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Design, Fabrication And Performance Study Of Frusto-Conical Solar Collector By Using Nanofluids

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Abstract

The design, construction and study of frusto-conical solar collector were carried out using locally available materials. Conical shaped concentrator made from galvanized iron sheet with a thickness of 0.644mm. The inner side of the cone shape with thickness of 10mm was gummed with insulating foam material. The aluminium sheet of thickness 0.3mm was used for focusing the solar radiation to the absorber. The primary objective of this paper is to study the frusto-conical Solar Collector with Al_2O_3 / H_2O nanofluid of various concentrations in absorber space. The experiments were carried out in different days and the data were record with respective local time.

Nomenclature:

Q_u Heat gain of water (W)
C_P Specific heat of the Water (J kg $^{-1}$ $^oC^{-1}$)
T_{fi} Inlet water temperature (^oC)
T_{fo} Outlet water temperature (^oC)
T Average receiver water temperature (^oC)
T_w Mean film temperature (^oC)
T_a Atmospheric temperature (^oC)
C Concentration ratio
A_a Aperture area (m^2)
A_r Receiver or Recover Area (m^2)
h_{wind} Heat transfer coefficient of wind (W m^{-2} $^oC^{-1}$)
h_r Radiation heat transfer coefficient (W m^{-2} $^oC^{-1}$)
h_i Inside heat transfer coefficient (W m^{-2} $^oC^{-1}$)
ρ Reflectance of the absorber surface
α Absorptance of the absorber surface
ε Emittance of the absorber surface
γ Intercept of the receiver
η Efficiency of the collector
σ Stefen-boltzman constant
U_O Over all heat transfer co-efficient (W m^{-2} $^oC^{-1}$)
U_L Loss co-efficient (W m^{-2} $^oC^{-1}$)
F_R Heat removal factor
F' Collector efficiency factor
H_b Beam solar irradiance (Wm^{-2})
S Absorbed solar energy of the collector (Wm^{-2})
D_O Outer diameter of the tube (m)
D_i Inner diameter of the tube (m)
K Thermal conductivity of tube material (Wm^{-1} $^oC^{-1}$)
m Mass flow rate (kg/s)

1. Introduction

The Worldwide energy demand is always growing. Nowadays, over 80% of primary energy demand is covered by fossil fuels. Excessive fossil fuel expenditure is causes lot of undesirable phenomena such as environmental and atmospheric pollution, consequently global warming, greenhouse effect, climatic change, Ozone layer depletion and acid rain. Sustainable energy generation is one of the most important challenges for our society. Electrical energy consumption is increasing year by year and its generation is the most important problem for all the industry. In the entire World, most of the energy can be shared by electricity. The electricity usage will grow faster than liquid fuel, coal& natural gas. Fossil fuels such as coal, natural gas and petroleum are used for produce steam in boilers of power plants. Burning of fossil fuel release greenhouse gases such as carbon dioxide, nitrous oxide and carbon monoxide, these gases allows the high intensity solar radiation to the earth. These various air pollutants emitted into the atmosphere act as green house gases, which allows the incoming short wave solar radiation but does not allow the long wave outgoing terrestrial infrared radiation to escape and thus help in keeping the earth's surface warmer. Burning of such fossil fuels causes the air pollution; it has been the main issue for the inventers, government, researchers and environmentalists.

The gap between the electricity supply and demand continues to increases quickly. To replace the fossil fuel usages with a reduced emissive energy sources, such as environmental friendly, clean and renewable energy sources. Among these sources solar energy is an important clean, cheap and abundantly available renewable energy than any other renewable energy sources such as geothermal, wind, hydro, wave and tidal energies. These are the main resources to replaces the conventional energy sources. The use of conventional energy resources does not fulfil the energy demand in the next decades but steady increase will continue with undesirable environmental consequences. However, newly emerging renewable alternative energy resources are expected to take a vital role of increasing the energy scenarios of the future energy consumptions.

All the non-conventional energy sources encompass their origin in the sun. The sun rays that get in touch with the earth's outer atmosphere were subjected to absorption, reflection and transmission process before reaching the earth Surface. Unfortunately this source of energy not consumed sufficiently at its full extend everywhere in the world, it is due to the fact that all the portions of the earth surface do not receive usable amount of solar energy. Only a small part of total produced energy would be irradiated onto the earth's surface. Solar radiation has very harmful radiation but it should be avoided with the help of Ozone layer.

