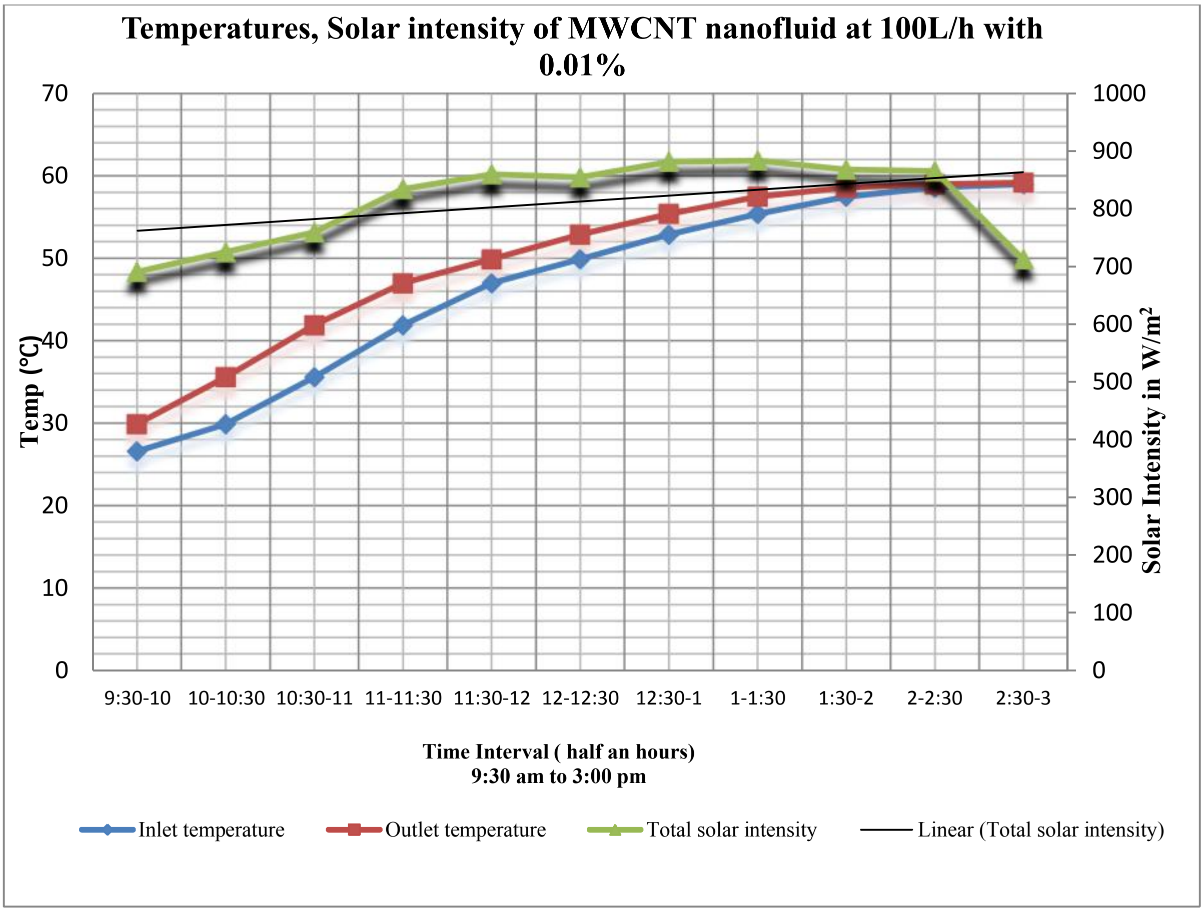


Figure 27: Shows Variation in temperatures and total solar intensity with change in day time for nano fluid at 100L/h with volume concentration 0.01%

Experimental readings taken from 9:00am to 3:00pm and it has seen that maximum rise in solar intensity is 883.919W/m^2 during the time interval 1:00-1:30pm and continuously increment in solar intensity is shown on graph upto 1:30pm and after that sudden decrement is noticed. Temperatures are continuously increasing both at inlet and outlet and maximum outlet temperature is measured 59.2℃ and minimum temperature at inlet 26.6℃ is noticed in the experimental study.

(c) Experimental Variations in Useful Heat Gain With Change in Time Interval for Nanofluid Mixture for Different Volume Flow Rates (Experimental Day 24/3/2015 & 25/3/2015)

Figure shows graphical representation of data related to variations in useful heat gain with time for MWCNT & Distilled water based mixture throughout the day. A variation in useful heat gain is dependent upon mass flow rate, specific heat of nano fluid mixture and also upon temperature difference. Specific heat of nano fluid mixture is little bit less than distilled water. Nano fluid is flowing through receiver at different volume flow rate as decided before i.e. 160L/h and 100L/h.

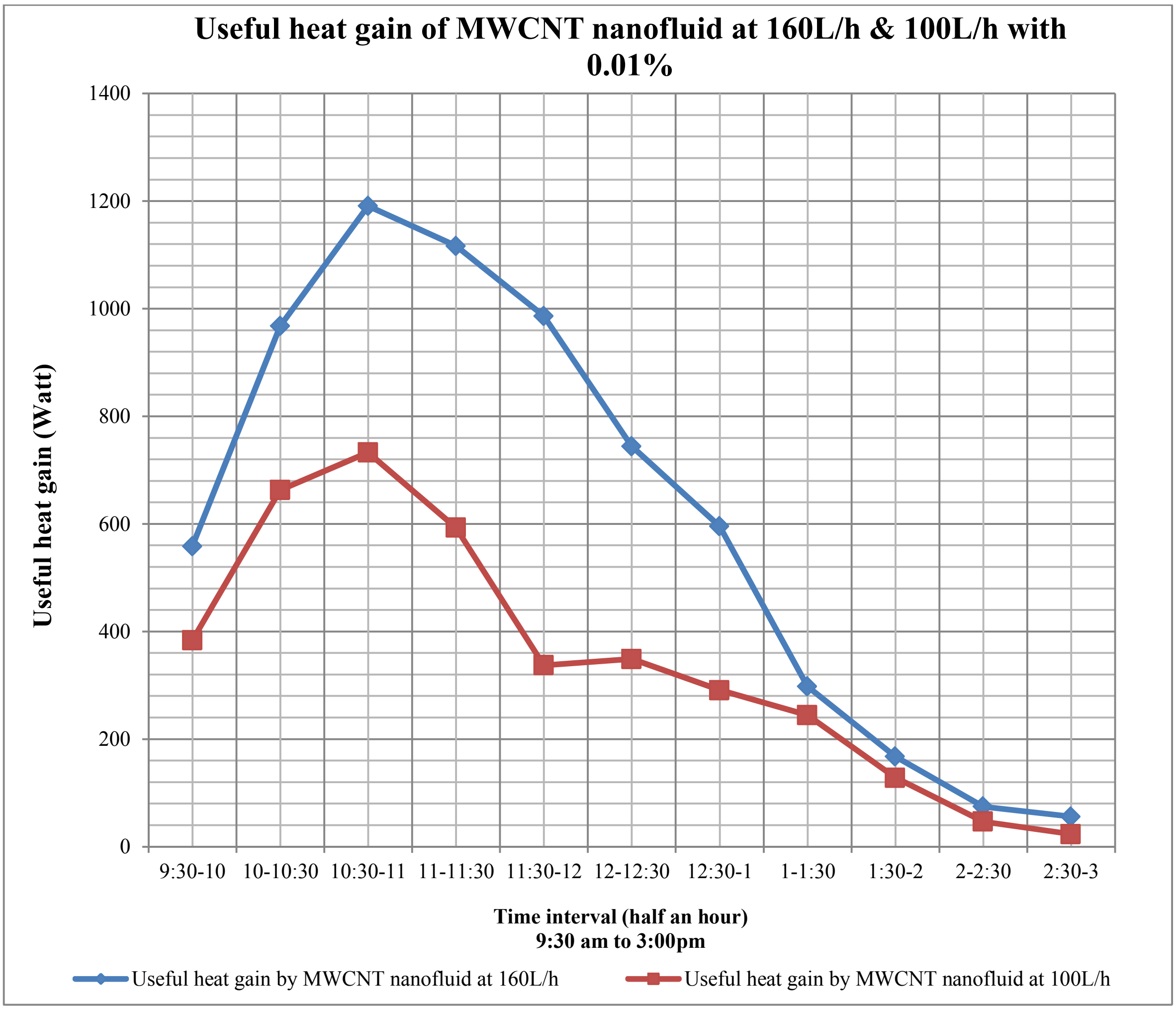


Figure 28: Experimental variations in useful heat gain with the change in day time for nano fluid mixture (0.01%) at 160L/h and 100L/h volume flow rates

At higher volume flow rate 160L/h useful heat gain by the mixture is also higher as comparison to useful heat gain by the nano fluid mixture at 100L/h, which is shown clearly in the figure. At 160 L/h the highest amount of useful heat gain is 1190.824Watt, which is very larger from highest value of useful heat gain around 732.63Watt observed at 100L/h. From graphical figure, it has been shown clearly that useful heat gain by mixture increasing continuously in beginning up to 11:00 am for 160L/h and 100L/h and after that it starts decreasing.

(d)Experimental Variations in Difference b/w Temperature at Inlet and Outlet With The Change in Day Time for Nanofluid Mixture at Different Volume Flow Rates (24/3/2015 & 25/3/2015)

Figure shows graphical representation of variations in difference b/w temperatures measured at inlet and outlet of the collector receiver tube. Temperatures are measured through thermometer and then temperature difference also calculated. In this experimental study variation in temperature difference during a time interval for nano fluid mixture with 0.01% volume concentration at different volume flow rate like 160L/h and 100L/h is studied.

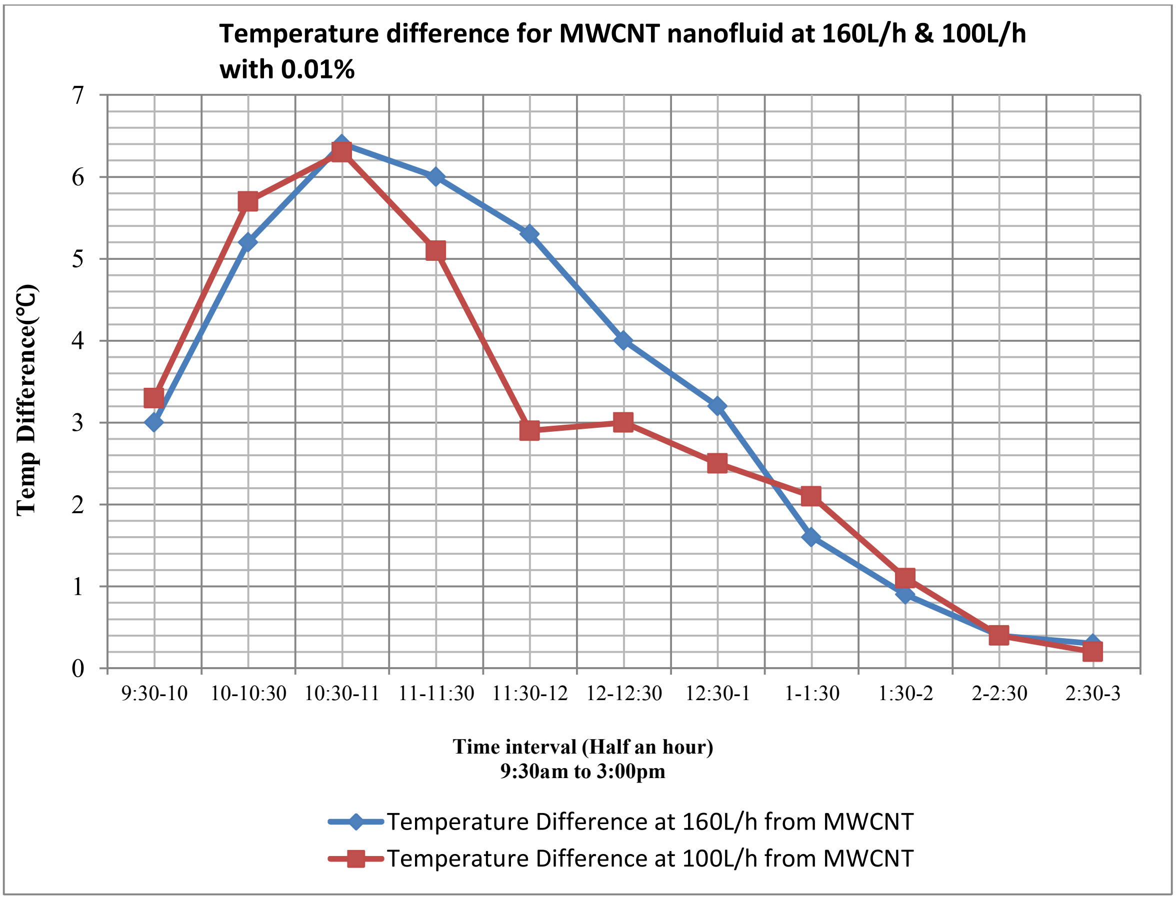


Figure 29: Experimental variations in difference b/w temperatures at inlet and outlet with change in day time for nano fluid mixture (0.01%) at 160L/h and 100L/h.

Variations in temperature difference directly affect to the useful heat gain, thermal and overall efficiency and instantaneous efficiency. Temperature difference is increasing with increase of solar intensity up to a certain point. Heat capacity of working nano fluid is increasing due to continuous falling of maximum solar radiations on receiver tube after reflect through mirror strips. Temperature difference is also dependent upon existing temperature of working nano fluid mixture, which is flowing through receiver tube on continuous basis. Maximum temperature difference is 6.4℃ at 160L/h and 6.3℃ at 100L/h through MWCNT & distilled water based nano fluid and this maximum temperature difference is measured on around 10:45 am and after that it starts decreasing in both cases of volume flow rates.

(e) Experimental Variations in Instantaneous Efficiency of Nanofluid With Change in Day Time at Different Volume Flow Rates (24/3/2015 & 25/3/2015)

Figure shows graphical representation of variations between the instantaneous efficiency of MWCNT and distilled water based nano fluids at 160L/h and 100L/h. In this experimental study MWCNT (0.01%) based nano fluid as a working fluid flowing through receiver of the parabolic trough collector at two different volume flow rates. Instantaneous efficiency is majorly dependent upon useful heat gain and further useful heat gain is directly proportional to mass flow rate, specific heat and also upon temperature difference, in which major dominant factor is mass flow rate, which is directly dependent upon volume flow rate of the mixture. Thus Instantaneous efficiency is higher for higher volume flow rate i.e. instantaneous efficiency is higher for 160L/h as compare to instantaneous efficiency comes out at 100l/h and clearly shown in the graphical figure. The maximum value of instantaneous efficiency is 96.49% and 87.85% in the time interval of 10:30-11:00 am for 160L/h and 100L/h with 0.01% volume concentration. Graphical pattern for both the volume flow rates are approximately same, after 11:00 am graph of instantaneous efficiency for both the volume flow rates start decreasing and further between time interval of 12:30-1:00pm, instantaneous efficiency for 160L/h posses less value than instantaneous efficiency comes out from 100L/h.

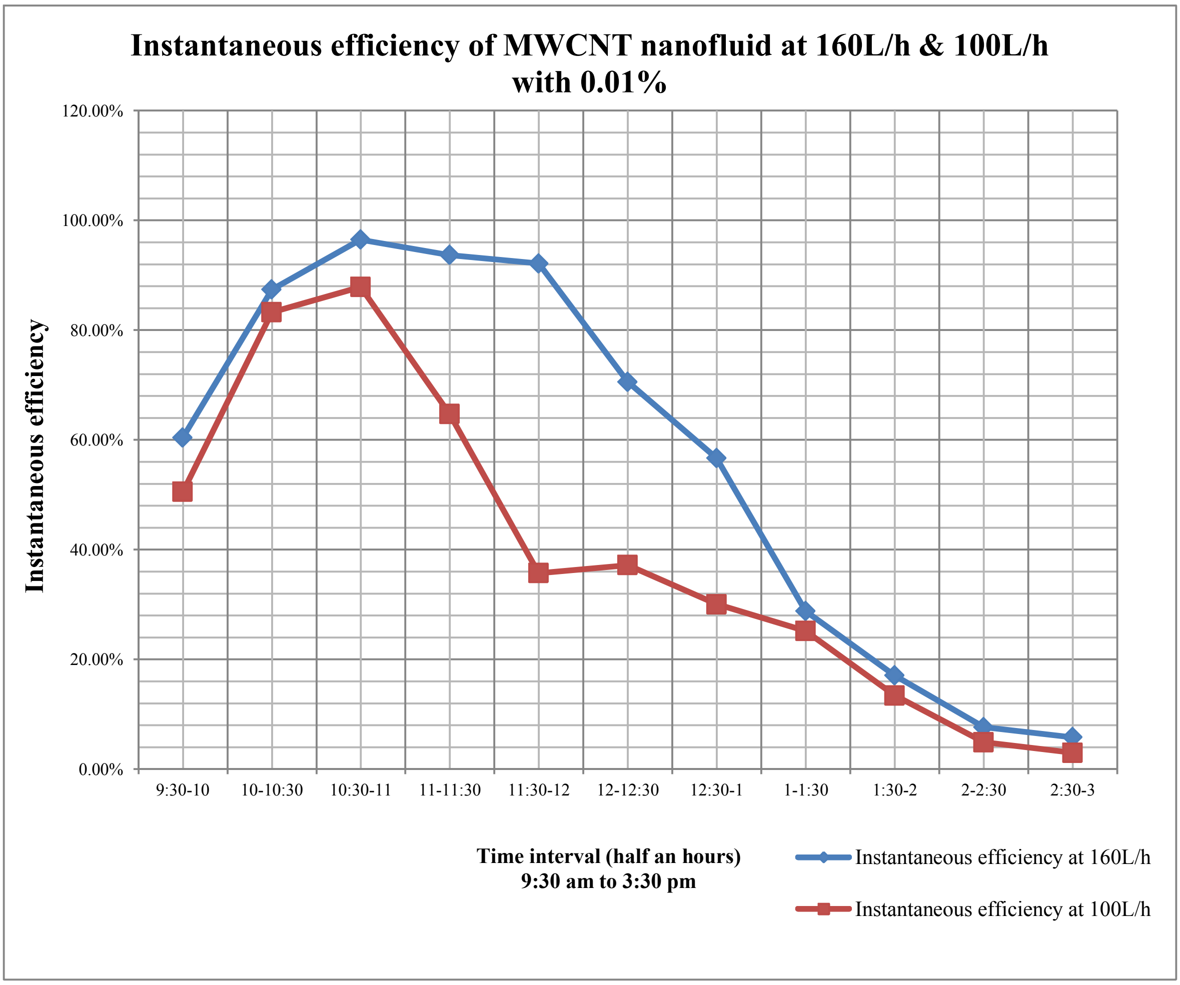


Figure 30: Experimental variations in instantaneous efficiency of nano fluids for different volume flow rates at 0.01% volume concentration

(f) Experimental Variations in Thermal Efficiency for Nanofluid With Change in Day Time at Different Volume Flow Rates (Experimental day 24/3/2015 & 25/3/2015)

Figure shows graphical representation of thermal efficiency of MWCNT (0.01%) & distilled water based nano fluid with the change in time interval throughout the day at different volume flow rates. At 0.01% nano fluid acquire little bit less amount of density and specific heat as comparison to water. But mass flow rate approximately same for both nano fluid and water at different volume flow rates i.e. 160L/h and 100L/h. Further nano fluid showed better temperature difference as comparison to water. So an increment comes in the thermal efficiency of nano fluid.

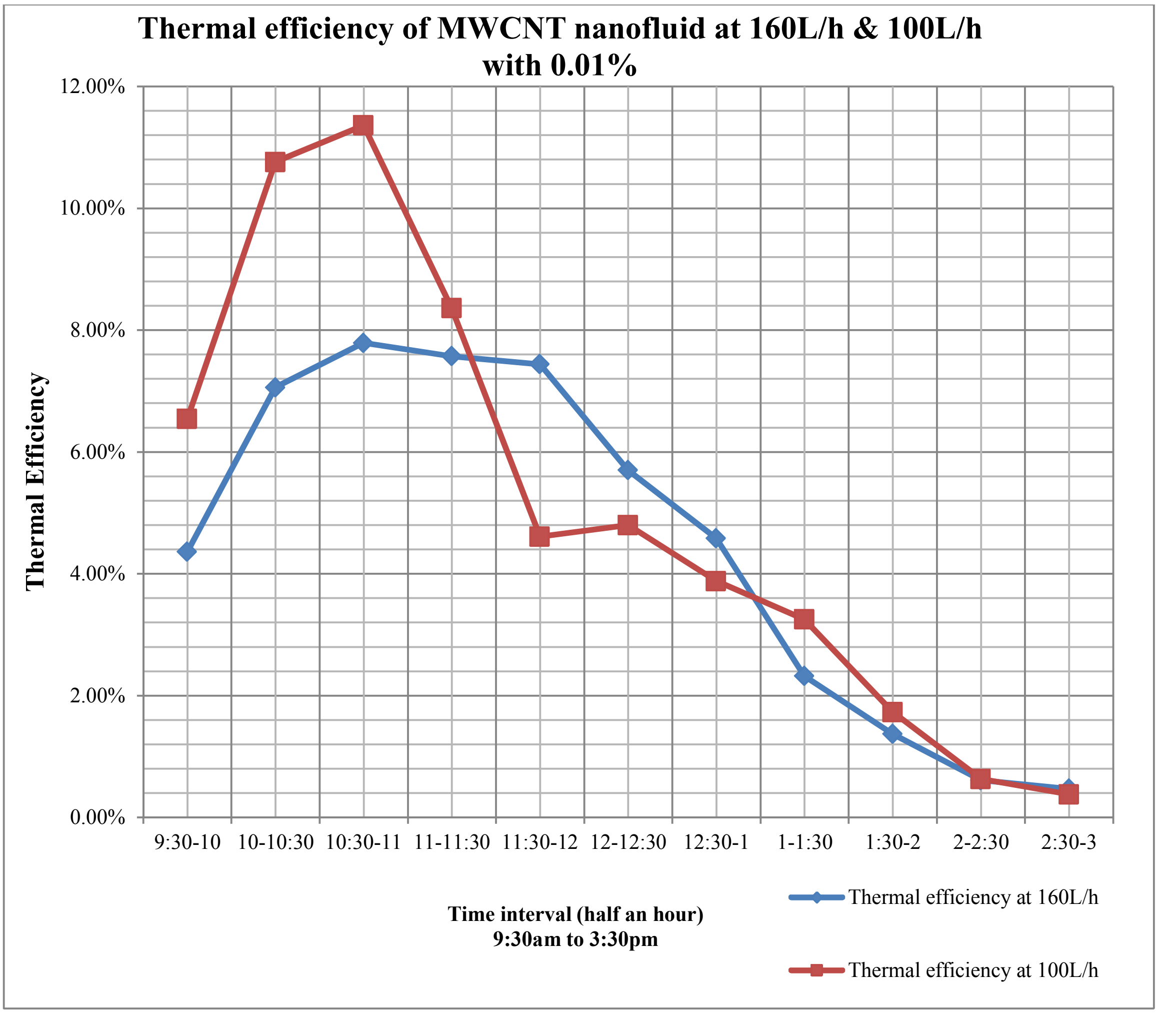


Figure 31: Experimental variations in thermal efficiency of nano fluid change with day time for different volume flow rates at 0.01% volume concentration

In this experimental study thermal efficiency of nano fluid at 100L/h showed better results as comparison to thermal efficiency of nano fluid comes out at 160L/h. Maximum thermal efficiency 11.36% through MWCNT nanofluid (0.01wt%) at 100L/h measured, which is higher than maximum value of thermal efficiency through same MWCNT nanofluid (0.01wt%) at 160L/h 7.79% during the same time interval 10:30am to 11:00am.

10.2.2 Results of Experimental Work with the Use of Nanofluid at 0.02% Volume Concentration

(a) Experimental Variation in Total Solar Intensity, Inlet and Outlet Temperatures with The Change in Time for Nanofluid Mixture (Experimental day 27/3/2015)

Figure shows complete graphical representation of data related to change in solar intensity, inlet & outlet temperatures with the change in time for mixture of MWCNT & distilled water, which is flowing through solar parabolic collector at 160L/h with concentration of 0.02%.

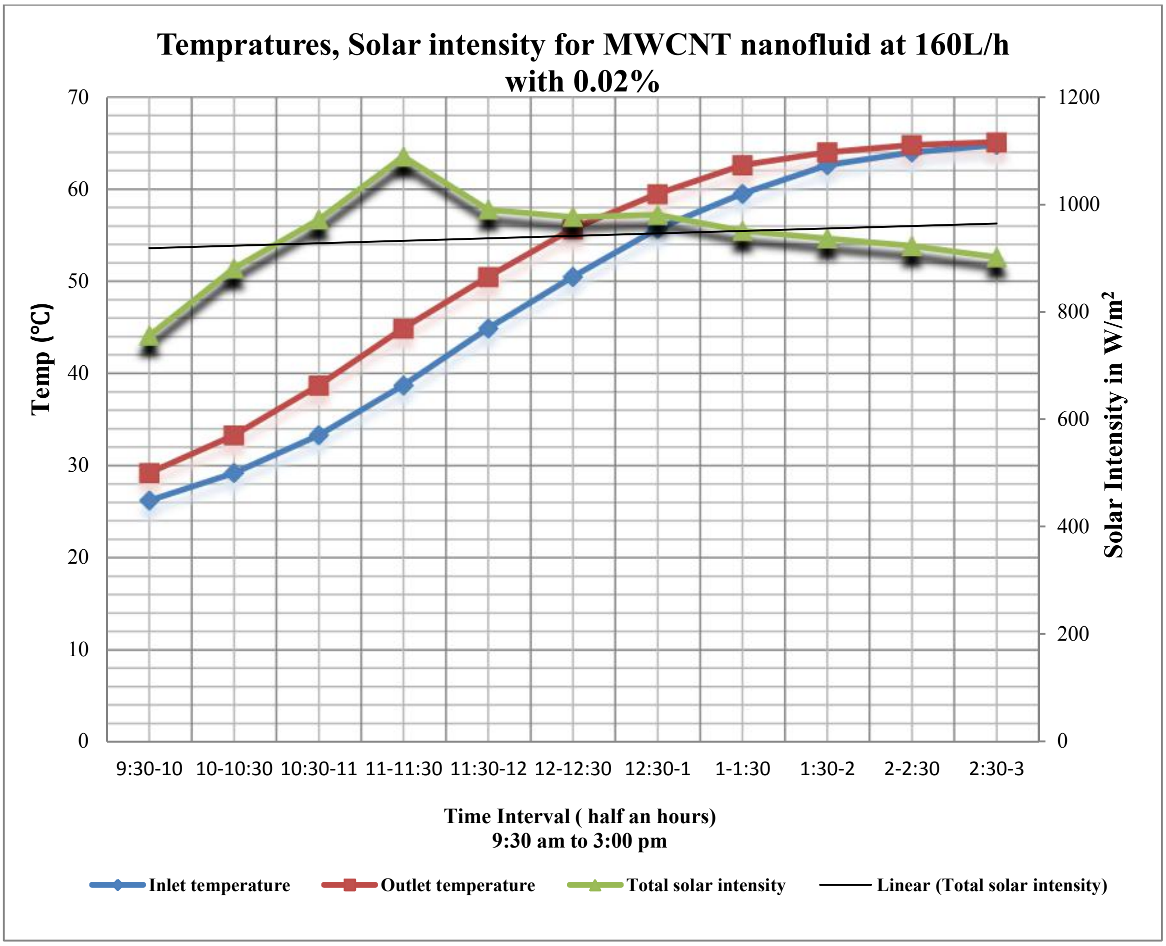


Figure 32: Shows Variation in temperatures and total solar intensity with change in day time for nano fluid at 160L/h with volume concentration 0.02%

Experimental readings taken from 9:00am to 3:30pm and it has been seen that maximum rise in solar intensity is 1089.134W/m^2 in the time interval 11:00-11:30am and also continuous increment in inlet and outlet temperatures is measured throughout the decided experimental time. Initial starting temperature is 26.2℃ and maximum outlet temperature is noticed around 65.1℃.

(b)Experimental Variation in Total Solar Intensity, Inlet And Outlet Temperatures With The Change In Time for Nano Fluid Mixture (Experimental Day 28/3/2015)

Figure shows complete graphical representation of data related to change in solar intensity, inlet & outlet temperatures with the change in time for mixture of MWCNT & distilled water, which is flowing through solar parabolic collector at 100L/h with concentration of 0.02%.

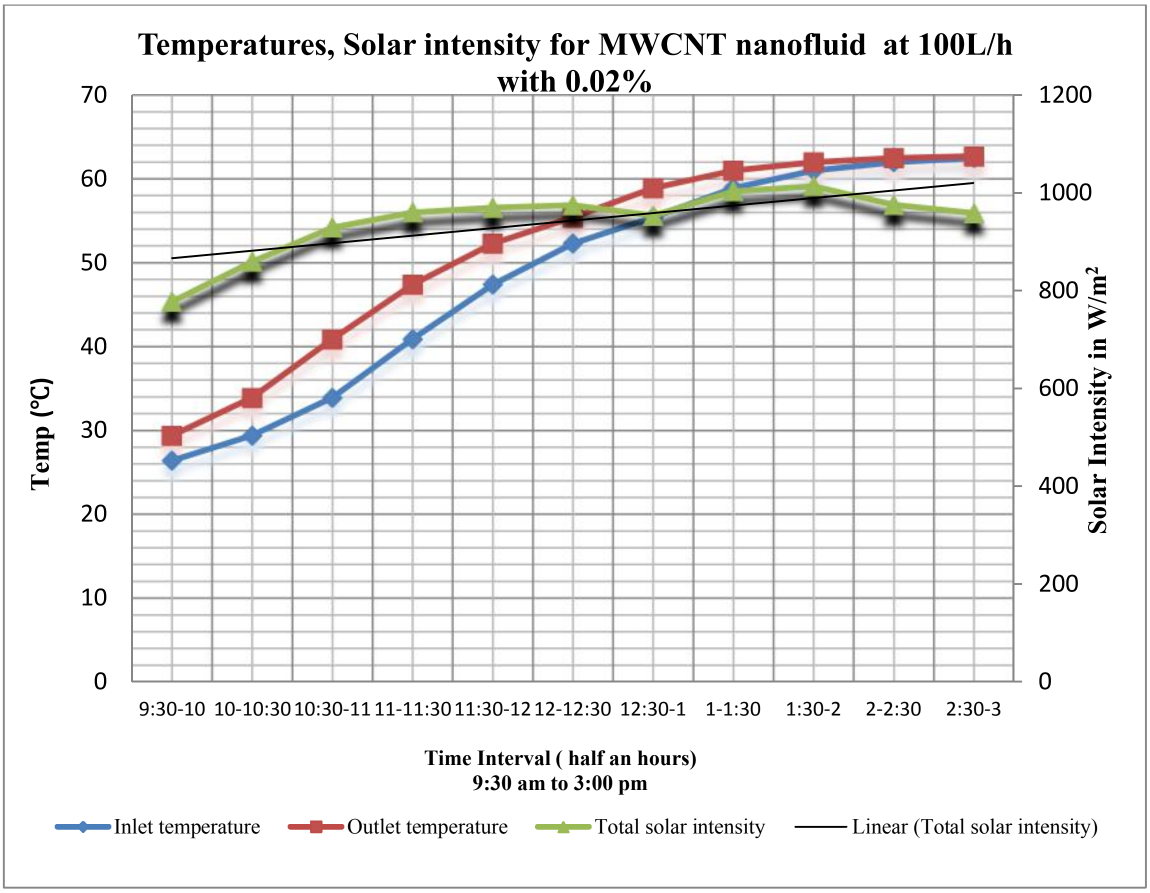


Figure 33: Shows Variation in temperatures and total solar intensity with change in day time for nano fluid at 100L/h with volume concentration 0.02%

Experimental readings taken from 9:00 am to 3:00pm and it has seen that maximum rise in solar intensity is 1013.549W/m^2 during the time interval 1:30-2:00pm and continuously increment in solar intensity is shown on graph up to 2:00pm only except at 12:45pm and after 2:00pm sudden decrement is noticed. Temperatures are continuously increasing both at inlet and outlet during the experimental work and maximum outlet temperature is measured 62.7°C and minimum starting temperature at inlet 26.4°C is noticed in the experimental study.