2. Conversion Technologies

- *Photovoltaic cells*

For solar energy conversion the photovoltaic cells are used. In this advanced photon utilization method the solar cell to which the photovoltaic effects of the semiconductors are applied. Especially the utilization of solar energy through solar cells and solar thermal power plants will play the key role. Long term scenario forecast that by 2100, the utilization of solar energy will face the more than 50% of the global energy demand. These conventional solar cells are made up of semiconducting material usually silicon. When the light energy fall on photovoltaic cell then it absorb the energy from the photons. This energy knocks out electrons or electricity. Some drawbacks have been present in conventional solar cells such as inefficient and its expensive manufacturing cost. The inefficiency should be unavoidable with silicon cells. Because the incoming photons or light must have right energy called band gap energy, it knocks out the electron. If the photon has the less energy than the band gap energy then it will pass through it. If it has the more energy than the band gap energy then the extra energy will be wasted in the form of heat. These two effects cause loss of around 70% of radiation energy incident on the cell.

- *Solar thermal collectors*

Solar thermal collectors are the heat exchanger that has been used to transform solar radiation energy to internal energy of the transport medium. Solar collectors because of its simplicity and low cost are a promising heating technology for industrial and buildings process. In basically the solar thermal collector is the heart of all types of solar thermal systems in which sunlight is trapped and it converted into heat energy. But its efficiency is poor.

- *Nanotechnology*

Nanofluids are suspensions of metallic or non metallic nanoparticles in the base fluid. This term of fluid was used by Choi [1]. A substantial increase in liquid thermal conductivity, liquid viscosity and heat transfer coefficient are the unique characteristic of nano fluids. It is well known that metals in solid phase have higher thermal conductivities than those of fluids [2]. For example, the thermal conductivity of copper at room temperature is about 700 times greater than that of water and about 3000 times greater than that of engine oil. The thermal conductivity of metallic liquids is much greater than that of non metallic liquids. Thus, fluids containing suspended metal particles are expected to obvious enhanced thermal conductivities relative to pure fluids [3]. Masuda et al [4] dispersed oxide nanoparticles (Al_2O_3 and TiO_2 with 4.3 wt %) in liquid and showed the increase in the thermal conductivity to be 32 and 11%, respectively. Grim [5] dispersed aluminium particles (1-80nm) into a fluid and claimed a 100% increase in the thermal conductivity of the fluid for 0.5 -10wt%.

Recently some studies were reported about using the nanofluids in solar collectors. E.Natarajan [6] has investigated the thermal conductivity enhancement of base fluids using carbon nanotube (CNT) and suggested if these fluids are used as a heat transport medium, it increased the efficiency of the conventional solar water heater. H.Tyagi [7] has studied theoretically the capability of using a non concentrating direct absorption solar collector (DAC) and compared its performance with that of conventional flat-plate collector. In Tyagi's research a nanofluid that is a mixture of water and aluminium nanoparticles, was used as the absorbing medium. According to the results of Tyagi's study, the efficiency of a DAC using nanofluid as the working fluid is up to 10% higher than that of a flat-plate collector. Otanicar [8] has studied environmental and economic influence of using nanofluids to enhance solar collector efficiency in compare with conventional solar collectors. Otanicar [9] has studied experimentally the effect of different nanofluids on the efficiency improvement up to 5% in solar thermal collectors by utilizing the nanofluids as the absorption medium.

Based on the studies, the aim of the current experimental work is to study the effect of nanofluids as absorbing medium on the efficiency of a frusto-conical solar collector.

The improvement of solar to thermal energy conversion will enhance the development of efficient concentrated solar power systems. Nanotechnologies give the special promise to both enhance efficiency of solar energy conversion and reducing the manufacturing cost. Nanotechnology is only accomplished of producing low power devices with sufficient energy. It will enhance the absorption efficiency of light as well as the overall radiation to electricity would help preserve the environment. Nano particles, which is present in nanofluids absorb the heat in the solar radiation and increase the performance of the system as well as decreases the emissive losses. Application of nanotechnology helps us to make solar energy most economically. Nanotechnology in solar thermal collector is to be improves the efficiency for creating efficient systems for conversion cost, efficient solar energy systems or solar energy on a large scale.