(c) Experimental Variations in Useful Heat Gain With Change in Time Interval for Nano Fluid Mixture at Different Volume Flow Rates (Experimental Day 27/3/2015 & 28/3/2015)

Figure shows graphical representation of data related to variations in useful heat gain with change in day time for MWCNT & Distilled water based mixture with 0.02% vol. concentration during the whole day i.e. 9:30am to 3:00pm. A variation in useful heat gain is dependent upon mass flow rate, specific heat of nano fluid mixture and also upon temperature difference. Specific heat of nano fluid mixture with 0.02% vol. concentration is little bit less than specific heat of distilled water and nano fluid with 0.01% vol. concentration as shown in the table related to properties of nano fluid. Nano fluid is flowing through receiver at different volume flow rate as decided before i.e. 160L/h and 100L/h. Due to higher volume flow rate nano fluid showed more enhancements in useful heat gain as comparison to enhancement in useful heat gain at 100L/h. the enhancement in useful heat gain is also depend upon the temperature difference as discussed before, which is again depend upon increment comes in solar intensity on continuous basis and temperature difference is the main dominant factor in this study when working with 0.02%. At 160L/h maximum useful heat gain by nano fluid is 1153.508J/s during the time interval 11:00-11:30am and after that graph start to decline and at 100L/h maximum useful heat gain by nano fluid is 813.98J/s measured in the time interval of 10:30-11:00am.

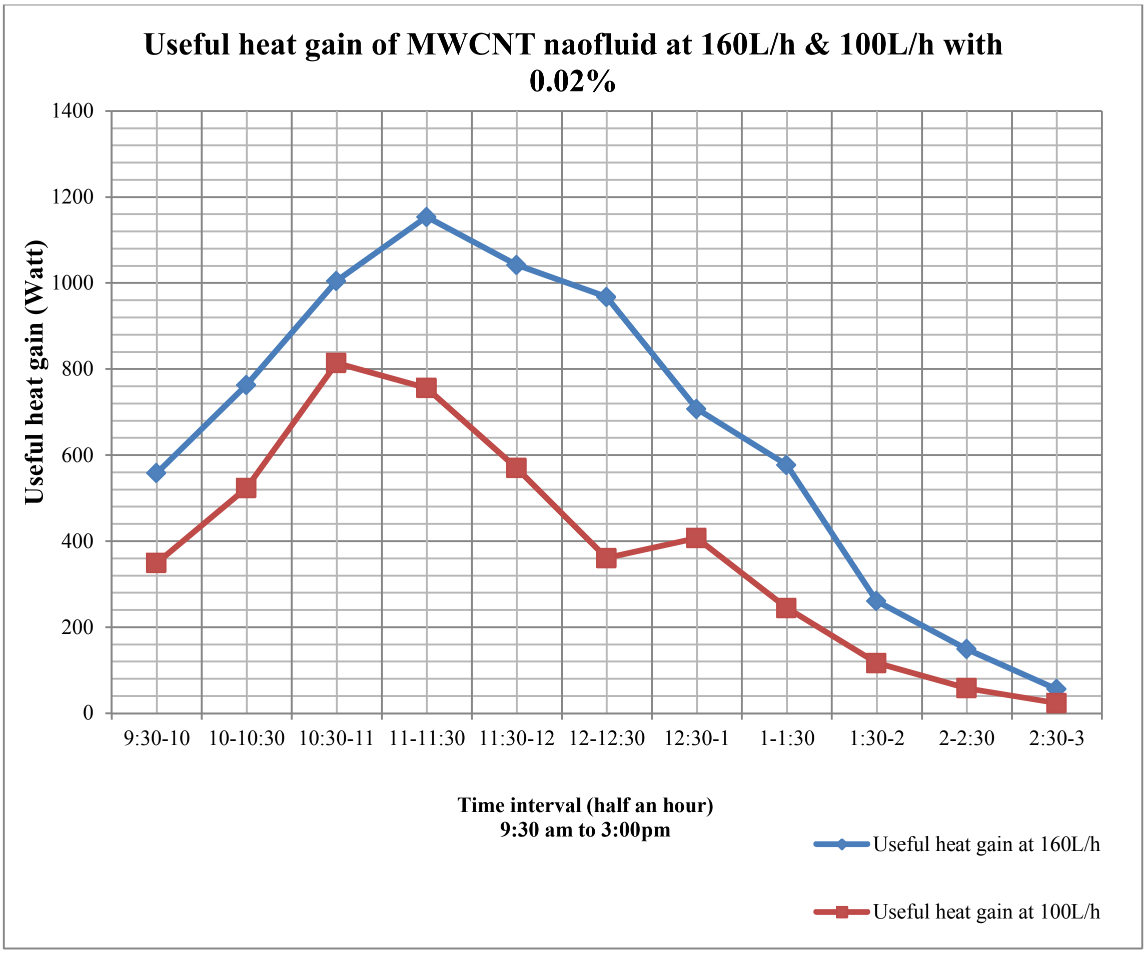


Figure 34: Experimental variations in useful heat gain of nano fluid with the change in day time for different volume flow rates at 0.02% volume concentration

(d)Experimental Variations in Difference b/w Temperature at Inlet and Outlet With The Change in Day Time for Nano Fluid Mixture at Different Volume Flow Rates (27/3/2015 & 28/3/2015)

Figure shows graphical representation of variations in difference b/w temperatures measured at inlet and outlet of the receiver and in this experimental study variation in temperature difference during a time interval for nano fluid mixture with 0.02% volume concentration at different volume flow rate like 160L/h and 100L/h is studied.

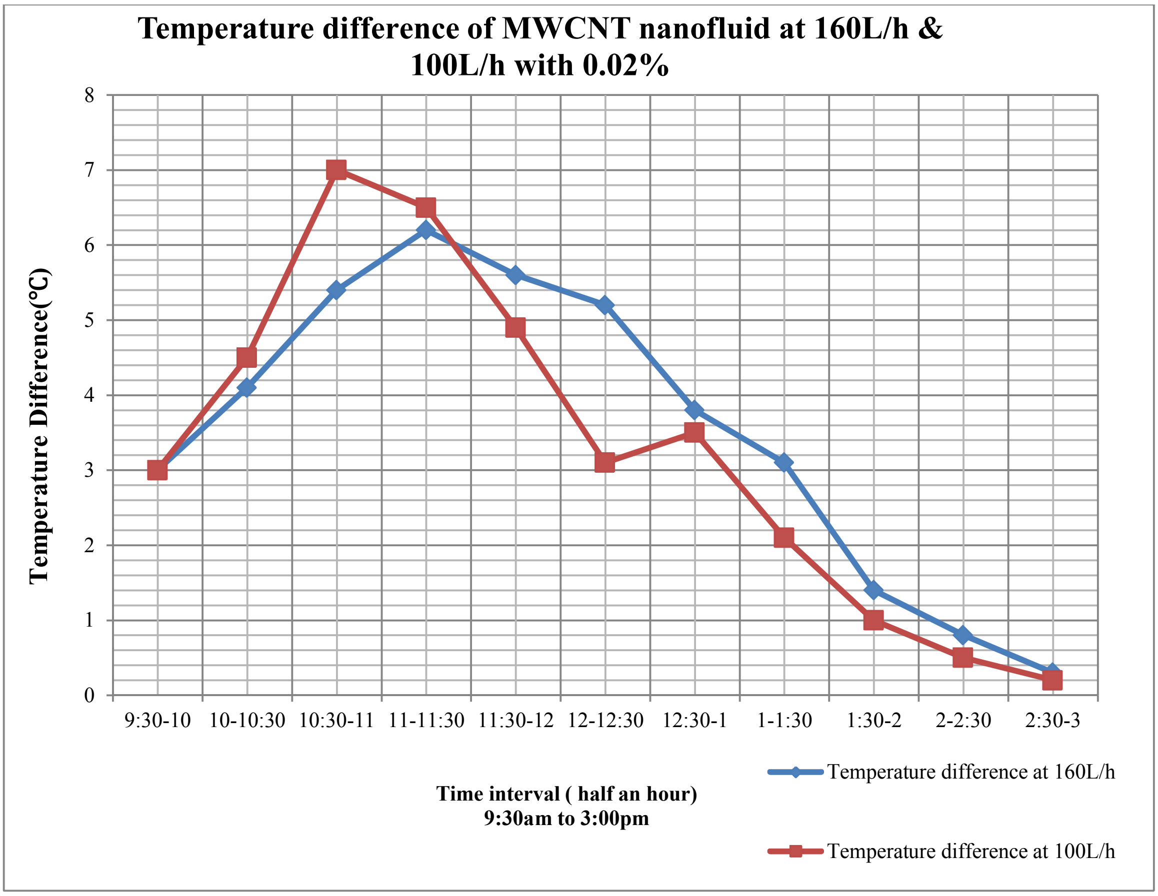


Figure 35: Experimental variations in difference b/w temperature at inlet and outlet with the change in day time for nono fluid at different volume flow rates with 0.02% volume concentration

As we discussed before, temperature difference directly affect to useful heat gain, thermal and overall thermal efficiency and instantaneous efficiency. Figure showed that higher volume flow rate acquire higher quantity of temperature difference and this fact is completely depends upon higher amount of solar intensity falling on receiver tube throughout the experimental time. In this experimental study nano fluid at 100L/h showed maximum temperature difference around 7℃ at 10:45am which is greater than maximum temperature difference comes out 6.2℃ at 11:15am from working nano fluid at 160L/h.

(e) Experimental Variations in Instantaneous Efficiency of Nano Fluid With Change in Day Time at Different Volume Flow Rates (27/3/2015 & 28/3/2015)

Figure showed graphical representation of variations in instantaneous efficiency change with time interval throughout the day for MWCNT based nano fluid mixture at different volume flow rates with 0.02% vol. concentration. Instantaneous efficiency is fully dependent upon useful heat gain and useful heat gain is directly proportional to mass flow rate, specific heat and also upon temperature difference and here major dominant factor is mass flow rate due to which nano fluid mixture at 160L/h show higher amount of instantaneous efficiency as comparison to instantaneous comes out from nano fluid at 100L/h at same vol. concentration. The maximum instantaneous efficiency of nano fluid at 160L/h is 96.46% measured in time interval 11:00-11:30am shown in figure 36, While maximum instantaneous efficiency of nano fluid mixture at 100L/h is 79.77% measured during the time interval 10:30-11:00am.

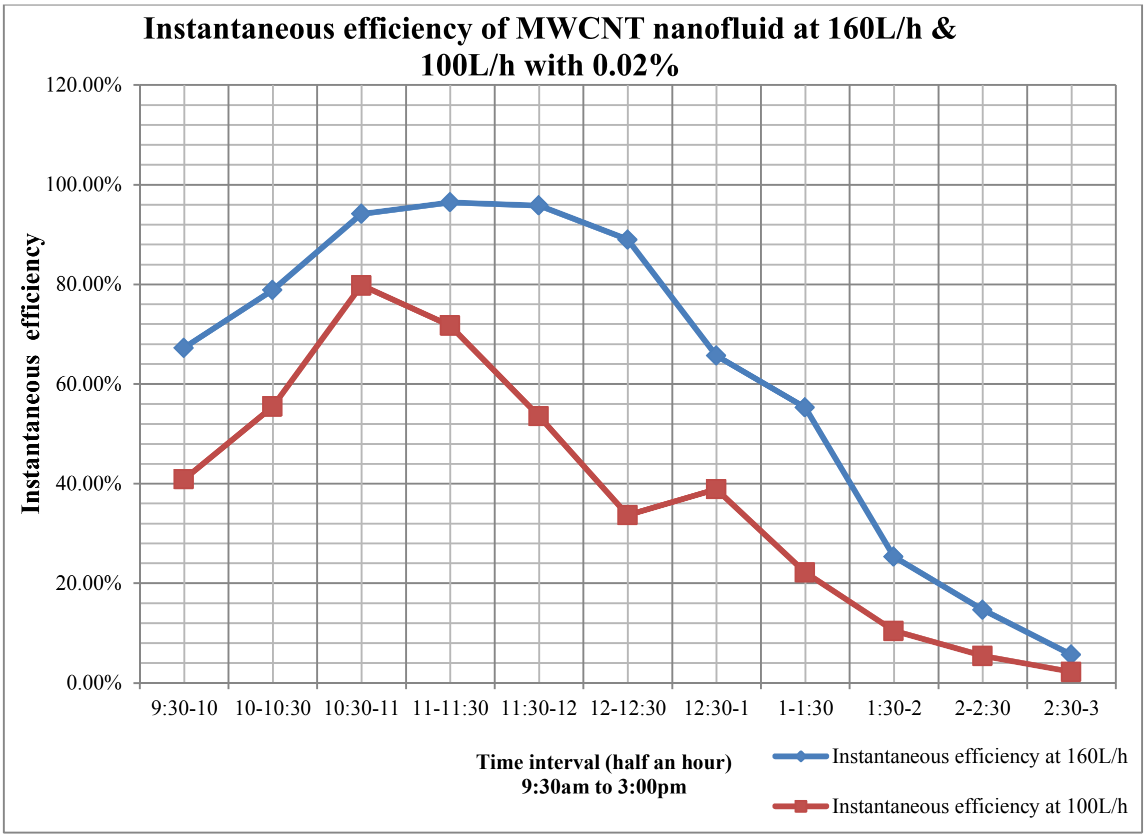


Figure 36: Experimental variations in instantaneous efficiency of nano fluid with change in day time at different volume flow rates with 0.02% volume concentration

(f) Experimental Variations in Thermal Efficiency of NanoFluid With Change in Day Time at Different Volume Flow Rates (27/3/2015 & 28/3/2015)

Figure shows graphical representation of thermal efficiency of MWCNT (0.02%) & distilled water based nano fluid with the change in time interval throughout the day at different volume flow rates. At 0.02% vol. concentration nano fluid shows higher temperature difference and less specific heat as comparison to nano fluid with 0.01% vol.

concentration and water. Density of MWCNT (0.02%) based nano fluid showed less value as comparison to MWCNT (0.01%) nano fluid and water. Increasing concentration of nano particles in base fluid create the chances of agglomeration of nano particles, which results in instability of nano fluid mixture. There are some chances of energy losses by nano fluid at 100L/h due to increase of viscosity of nano fluid, which is a reason for pressure drop in the system and also affect to the system performance. In this experimental study thermal efficiency of nano fluid at 160L/h with 0.02% vol. concentration showed better results overall as comparison to nano fluid with 0.01% concentration.

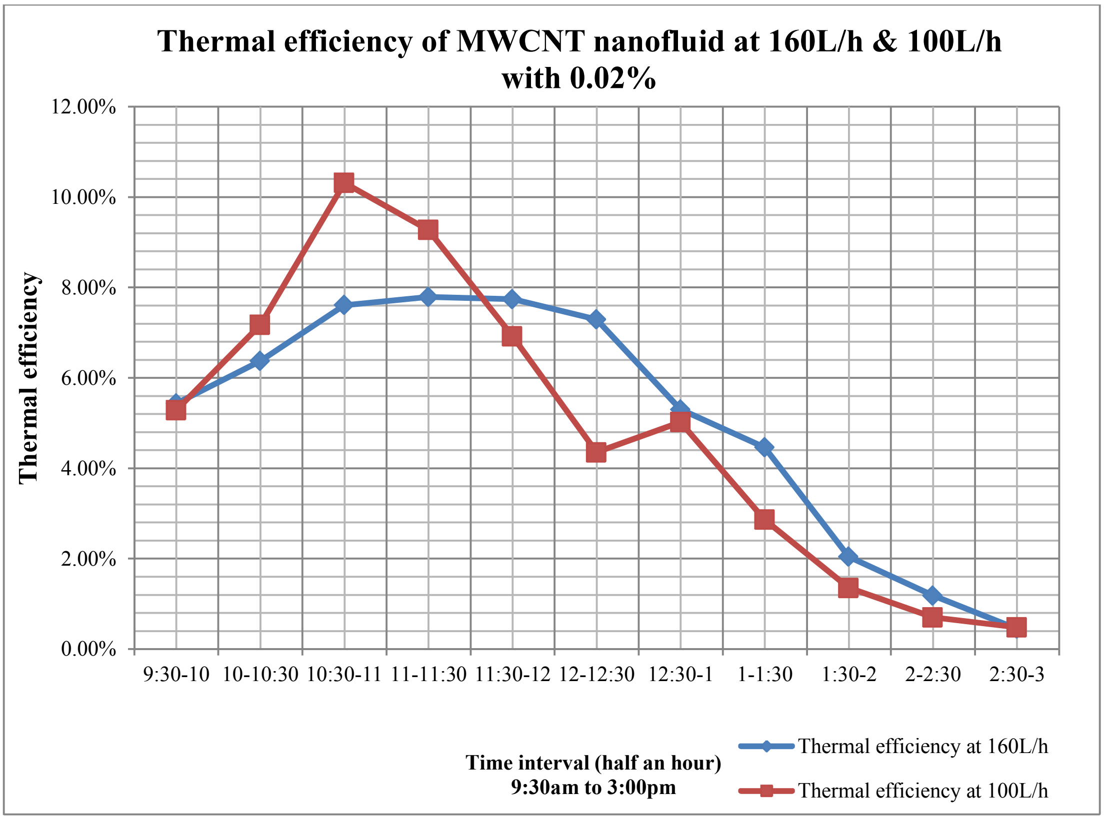


Figure 37: Experimental variation in thermal efficiency of nano fluid with change in day time for different volume flow rates with 0.02% volume flow rates

In this work maximum thermal efficiency at 160L/h is 7.79% measured in the time interval 11:00-11:30am and maximum thermal efficiency at 100L/h is 10.31% during the time interval 10:30-11:00am. Overall thermal efficiency through MWCNT nanofluid at 160L/h with 0.02wt% showed highest value among all other experiments through MWCNT nanofluid and water.

10.2.3 Results of Experimental Work with the Use of Water

In this experimental study water is used as a working fluid and flowing through the receiver of parabolic trough collector at different volume flow rates like 160L/h and 100L/h. Water is used to evaluate the temperatures at inlet and outlet of collector's receiver, useful heat gain, thermal efficiency, overall thermal efficiency and instantaneous efficiency also. All the experimental results outcome are shown graphically in this section and discussion on that results are described below.

(a) Experimental Variations in Temperatures at Inlet and Outlet and Solar Intensity With The Change in Time Interval at 160L/h

Figure shows graphical representation of data related to inlet and outlet temperatures and solar intensity for water (i.e. base fluid) with the change in day time at 160L/h. solar intensity increasing continuously with change in time interval but up to certain limit and after that it starts decreasing, while temperature are continuously increasing throughout the day.

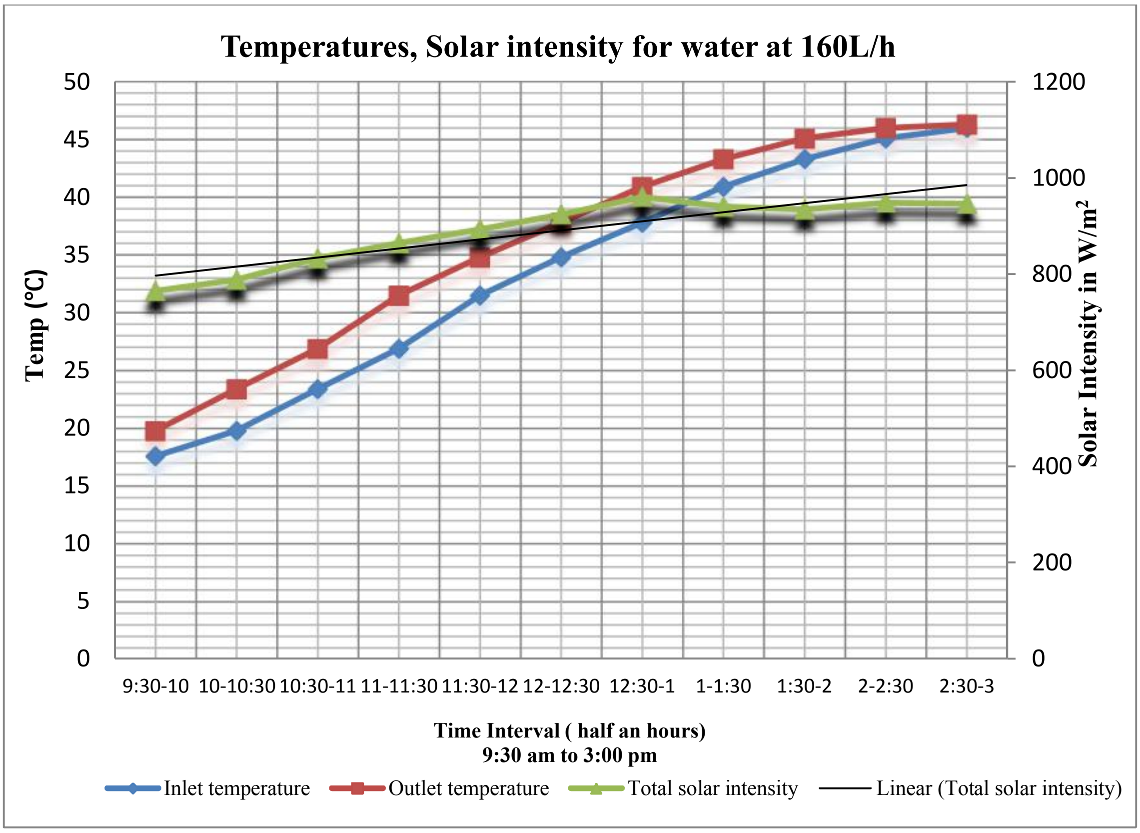


Figure 38: Experimental variation in inlet and outlet temperatures and solar intensity for water with change in day time at 160L/h

In this experimental study maximum solar intensity is 960.654W/m^2 measured during the time interval 12:30-1:00pm after that solar intensity starts to decrease. Further maximum outlet temperature is observed 46.3℃ and minimum inlet temperature is 17.6℃ measured and shown in figure clearly.

(b)Experimental Variations in Temperatures at Inlet and Outlet and Solar Intensity With The Change in Time Interval at 100L/h

Figure shows graphical representation of data related to inlet and outlet temperatures and solar intensity for water (i.e. base fluid) with the change in day time at 100L/h. In this experimental study solar intensity increasing continuously up to 12:45pm and after that it starts decreasing and after 1:30pm, a sudden change is noticed in solar intensity and it starts to increase. Temperatures measured at inlet and outlet of receiver is continuously increasing throughout the day. Maximum solar intensity is 999.394W/m^2 measured during time interval 2:30-3:00pm and maximum outlet temperature is 43.5℃, while minimum inlet temperature is 15.3℃ measured.

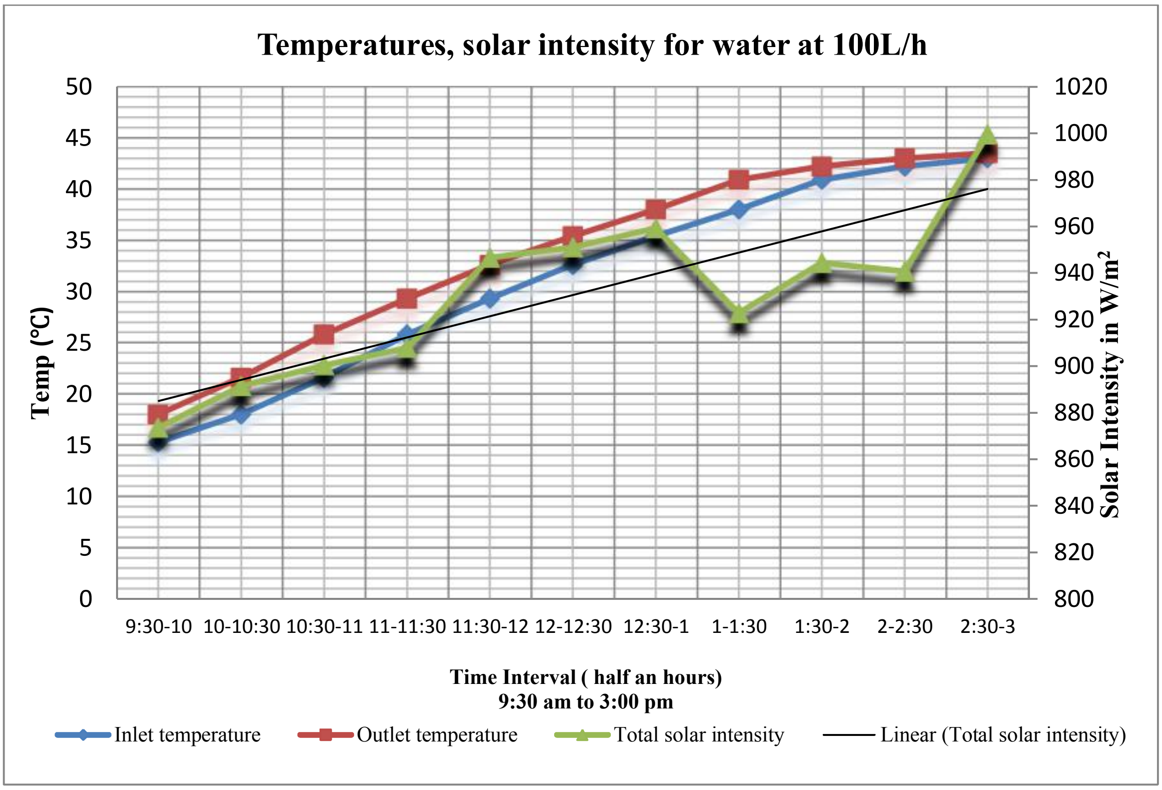


Figure 39: Experimental variations in solar intensity, inlet and outlet temperatures for water with change in day time at 100L/h

(c) Experimental Variations in Useful Heat Gain for Water With The Change in Day Time at Different Volume Flow Rates

Figure shows graphical representation of data related to useful heat gain for water with change in day time. Useful heat gain is directly proportional mass flow rate, specific heat and temperature difference also. Specific heat of water showed better results as compare to MWCNT based nano fluids at different concentrations. Mass flow rate is the major dominant factor for evaluation of useful heat gain, because it depends upon density of water. Major difference between mass flow rates of nano fluids and water is due to difference in density. Increased variation in temperature difference is due to incremental change in solar intensity throughout the day.

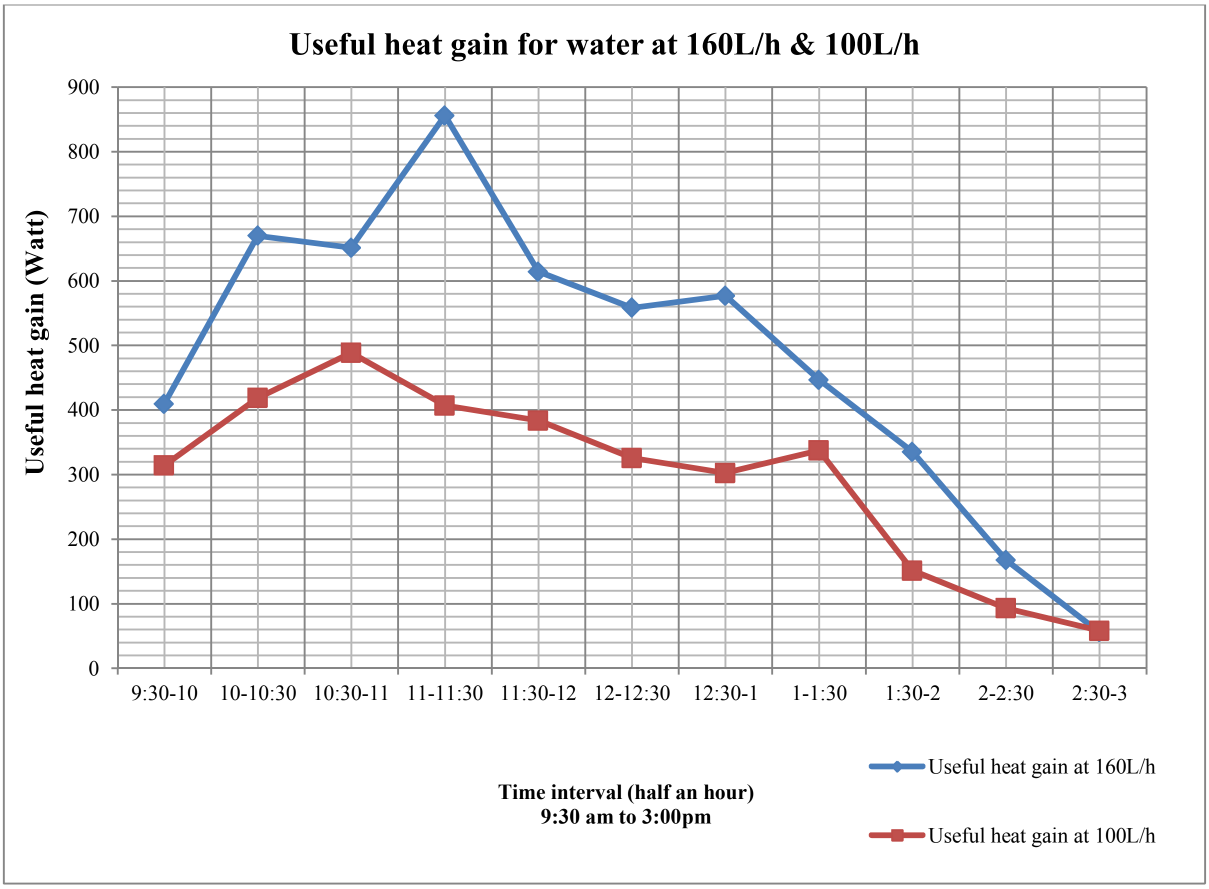


Figure 40: Experimental variation in useful heat gain for water with the change in day time at different volume flow rates.

In this experimental study maximum useful heat gain by water is 855.923 W/m^2 at 160L.h in the time interval 11:00-11:30am and at 100L/h water showed maximum useful heat gain is 488.346W/m^2 in the time interval 10:30-11am after that both the volume flow rates showed a decrement in useful heat gain.

(d)Experimental Variations In Temperature Difference For Water With The Change In Day Time For Different Volume Flow Rates

Figure shows graphical representation of data related to difference b/w inlet and outlet temperatures comes out with the use of water at different volume flow rates. Incremental change in temperature difference is due to increasing solar intensity but up to a certain time limit after that both solar intensity and corresponding temperature difference starts to decrease. Variation in temperature difference is dependent upon variation in solar intensity measured at solar collector throughout the day. Temperature difference is also affected by Wind flowing speed over the collector's receiver during experimental work.