3. Solar collectors

In future solar thermal energy will play a glowing role in the utilization of solar energy. It enables the relatively cheap provision of both electric power and heat. Solar thermal heat supply in buildings occurs decentralized through roof mounted solar thermal collectors with efficient of approximately 60% - 70%. Solar thermal can also be used on different industrial areas for power generation in solar power plants. In comparison to photovoltaic cell power generation, solar thermal power plants generation are currently more economic.

The Solar radiation can be mainly used as a hot water consumptions, crop drying, power of heat engines, power for refrigeration and air conditioning and to produce the direct electricity by using Photovoltaic cells. The Solar energy should be considered as the foundation of sustainable energy economy between sunlight is the most abundant sources of renewable energy. The solar energy can be harnessed in different variety of form in simple solar cookers now used in different parts of the world.

Solar energy collectors are special type of heat exchanges that transform solar energy into internal energy of the transport medium. The important part of any solar system is the solar collector. This is a special kind of device which absorbs the incoming solar radiation converts it into heat and transfer this heat to a fluid (particularly air, water or oil) flowing through the collector. The Solar energy thus collected is carried from the circulating fluid either directly to the hot water or space conditioning equipment or to a thermal energy storage tank. Most of the low temperature solar heating systems can be depends on the use of glazing. Because it has the ability to transmit the incoming visible light and prevent the infrared radiation. In high temperature solar collectors employ mirrors and lenses. In order to catch the solar radiation directly by devices, house roofs are constructed as discrete solar collectors. There are typically two types of solar collectors

- ✓ Non-concentrating
- ✓ Concentrating

A non-concentrating collectors (stationary) has the same area for intercepting and for absorbing solar radiation but in sun tracking concentrating solar collector usually contains the concave reflecting surfaces to intercept and to focus the sun radiation to a smaller receiving area and thereby increasing the radiation flux. In cover glazed collectors with different type of covers solar selective or black paint absorbers different roughness elements on absorber plates, fin structures, air flow channel geometry etc. can be used. A large number of solar collectors are available in the market [10].

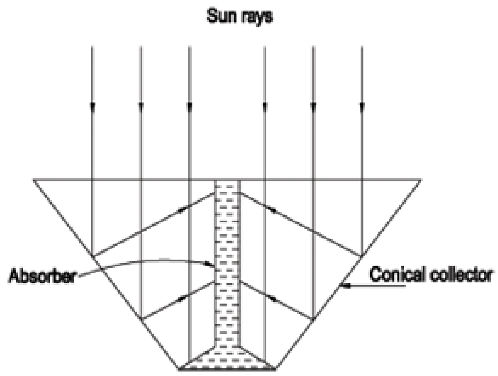
4. Design details of Experimental setup

In the last decade, lot of attention has been given to concentrating solar collectors, which can reach higher temperatures compared to flat plate collectors. So many studies were conducted on their extensive usage in liquid heating.

The experimental set-up and important size parameters of the collectors are shown in Fig.1. The collector has a conical concentrator with one dimensional manual tracking system, cylindrical absorber, a movable main water tube and temperature recording unit. This assembly was located on the open ground to have a good view of the sky radiation. The base conical system is constructed from galvanized iron sheet of 0.644mm thickness and mounted square tube structure and is placed on a wheeled table.

The frustum of conical collector was chosen for concentrating the sunrays. Absorbing surface contains an integrated structure of smaller cone and cylindrical pipe. In this setup mainly consists of

- Frusto-conical collector
  - ➢ GI sheet outer structure
  - ➢ Intermediate insulating structure
  - ➢ Reflecting surface
- Absorbing surface
- Cylindrical receiver



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4.1. Frusto-Conical collector

The collector is a frustum of a light circular cone. This conical collector is mainly made up of sandwiched structure of different materials. It consists of mainly three layers. The first layer is a basic structure of conical surface which is made up of galvanized iron sheet. The intermediate layer is an insulating layer which is made up of foam material. The third layer is reflecting layer which is made up of aluminium sheet. These three layers are joined together to form a sandwiched structure for collect the radiation of sun light.

4.1.1. Outer layer of conical structure. In the first layer of conical concentrator made up of GI sheet. It has the thickness of 22 gauge (0.644mm).The upper circular diameter of the cone is equal to 800mm and lower diameter 200mm.The vertical height of the cone is 340mm. It provides the basic skeleton of the conical collector.