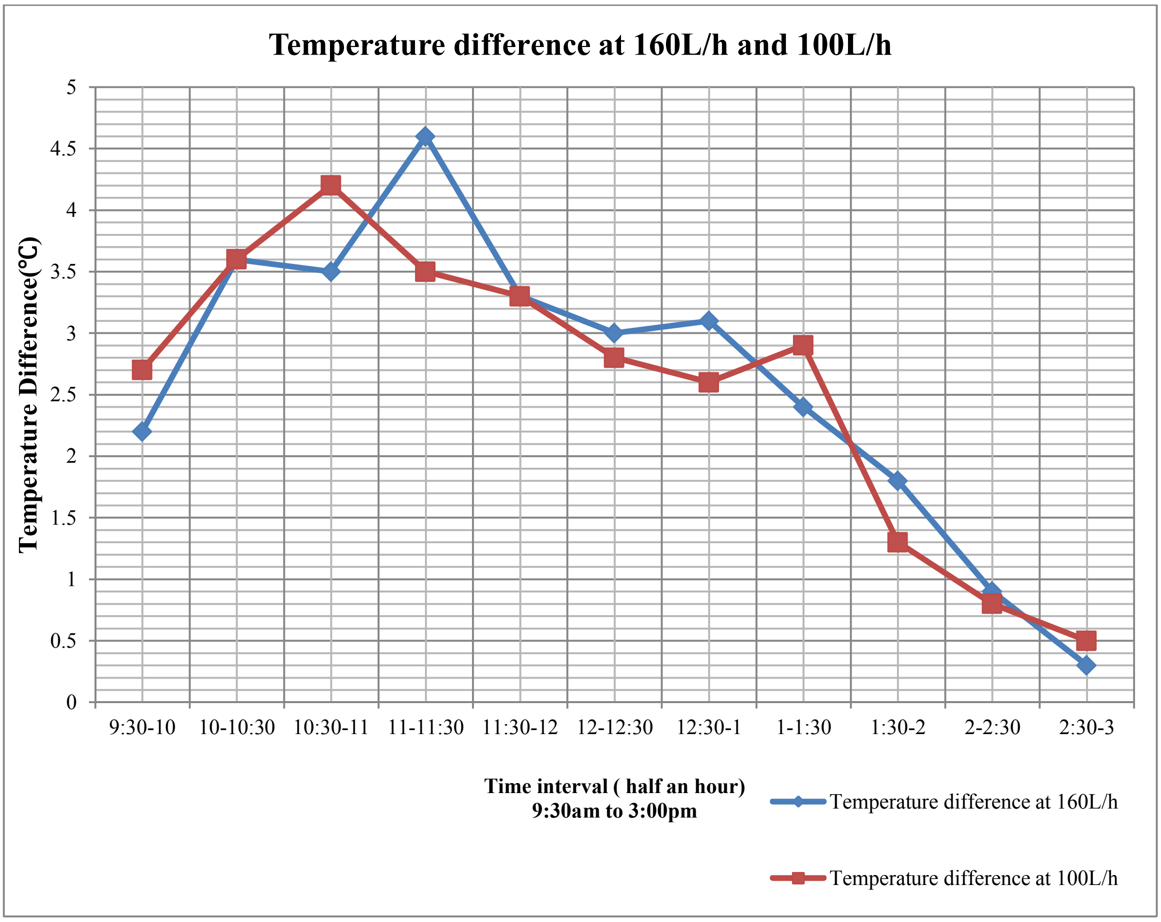


Figure 41: Experimental variations in temperature difference of water with change in day time at different volume flow rates

In experimental study water at 160L/h showed better results throughout the experimental work as comparison to water at 100L/h. Maximum temperature difference is 4.6℃ measured with water at 160L/h in the time interval 11:00-11:30am and maximum temperature difference is 3.6℃ with water at 100L/h in the time interval 10:30-11:00am. Temperature difference is directly proportional to useful heat gain, instantaneous efficiency and thermal and overall thermal efficiency.

(e) Experimental Variations in Instantaneous Efficiency for Water With The Change in Day Time at Different Volume Flow Rates

Figure shows graphical representation of instantaneous efficiency for water with the change in day time at different volume flow rates. Instantaneous efficiency is widely dependent upon useful heat gain or temperature difference and also upon solar intensity measured throughout the day time. Solar intensity is inversely proportional to instantaneous efficiency, so a decrement comes in instantaneous efficiency with incremental change in solar intensity.

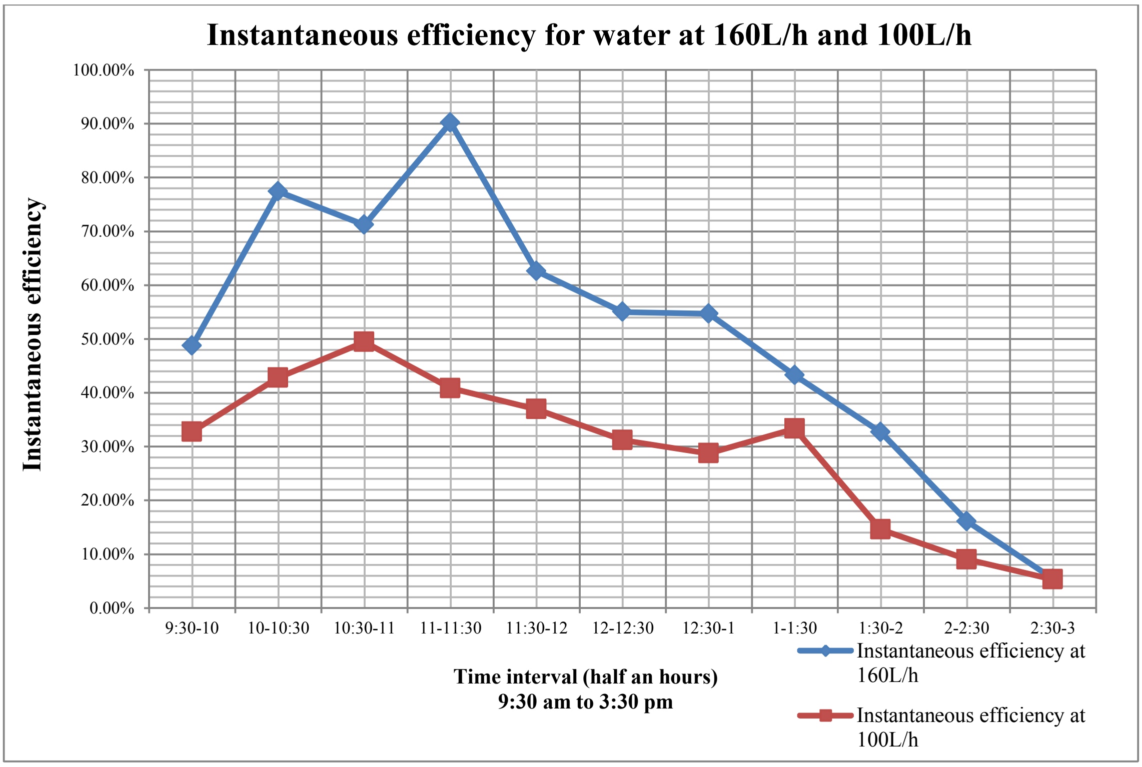


Figure 42: Experimental variation of instantaneous efficiency for water with change in day time at different volume flow rates

Maximum Instantaneous efficiency for water at 160L/h is 90.17% measured in the time interval 11:00-11:30am and maximum instantaneous efficiency for water at 100L/h is 49.40% measured in the time interval 10:30-11:00am after that graph for instantaneous efficiency at both the volume flow rates tends to decrease continuously.

(f) Experimental Variations in Thermal Efficiency for Water With The Change in Day Time at Different Flow Rates

Figure shows graphical representation of data related to thermal efficiency of water with the change in day time for different volume flow rates. Thermal efficiency is directly proportional to mass of base fluid i.e. water, specific heat and temperature difference. Density and specific heat for water are little bit more than MWCNT nano fluid and here in this experimental work major dominant factor is temperature difference behind the incremental change in thermal efficiency. Variation in thermal efficiency majorly dependent upon the variation comes in temperature difference and solar intensity throughout the experimental work. In this figure shown below, maximum thermal efficiency is 7.28% is measured from water working at 160L/h during the time interval of 11:00-11:30am and maximum thermal efficiency for water at 100L/h is 6.39% measured in the time interval of 10:30-11:00am. Therefore water at 160L/h showed better result outcomes for thermal efficiency as comparison to result comes out for thermal efficiency of water at 100L/h

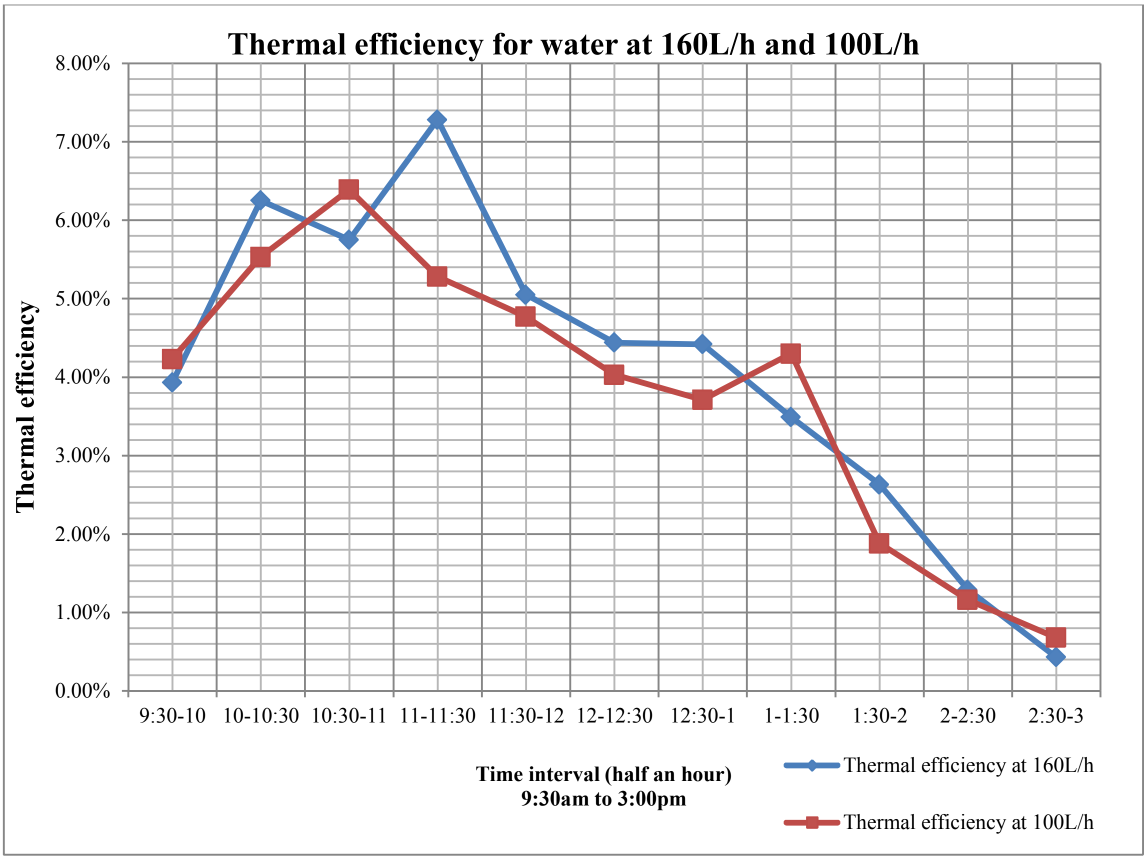


Figure 43: Experimental variations in thermal efficiency of water with change in day time at different volume flow rates

10.2.4 Comparison of performance through MWCNT Based Mixture and Water

(a) Experimental Comparison of Instantaneous Efficiency Change With Day Time With The Use of Water and Nano Fluid at 0.01% With Volume Flow Rate 160L/h

Figure showed graphical representation of data related to instantaneous efficiency of both MWCNT based nano fluid at 0.01% volume concentration and water at same volume flow rate i.e. 160L/h. This section also include the comparison between the results of instantaneous efficiency comes out from different kind of fluids. In this experimental study maximum instantaneous efficiency of nano fluid at 0.01% with 160L/h comes out 96.49% in the time interval 10:30-11:00am and maximum instantaneous efficiency is 90.17% for water at 160L/h in the time interval 11:00-11:30am. After 12:45pm water shows better results as comparison to nano fluid at 0.01% as shown in figure, it can be due to instability and agglomeration of nano particles with change in time and also due to some external effect like wind speed over the collector and discontinuous solar flux or solar intensity throughout the day. Apart from this MWCNT shows better thermo physical properties like thermal conductivity as comparison to water i.e. base fluid. Nano fluid also possess less mass and mass flow rate as comparison to water because MWCNT acquire less density as comparison to water.

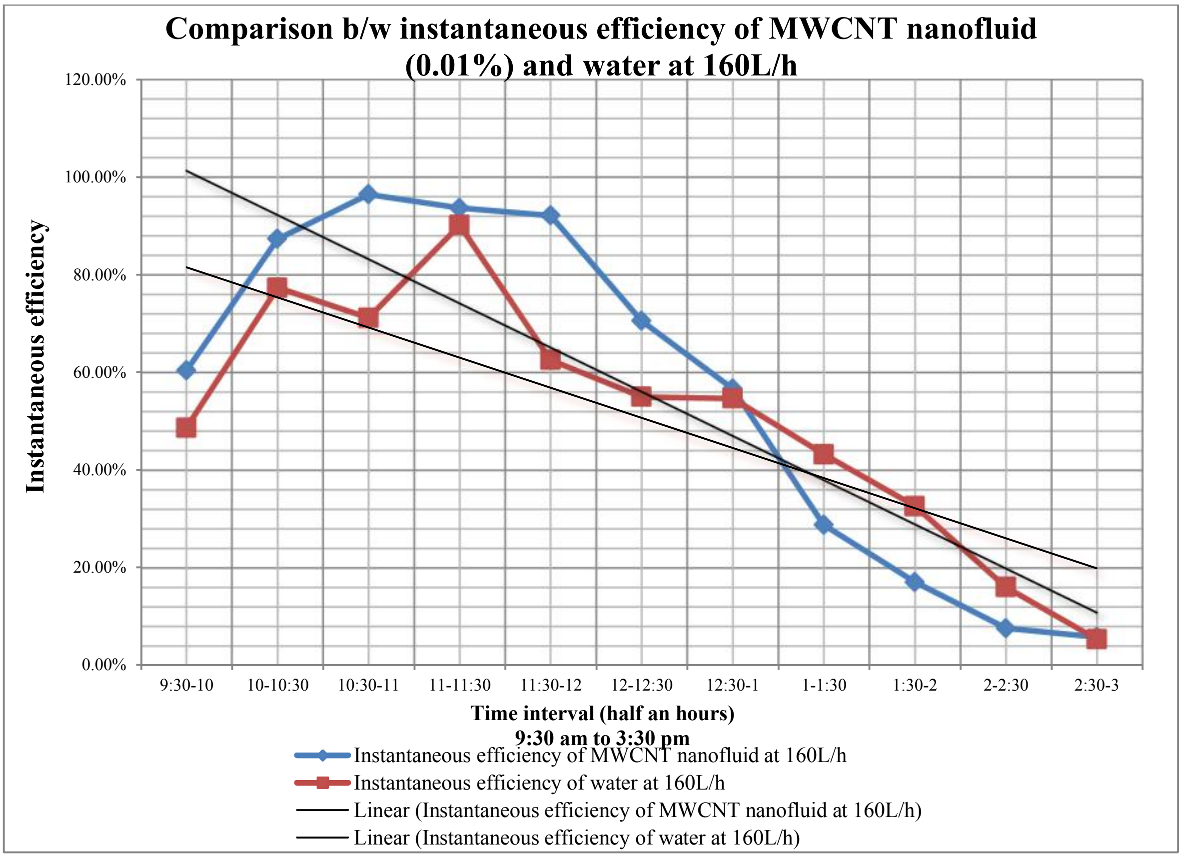


Figure 44: Experimental variation in instantaneous efficiency of nano fluid at 0.01% and water with the change in day time for same volume flow rate i.e. 160L/h.

(b) Experimental Comparison of Instantaneous Efficiency Change With Day Time With The Use of Water and NanoFluid at 0.01% With Volume Flow Rate 100L/h

Figure shows graphical representation of instantaneous efficiency of water and nanofluid with 0.01% at same volume flow rate 100L/h. This section include the comparison between results comes out at various points on graphical figure for different fluids at same volume flow rate. In this experimental study MWCNT based nano fluid showed greater enhancement in instantaneous efficiency as comparison to enhancement in instantaneous efficiency of water. For MWCNT based nano fluid showed maximum instantaneous efficiency is 87.85% in the time interval 10:30-11:00am and for water maximum instantaneous efficiency is 49.40% in the time interval 10:30-11:00am is measured.

Suspension of nano particles in to base fluid is the better solution to increase the heat transfer properties or to improve the thermo physical properties of the base fluid. But it completely depends upon the type of nano particle used in experimental work. In this study MWCNTs used for experimentation because multi walled carbon nanotubes acquire better thermal properties as comparison to other nano particles, but MWCNT based nano fluid with 0.01% vol. concentration does not showed satisfactory results for thermo physical properties like specific heat and density due to which efficiency tend to decrease. Apart from this MWCNT based nano fluid also possess some advantages like higher thermal conductivity as comparison to base fluid and this is the major dominant factor in conduct of high quantity heat.

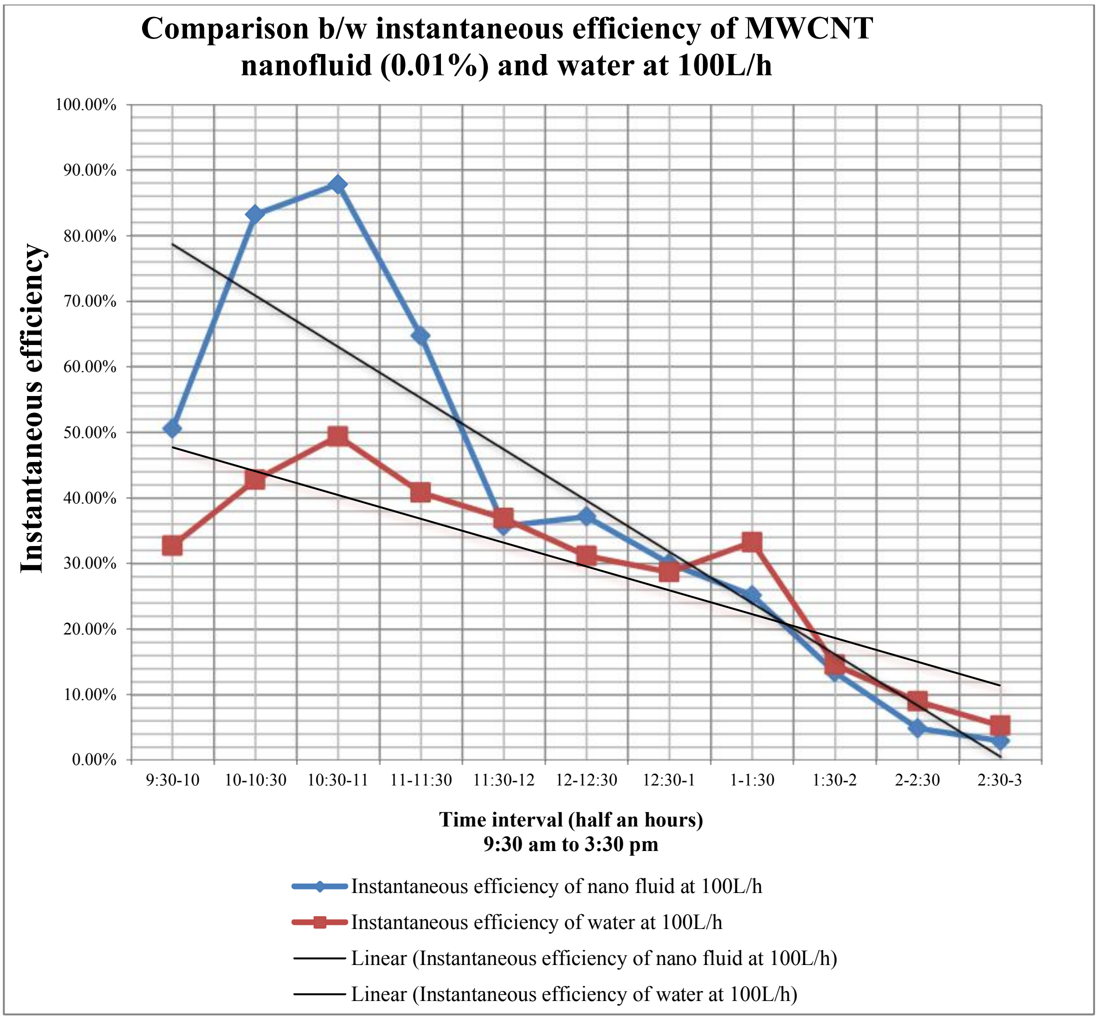


Figure 45: Experimental variations in instantaneous efficiency of water and nano fluid (0.01%) with change in day time at 100L/h

(c) Experimental Comparison b/w Instantaneous Efficiency of Water and Nano Fluid With Change in Day Time With 0.02% Vol. Concentration at 160L/h Volume Flow Rate

Figure showed graphical representation of instantaneous efficiency for nano fluid and water change with time interval for same volume flow rate. This section includes comparison b/w instantaneous efficiency comes out from experimentation for different type of fluids and shown in graphical figure. Increasing concentration of nano particles, there is a chance to increase the thermo physical properties of nano fluids, which is further very helpful for enhancement in working performance of system. In this experimental work MWCNT based nano fluid showed maximum instantaneous efficiency is 96.46% in the time interval 11:00-11:30am and water showed 90.17% maximum instantaneous efficiency in the same time interval, which is less in amount as comparison to nano fluid.

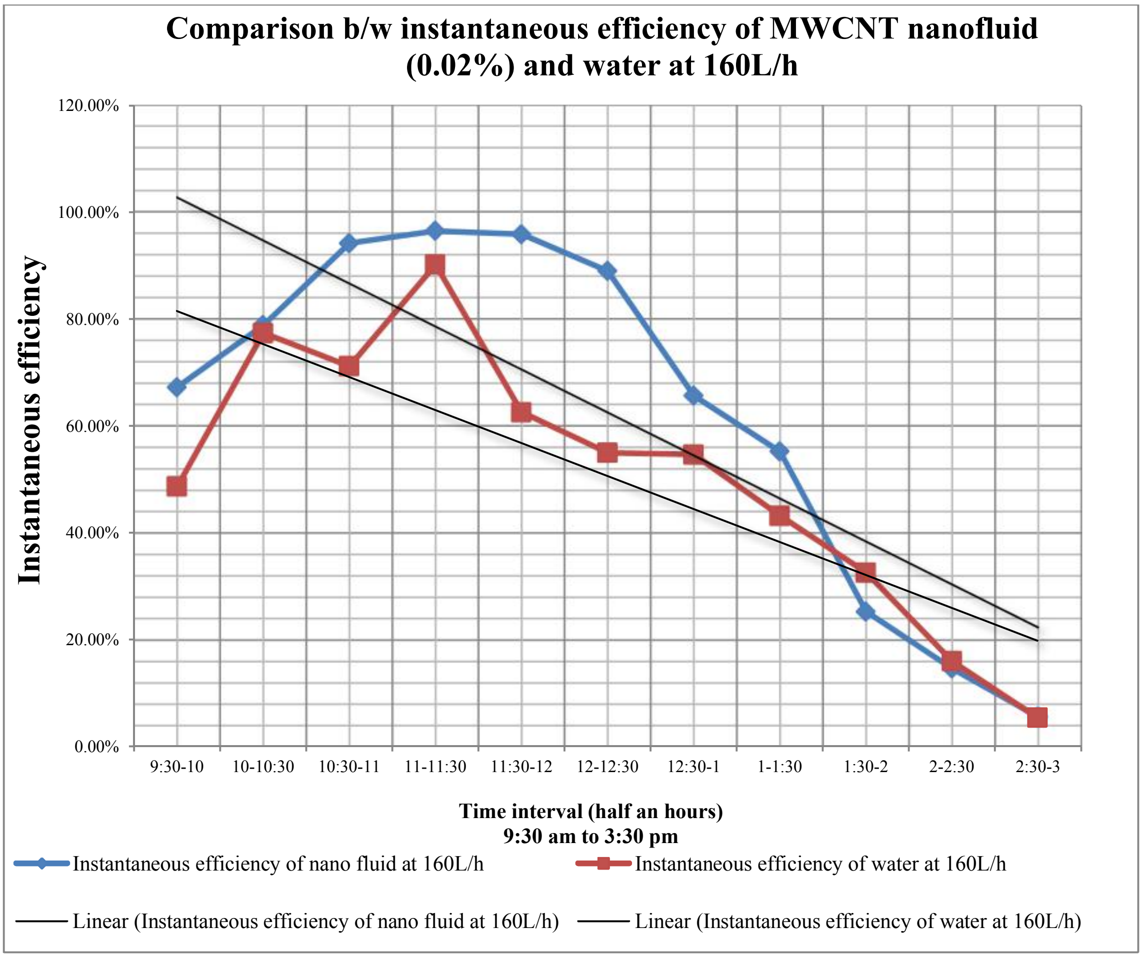


Figure 46: Experimental variations in instantaneous efficiency for nano fluid (0.02%) and water with change in day time at 160L/h volume flow rate

(d) Experimental Comparison b/w Instantaneous Efficiency of Water and NanoFluid With Change in Day Time With 0.02% Vol. Concentration at 100L/h Volume Flow Rate

Figure shows graphical representation of variation in instantaneous efficiency of water and MWCNT based nano fluid change with day time with 0.02% volume concentration at same volume flow rate i.e. 100L/h. It has been discussed before that with increment in volume concentration viscosity of nano particles also increase as comparison to viscosity comes out at 0.01% vol. Concentration. Incremental change in viscosity has an ability to increase the pressure losses in system, which decreases the efficiency through the working fluid. Wind speed over the collector and variation in the amount of solar intensity also affect the performance of nano fluids. Further at less volume flow rate and with higher concentration nano particles tend to start agglomeration and showed instable behaviour in base fluid. In this experimental study MWCNT based nano fluid showed maximum instantaneous efficiency is 79.77% in the time interval 10:30-11:00am and water at 100L/h showed maximum instantaneous efficiency is 49.40% measured at same volume flow rate and also at same time interval.

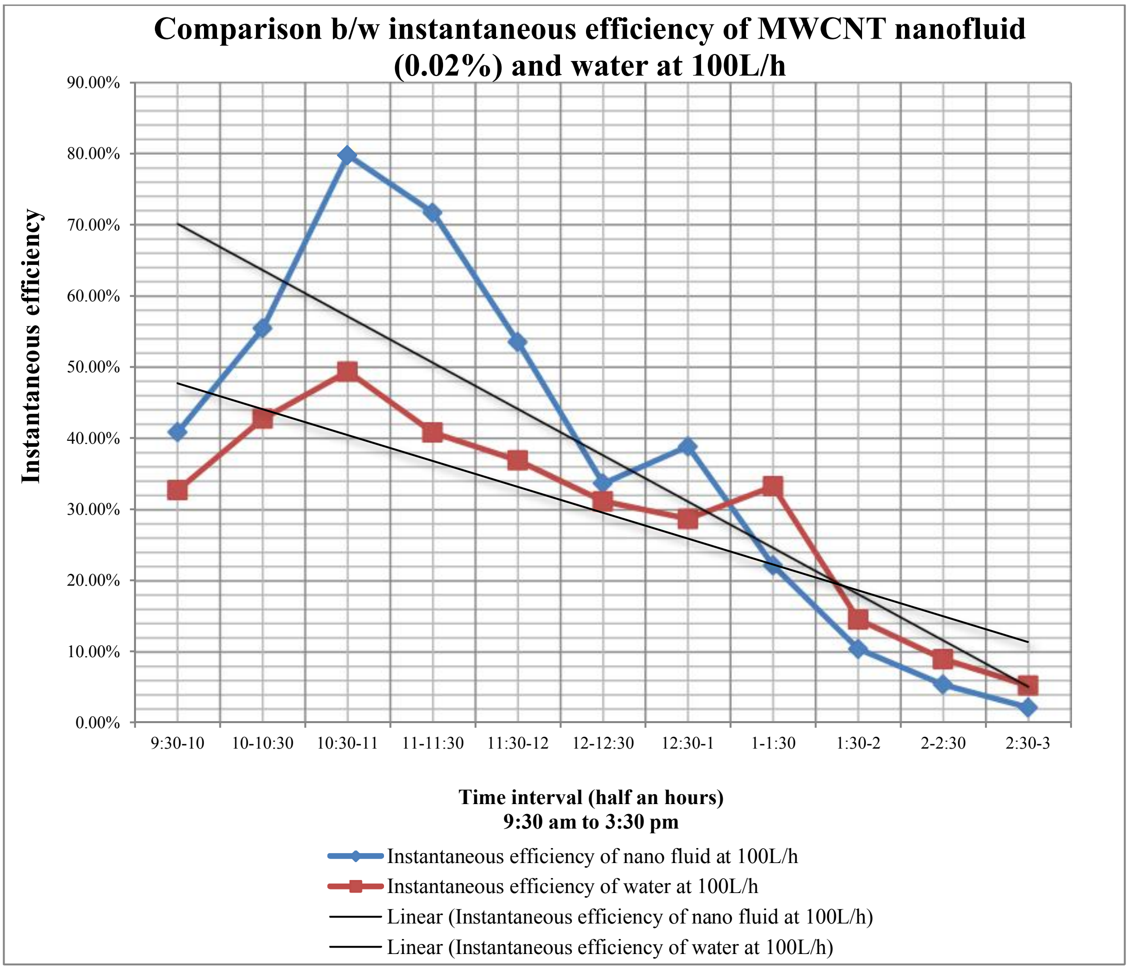


Figure 47: Experimental variations in instantaneous efficiency of water and nano fluid (0.02%) with change in day time at 100L/h volume flow rate

(e) Experimental Comparison b/w Thermal Efficiency of NanoFluid (0.01%) and Water With Change in Day Time at 160L/h Volume Flow Rate

Figure showed graphical representation of variations in thermal efficiency of MWCNT (0.01%) based nano fluid and water with change in day time at same volume flow rate. MWCNT nano particles showed better thermo physical properties as comparison to other nano particles, while MWCNT and water based nano fluid at 0.01% vol. concentration showed better thermal conductivity as comparison to water but nano fluid also possess less specific heat and density as comparison to water. Therefore major dominant factor behind the improvement in thermal efficiency is only thermal conductivity. This experimental study showed maximum thermal efficiency of nano fluid is 7.79% in the time interval 10:30-11:00am, which is larger than maximum thermal efficiency achieved from water i.e. 7.28% in the time interval 11:00-11:30am and after that both the graph start to decrease continuously. After 12:45pm Thermal efficiency of water showed better results as comparison to nano fluid.