4.1.2. Intermediate Insulating structure. The second layer which is an insulating structure made up of foam material with thickness 10 mm. This foam material is adhesed into the GI sheet. It acts as an insulating surface that is it should avoid or reduce the heat transfer from reflecting structure to basic GI structure.

4.1.3. Reflecting surface. The reflecting surface of the collector is made up of locally available aluminium sheet with the thickness of 0.3mm.This aluminium sheet is gummed to the surface of the foam material. Aluminium acts as a good refracting surface. It provides the refractivity of 0.8 - 0.9. It reflects the incident solar radiations to the absorber.

4.2. Absorbing Surface

The absorbing surface is a combined structure of smaller cone and circular pipe made up of copper sheet of thickness 0.5mm.The lower part of absorber is a smaller cone. The lower circular diameter is smaller cone is equal to 200mm and upper diameter is equal to 50mm.The height of the cone is 40mm.Then upper part of cone is connected with circular pipe of diameter 50mm and with a height of 300mm. The bottom side of the absorber is closed. The upper side of circular pipe is closed with a temporary cap. This absorbing structure is coated with black paint for collect all the reflected rays.

4.3. Cylindrical receiver

The copper tube is used for circulating water inside the absorber. It is constructed to recover maximum solar radiation in the form of cylindrical shape. It is inserted inner side of the absorber. The outer diameter of the copper tube is 6.35mm and inner diameter is 5mm.The length of the tube is 3.5 m. The mean diameter of the spring is 39.35mm.The inner diameter of the spring is 33mm.The outer diameter of the spring is 45.7mm.

4.4. Selection of nanoparticle

The aluminium oxide (Al_2O_3) taken as the particles to mix with the base fluid. The aluminium oxide was selected for the superior quality of higher thermal conductivity, less cost, and also non-reactive with base fluid. The nanoparticles are directly mixed in the base liquid and thoroughly stirred. Nanofluids are prepared by the volume fractions of 0.05%, 0.075% & 0.1%.

5. Operational technique

Al_2O_3 / H_2O nanofluid was filled inside of the absorber and water was allowed to circulate inside of the cylindrical receiver. The mass flow rate of water kept constant as 8.33×10^{-3}kg/s. Heat transferring fluids are filled in the constant capacity of 1.3litre. The total experimental set-up is kept in open area. The sunrays are fallen on the reflecting surface. These reflected rays are absorbed by absorber. The helically coiled heat exchanger are used circulate water inside of absorber, where the heat was absorbed. The initial temperature of water and heating temperature of water was taken with help of temperature recording unit. These readings were taken every one hour interval. The actual experimental setup has been shown in Fig.2

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The following tables provide the measurements of outlet water temperature where water and nanofluid as heat transfer medium of various concentration at local day time.

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Time	Day 1			Day 2		
	Water		Absorber	Water		Absorber
	Inlet	Outlet	plate temp	Inlet	Outlet	plate temp
9:00 AM	32	32	31	28	28	28
10:00 AM	34	43	52	30	38	45
11:00 AM	35	45	53	30	40	46
12:00 PM	37	48	55	33	41	48
1:00 PM	36	46	52	35	44	51
2:00 PM	35	45	51	34	42	50
3:00 PM	35	44	48	34	42	49
4:00 PM	34	43	48	33	40	47

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Time	Day 1			Day 2		
	Water		Absorber	Water		Absorber
	Inlet	Outlet	plate temp	Inlet	Outlet	plate temp
9:00 AM	32	31	31	34	33	33
10:00 AM	34	45	52	34	44	48
11:00 AM	35	47	53	36	49	53
12:00 PM	35	50	55	37	51	56
1:00 PM	36	47	52	36	48	54
2:00 PM	35	45	51	36	46	51
3:00 PM	35	44	48	35	42	48
4:00 PM	34	43	48	34	40	45

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Time	Day 1			Day 2		
	Water		Absorber	Water		Absorber
	Inlet	Outlet	plate temp	Inlet	Outlet	plate temp
9:00 AM	34	32	33	33	32	33
10:00 AM	35	49	52	34	45	49
11:00 AM	35	51	55	36	49	53
12:00 PM	37	52	56	36	50	54
1:00 PM	38	53	56	36	49	52
2:00 PM	37	49	53	35	48	49
3:00 PM	37	50	54	34	46	48
4:00 PM	36	47	50	34	45	48