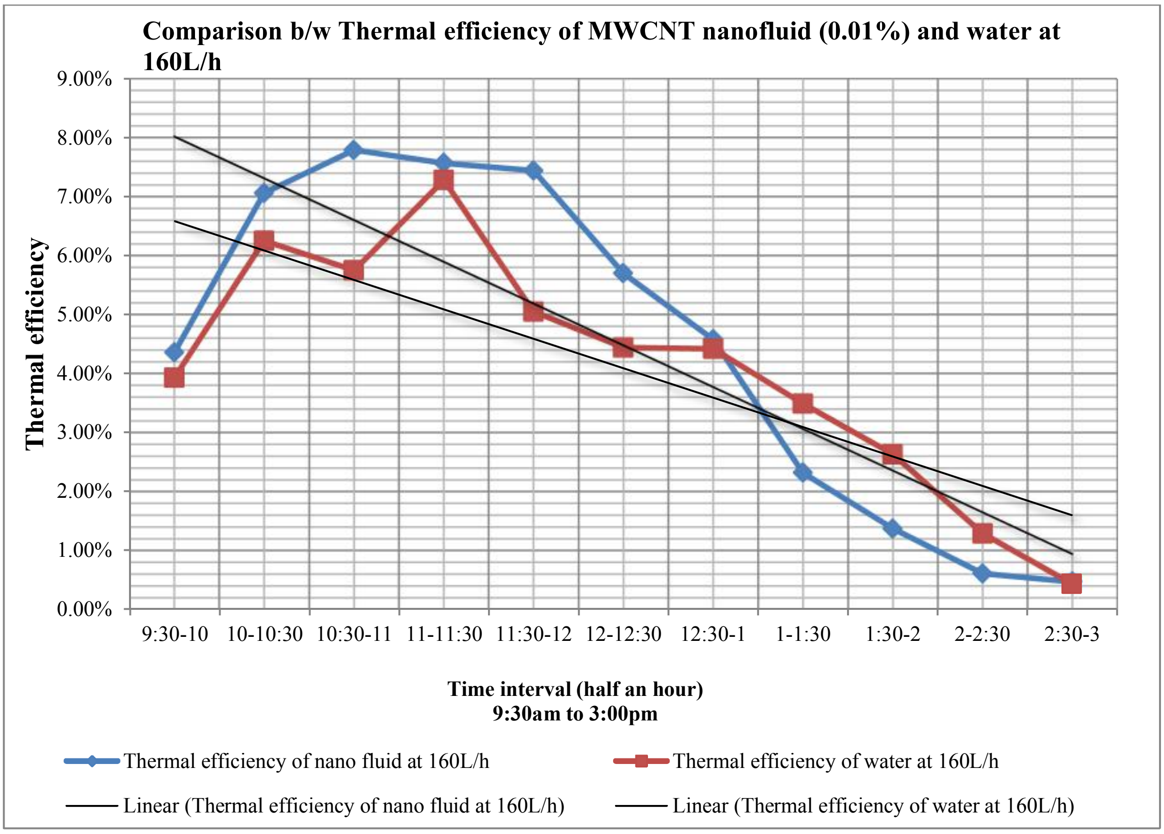


Figure 48: Experimental variation in thermal efficiency of nano fluid mixture (0.01%) and water with change in day time at same volume flow rate

(f) Experimental Comparison b/w Thermal Efficiency of Nano Fluid (0.01%) and Water With Change in Day Time at 100L/h Volume Flow Rate

Figure showed graphical representation of thermal efficiency of nano fluid (0.01%) and water with change in time interval at same volume flow rate i.e. 100L/h. In this experimental study MWCNT based nano fluid with 0.01% vol. concentration showed better results of thermal efficiency as comparison to water. Maximum thermal efficiency possessed by nano fluid is 11.36% in the time interval 10:30-11:00am, which is greater than maximum thermal efficiency of water is 6.39% measured in the same time interval.

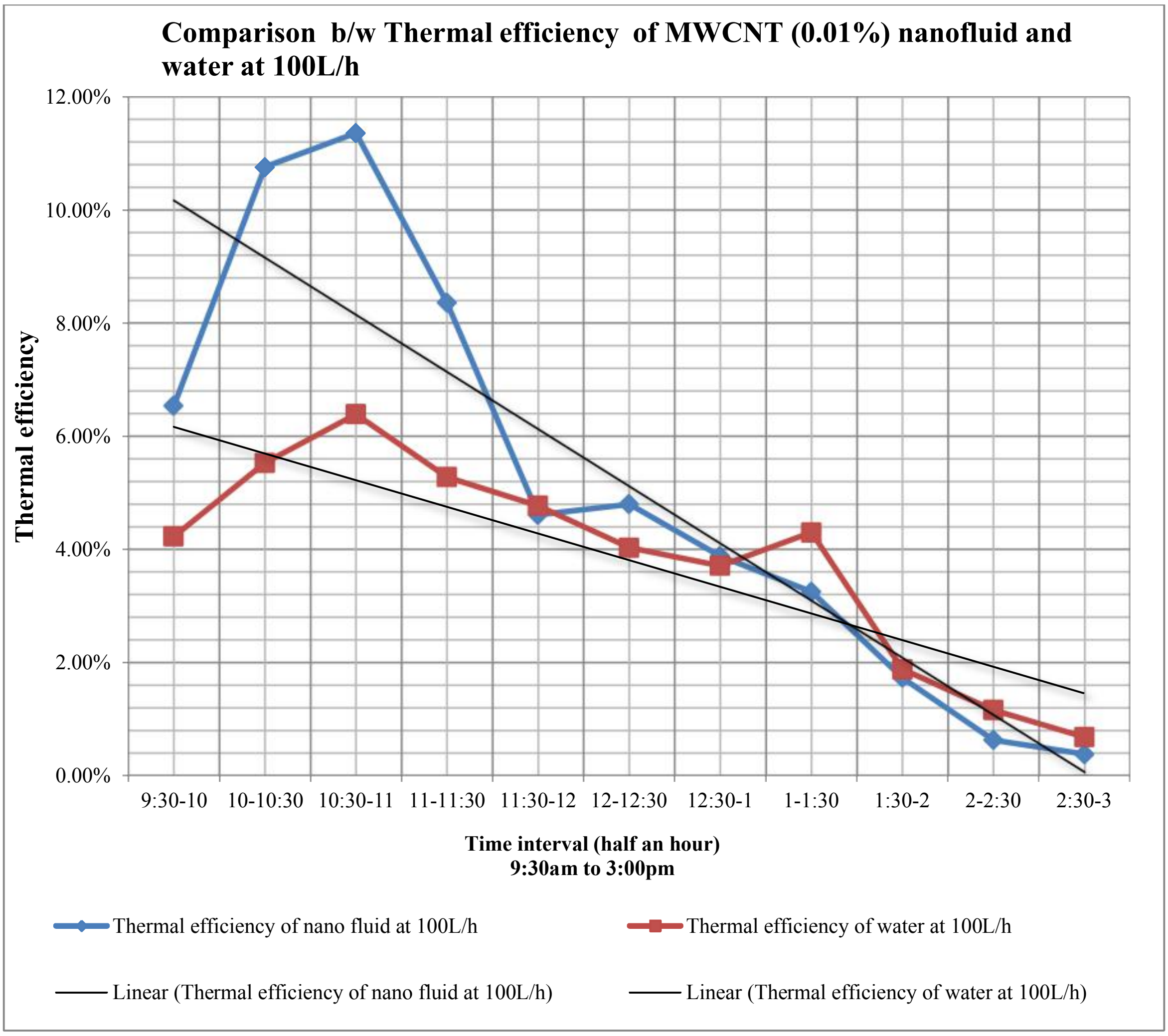


Figure 49: Experimental variations in thermal efficiency of nano fluid (0.01%) and water with change in day time at same volume flow rate i.e. 100L/h

(g) Experimental Comparison b/w Thermal Efficiency of Nano Fluid (0.02%) and Water With Change in Time Interval at 160L/h

Figure showed graphical representation of thermal efficiency of MWCNT based nano fluid (0.02%) and water with change in day time at 160L/h. MWCNT (0.02%) based nano fluid possesses maximum value of thermal efficiency i.e. 7.79% in the time interval 11:00-11:30am as comparison to maximum thermal efficiency achieved from water i.e. 7.28% in the same time interval. It has been discussed before that MWCNT based nano particles showed better thermo physical properties but nano fluid with concentration 0.02% does not showed expressive results for thermo physical properties like specific heat and density, which is less in amount than base fluid as shown in properties table clearly and it can be a reason for less value of thermal efficiency possessed by MWCNT based nano fluid as comparison to water after 1:45pm.

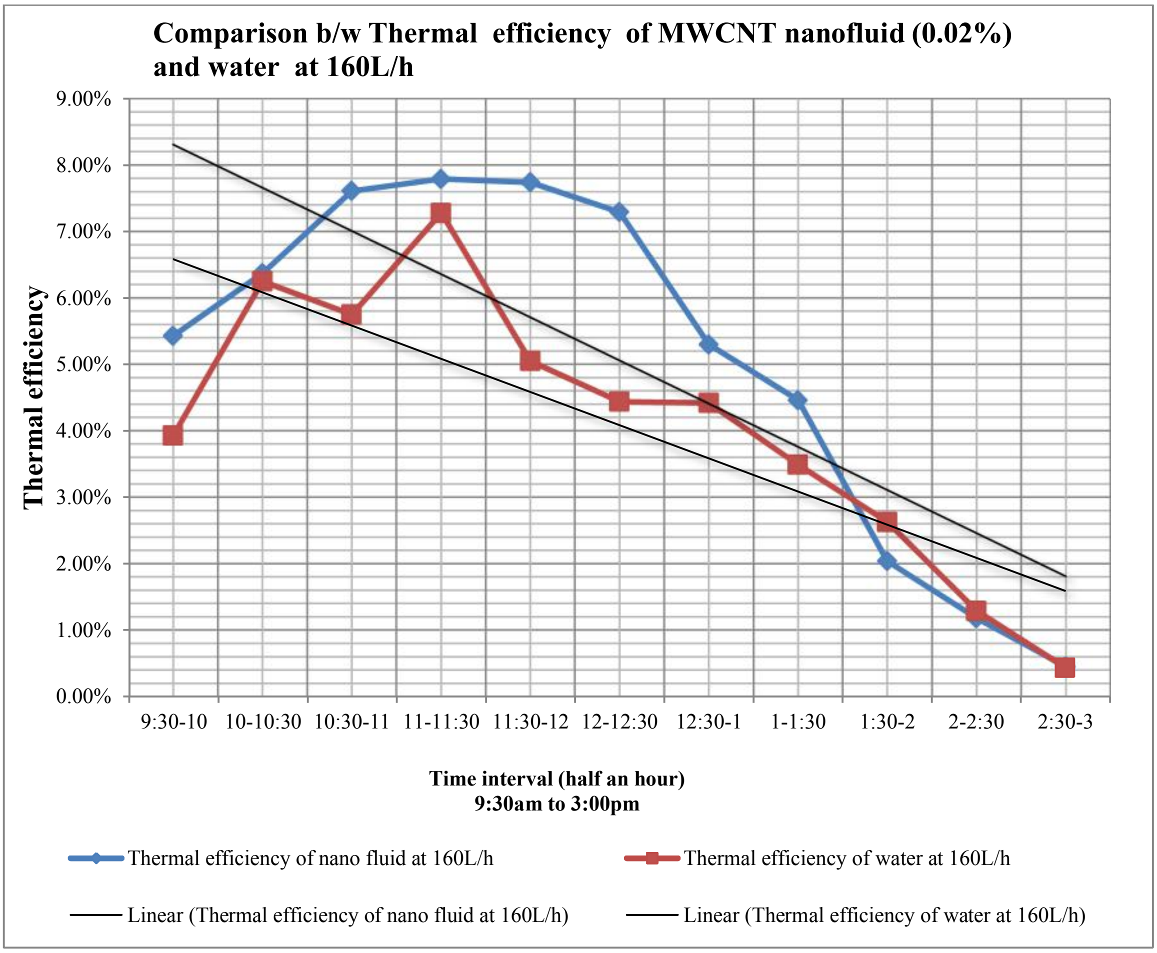


Figure 50: Experimental variations in thermal efficiency of nano fluid (0.02%) and water with change in day time at same volume flow rate 160L/h

(h) Experimental Comparison b/w Thermal Efficiency of Nanofluid (0.02%) and Water With Change in Time Interval at Same Volume Flow Rate i.e. 100L/h

Figure showed graphical representation of thermal efficiency of MWCNT based nano fluid (0.02%) and water with change in day time at same volume flow rate i.e. 100L/h. MWCNT based nano fluid showed Maximum thermal efficiency i.e. 10.31% at 100L/h in time interval 10:30-11:00am and water showed maximum thermal efficiency is 6.39% measured in the same time interval. Increasing concentration of nano particles in base fluid, which results in increasing viscosity of nano fluid and high viscosity of fluid also become an reason for pressure losses in the piping system at lower volume flow rate. Further incremental change in viscosity results in agglomeration and instability of nano particles in base fluid and also decrease down the performance of the solar collector during experimental work. Nano fluids acquire higher thermo physical properties like thermal conductivity as comparison to water

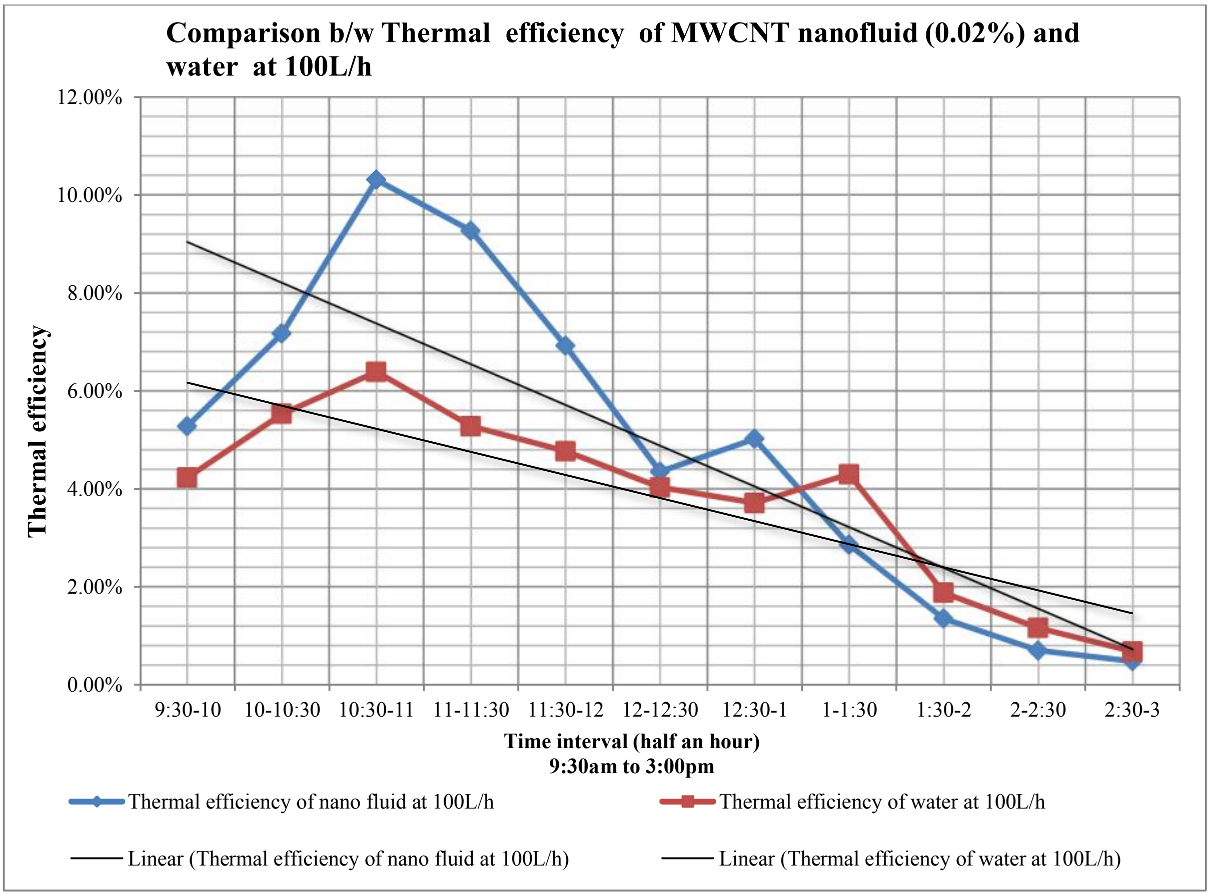


Figure 51: Experimental variations in thermal efficiency of nano fluid (0.02%) and water with change in day time at same volume flow rate 100L/h

Chapter-11

Conclusion

Experimental study concluded various results outcome with the use of MWCNT and water based nano fluid at 0.01% and 0.02% volume concentrations and water as a working fluid at different volume flow rates i.e. 160L/h and 100L/h. Important experimental results related to useful heat gain, instantaneous efficiency, thermal & overall thermal efficiency and also absorbed flux are concluded and discussion on that results are discussed below:

1. It has been discussed already that thermo physical properties of MWCNTs far better than base or conventional fluids like water. Further it has been concluded in this study that MWCNT and water based nano fluid at decided volume concentration i.e. 0.01% and 0.02% showed less value of specific heat, density and mass flow rate. But thermal conductivity of MWCNT based nano fluids is still higher than water at the decided concentration.

2. Useful heat gain by nano fluid mixture and water is fully dependent upon the mass flow rate, specific heat and also upon temperature difference measured during experimental working. In case of nano fluid mixture 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. Maximum useful heat gain by MWCNT based nano fluid with 0.01% and 0.02% volume flow rate at 160L/h is 1190.82j/s and 1153.50j/s measured, while maximum useful heat gain for nano fluid mixture at 0.01% and 0.02% vol. concentration at 100L/h is 732.63j/s and 813j/s measured and maximum useful heat gain by water at 160L/h is 855.923j/s and at 100L/h is 488.346j/s. 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.

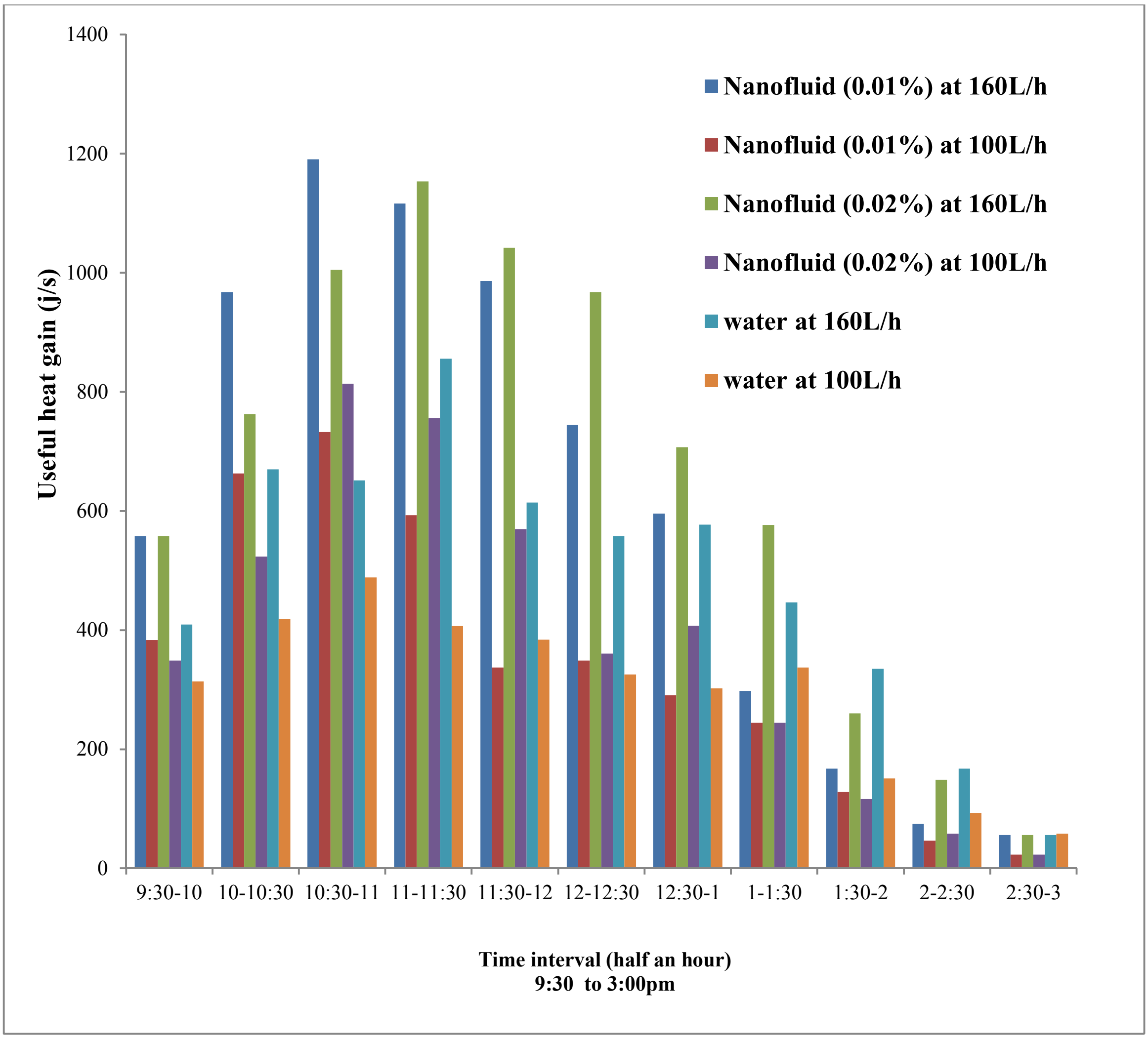


Figure 52: Experimental variation in useful heat gain by nano fluid at both 0.01% and 0.02% Vol. concentration and through water at decided volume flow rates i.e. 100L/h and 160L/h

3. From the experimental work it has been evaluated that 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%, while maximum instantaneous efficiency for nano fluid mixture with 0.01% and 0.02% vol. concentration at 100L/h is 87.85% and 79.76%. Further maximum instantaneous efficiency for water at 160L/h and at 100L/h is 77.36% and 49.40% measured.

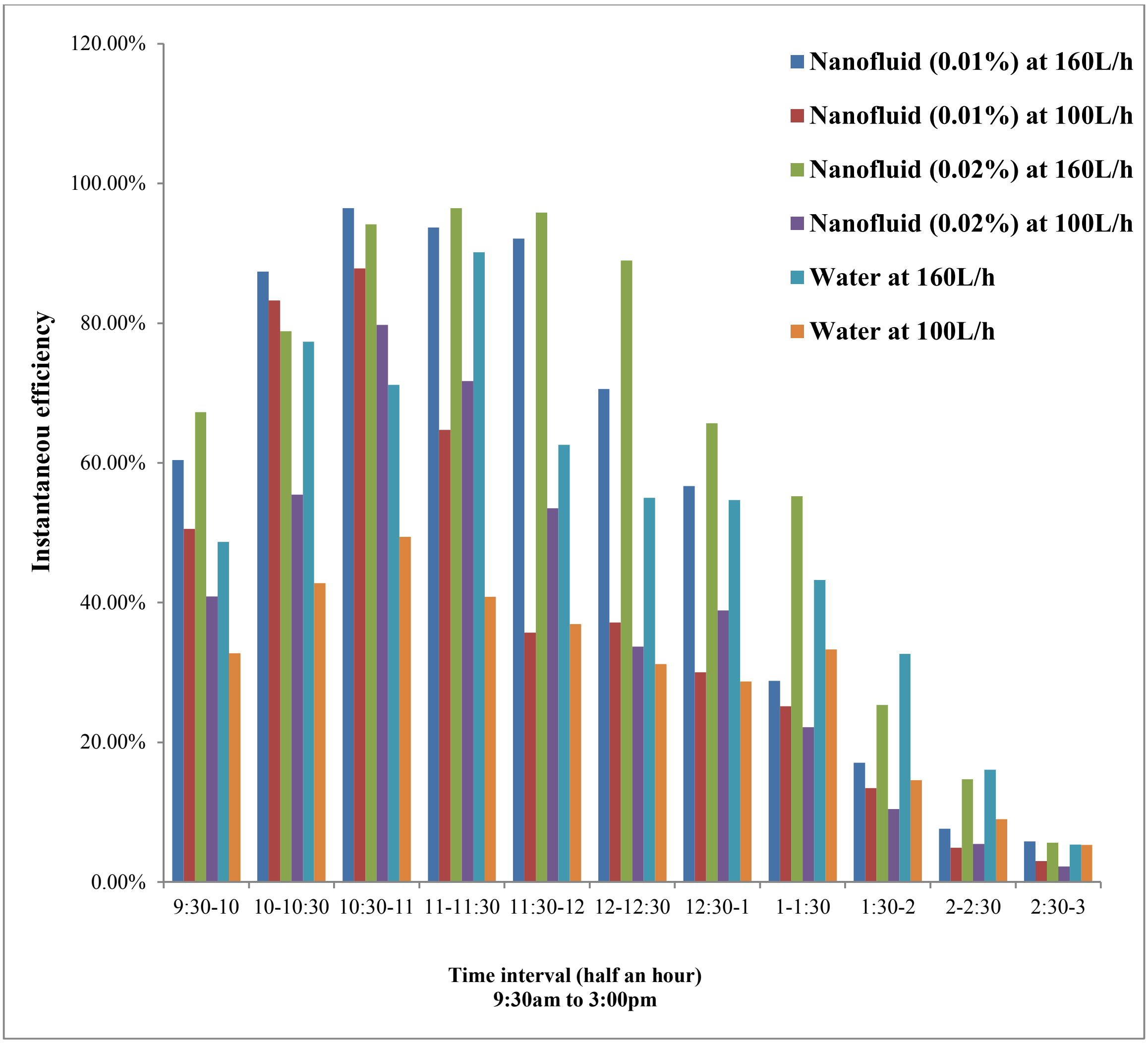


Figure 53: Experimental variations of instantaneous efficiency through MWCNT nanofluids with 0.01% and 0.02% vol. Concentration and through water at different volume flow rates like 160L/h and 100L/h.

Figure showed 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 concluded from experimentation that water at 160L/h showed highest value of instantaneous efficiency at some various points as compare to nano fluid with 0.01% and 0.02% vol. concentration at different volume flow rates.

4. From experimental study it has been seen that maximum thermal efficiency for nano fluid mixture with at 100L/h volume flow rate is 11.36% and 10.31% measured. Further maximum thermal efficiency for water is 7.28% at 160L/h and 6.39% at 100L/h. It has been also concluded from experimental study 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.

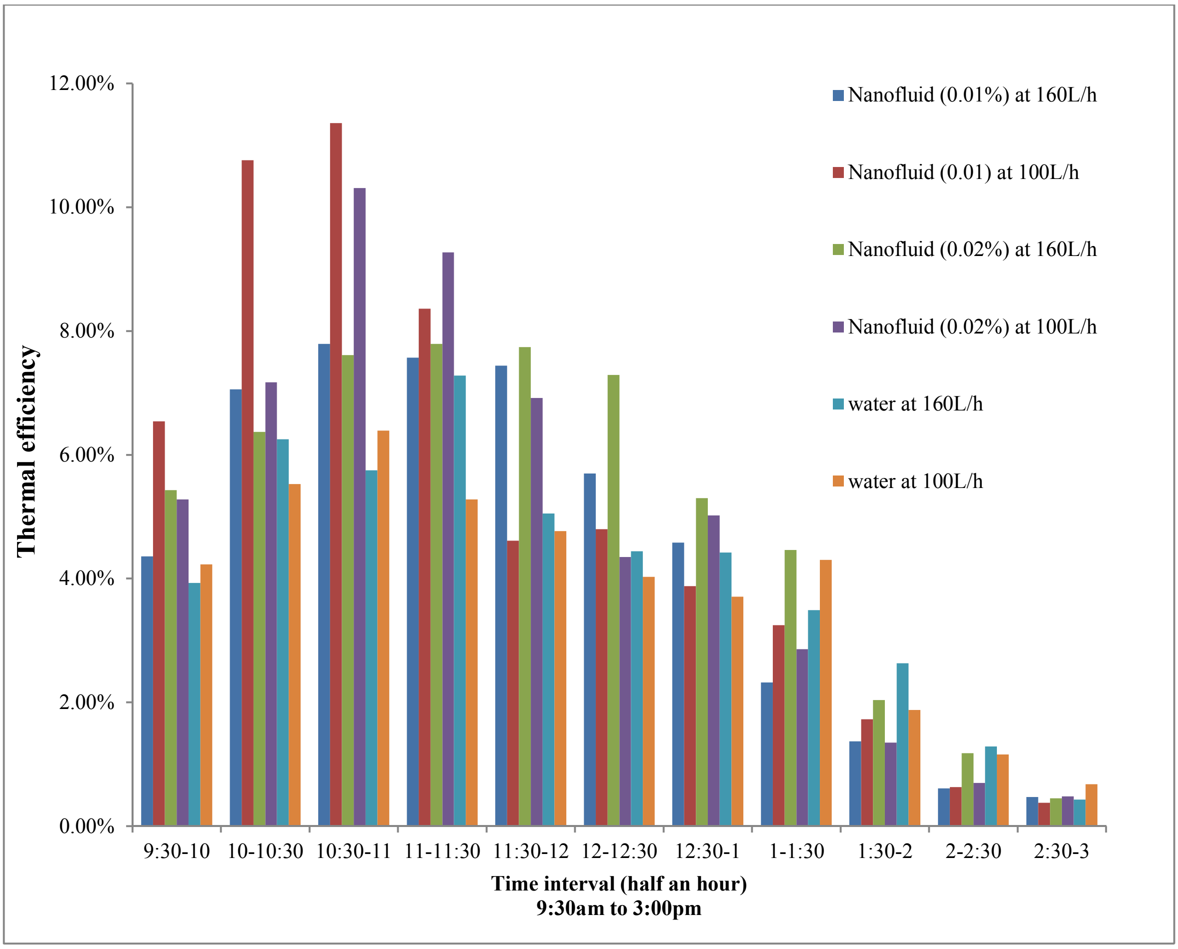


Figure 54: Experimental variations in overall thermal efficiency through MWCNT nanofluid and water with change in day time with different concentration i.e. 0.01% and 0.02% at different volume rates like 160L/h and 100L/h

5. Overall thermal efficiency is directly proportional to mass of fluid, specific heat and also temperature difference at various instant of time and inversely proportional to aperture area, average solar intensity and also total time of experimentation. Overall thermal efficiency of MWCNT based nano fluid mixture with 0.01% vol. concentration at different volume flow rates i.e. 160L/h and 100L/h is 4.66% and 4.99% and overall thermal efficiency with 0.02% vol. concentration at different volume flow rates i.e.

160L/h and 100L/h is 5.14% and 4.79%. Further water at 160L/h showed overall thermal efficiency 4.01% and at 100L/h is 3.77%.

6. At 0.01% and at 0.02% volume concentration with 160L/h volume flow rate nono fliud mixture acquired turbulent flow, while at 100L/h nano fluid possesses laminar flow because of Reynolds number at this volume flow rate is less than 2000.
7. Effective heat transfer due to the common factors like mass flow rate and thermal conductivity mainly, while there is no big role of specific heat in heat transfer because of smaller change in value of specific heat.
8. Use of MWCNT with surfactant in base fluid has an positive effect on thermal conductivity, while it has been seen that from past research work that the use of functionalize MWCNT does not give the positive effect on thermal conductivity of nanofluid.
9. Efficiency enhancement in case of MWCNT based nanofluid with increment change in volume concentrations at same volume flow rate 160L/h will be 10.3%, while efficiency enhancement between the MWCNT based nanofluid with 0.02wt% and water at same volume flow rates 160L/h will be 28.1%.
10. Collector heat removal factor is greater in case of MWCNT based nanofluid than collector heat removal factor evaluate through water and it is very important relation to calculate useful gain of energy because of known inlet fluid temperature.
11. Maximum temperature arise 65.1℃ at 160L/h and 0.02wt% of MWCNT based nanofluid, which is flowing through the receiver system. Maximum temperature occur during research work is depend upon collector parameters and ambient temperature conditions and also depends upon varying conditions of solar heat flux and wind speed.

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