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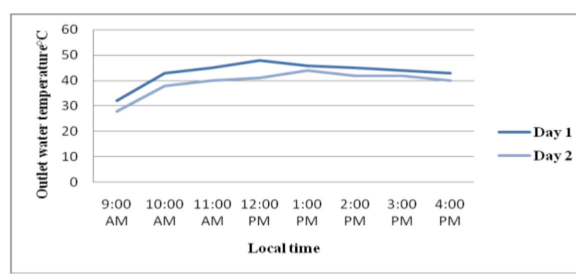
Time	Day 1			Day 2		
	Water		Absorber	Water		Absorber
	Inlet	Outlet	plate temp	Inlet	Outlet	plate temp
9:00 AM	33	33	34	32	33	32
10:00 AM	34	49	51	34	49	51
11:00 AM	35	51	52	34	54	55
12:00 PM	36	54	56	35	52	54
1:00 PM	37	57	60	36	53	54
2:00 PM	36	51	53	35	47	50
3:00 PM	35	46	48	35	46	48
4:00 PM	34	43	46	34	45	47

The following graphs give the measurements of outlet water temperature where water and nanofluid as heat transfer medium of various concentration at local day time.



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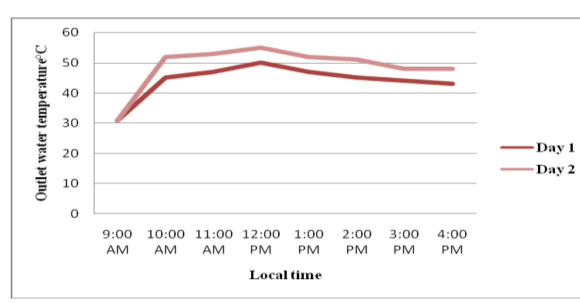

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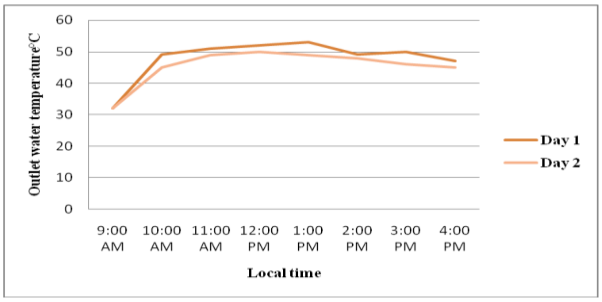

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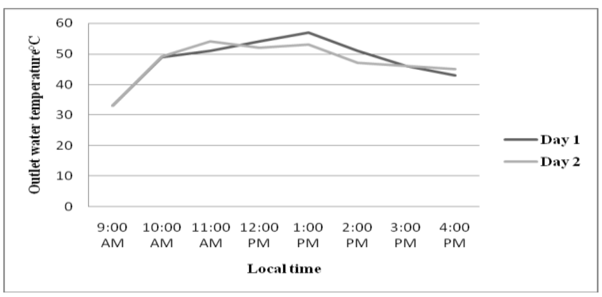

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6. Performance focus

Focusing collector differs in their thermal behaviour from the flat-plate type, because for receivers the shapes are widely variable, the temperature are higher, conduction terms are quite high and radiation flux on the receivers is not uniform.

The conical collector thermal performance can be found by using equations [11, 12 & 13]

$Q_u = A_r[C(\rho\alpha\gamma)H_b - U_L(T-T_a) - \varepsilon\sigma(T^4-T_a^4)]$ (1)

Equation (1) is then modified to another form,

$Q_u = F_R\, A_a\, [S-(A_r/A_a\, U_L(T_{fi} - T_a))]$ (2)

The actual or useful heat Q_u equals the sensible heat removed by the fluid through the receiver and can be calculated by using the equation (3)

$Q_u = mC_p(T_{fi} - T_{fo})$ (3)

Then the collector efficiency factor can be calculated from the following equation (4)

$F' = U_O/U_L$ (4)

Heat removal factor should be given by

$F_R = mC_p/A_rU_L\, [1-\exp^{(-ArULF'/ mCp)}]$ (5)

Where U_O is over all heat transfer coefficient and U_L is the Loss coefficient and can be calculated using equations (6&7) wind force was also taken into account,

$U_O = [1/U_L + D_O/h_iD_i + D_O \ln(D_O/D_i)/2K]$ (6)

$U_O = [1/h_{wind} + 1/h_r]$ (7)

The average value of overall heat transfer coefficient obtained by $U_O = 5\ W/m^2K$ and average value of Loss coefficient was $U_L = 5.4\ W/m^2K$. The aperture area of the of collector, $A_a = 0.9567 m^2$ and recover area (absorber area) was $A_r = 0.11813 m^2$. The concentration ratio of this conical collector is 8.1.

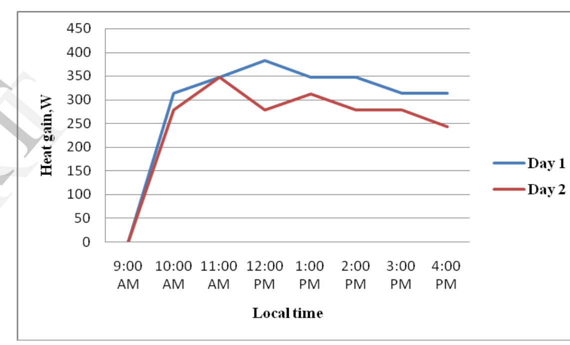
The collector efficiency is calculated by

$\eta = Q_u/H_bA_a$ (8)

Thus the concentration ratio was obtained by using the equation

$C = A_a/A_r$ (9)

Local time Vs Heat gain of water due to nanofluid of various concentrations is shown below.



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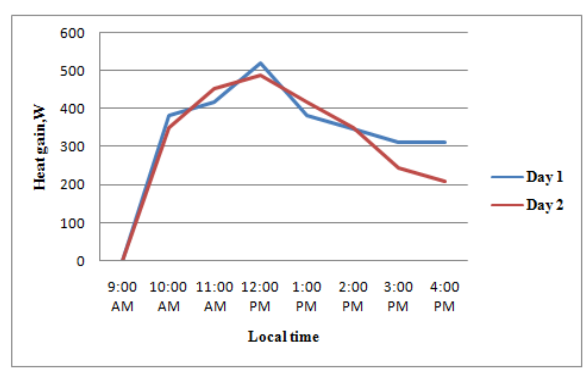

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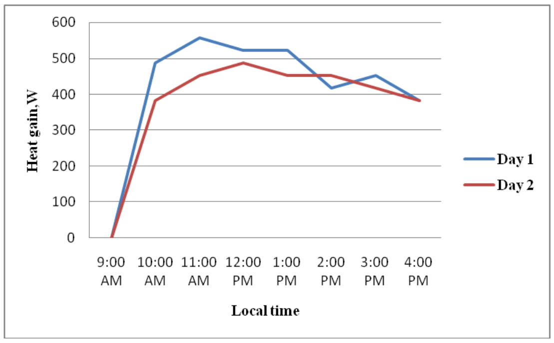

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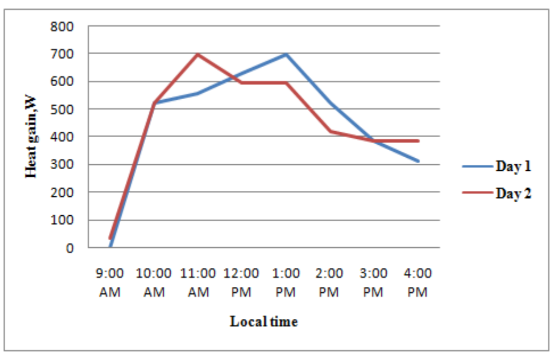

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7. Conclusion

Over the past few decades, great progress has been made in every facet of concentrated solar power technology. Striving towards a sustainable, 'clean' energy based culture has instilled many with the drive to help rid society of its dependence on fossil fuels. With the sun being an obvious and overabundant form of renewable energy, it is no wonder that it has been the subject of so much attention, especially at the turn of the 20th century. The variety of technologies with which we can harness the sun's energy continues to grow and improvements in every element of each concentrated solar power production administration are constantly added onto form more efficient, robust and economical and environ- mentally safe facilities.

In the present work the design of frusto-conical solar collector has been undertaken and the performance is thoroughly studied with heat transferring fluids of various concentrations. As compare to water, Al_2O_3 nanofluid has greater performance rate. Heat transfer rate increases with the increase of volume concentration of Al_2O_3 nanofluid. The efficiency of this system obtained as 59.7%.

8. Acknowledgment

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