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Improving the Efficiency of Solar Flat Plate Collector Using Phase Change Material and Nanofluids

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Abstract

In the present work, investigations are made to study performance characteristics of solar flat plate collector with PCM and nanofluids. Flat plate collector is one of the important solar energy-trappingdevice that uses as air of water as working fluid. In this project, we designed and fabricated the flat plate collector for the commercial application. It is capable of using both the diffuse and the direct beam solar radiation .For residential and commercial use , flat plate collectors can produce heat at sufficiently high temperatures to pre heating water for boiler and to heat swimming pools domestic hot water , and buildings , they also can operate a cooling unit , particularly if the incident sunlight is increased by the use of reflector . Temperatures upto 45 oCare easily attained by flat plate collectors. We are going to test the performance of the flat plate collector with outlet temperature of water without using PCM and using PCM (Zn (NO3)2.6H2O) and Nano fluid (Al2O3).By obtaining the values and compare the rate of heat transfer.

Keywords: Solar flat plate collector, efficiency, Phase change material (Zn (NO3)2.6H2O) and Nano fluid (Al2O3).

1. Introduction

The main objective of this work is to improving the thermal efficiency of the flat plate collector using phase change material and Nanofluids.The surface of the earth receives 1014kW photovoltaic energy from the sun, which is approximately 5 orders of magnitude higher than currently being bump off from all resources. Even though the sun light is filtered by using the environment one rectangular meter of the land exposed to, direct solar mild receives the energy equal of about 1 H.P or 1 KW. However, this substantial amount of solar power received by earth is now not easily convertible and virtually is not free.There are two apparent obstacles to harnessing solar energy. Firstly its availability and then its strength, since it is solar radiation is not constant, it need some device to store the energy for usage in nighttime. Second strength, it is diffused in nature, the collection and conservation of solar energy into beneficial forms must be carried out over a large region which entails a large capital investment for the conversion apparatus. Even though collecting of solar energy is difficult, it is less expensive and an alternate source for electricity sources it has few disadvantage as if exhaustible, more expensive, solar energy has some right blessings in assessment to the different sources of power. Solar radiation does not contaminate surroundings or endanger ecological balance. It avoids predominant problems like exploration, extraction and transportation [1-5].

1.1. Flat plate collector

A simple flat plate collector consists of an absorber plate in an insulation box covered with glass. The main portion of a solar collector is the absorber plate, which normally made of metal sheets. The liquid utilized for heat move largely moves through a metallic line, which is associated with the plate strip. The insulation casing is used to prevent the heat losses at the back and side of the system. In an effective system, high thermal conductivity materials can be used in absorber plate.

1.2. Phase Change Material

PCM is a latent heat storing material. Thermal energy stores when a material changes their phase. They store almost 5-14 times more heat than the sensible storing material water. The utilization of phase change materials must show certain thermal, physical and chemical properties such as, suitable soluble temperature, highly soluble, phase balance, small volume change, chemically stable, harmless, abundant, and reliable and economical PCM can classified into two types, they are Organic Phase change Material and In-organic Phase Change Material. Organic Phase change Material is sub divided into Paraffin and non-paraffin. In-organic Phase change Material is sub grouped as Salt hydrates and metallic. Its Advantages and disadvantage are, Organic: Chemical and thermal stability, no super cooling, Non-corrosives, Non-toxic, High heat of fusion but Low thermal conductivity, High changes in volumes on phase change, In flammability, Lower phase change enthalpy

Inorganic: High heat of fusion, Good thermal conductivity, Cheap and non-flammable but Phase decomposition, lack of thermal stability, Super cooling, Corrosion.[6-10]

1.3 Classification of Phase Change Material

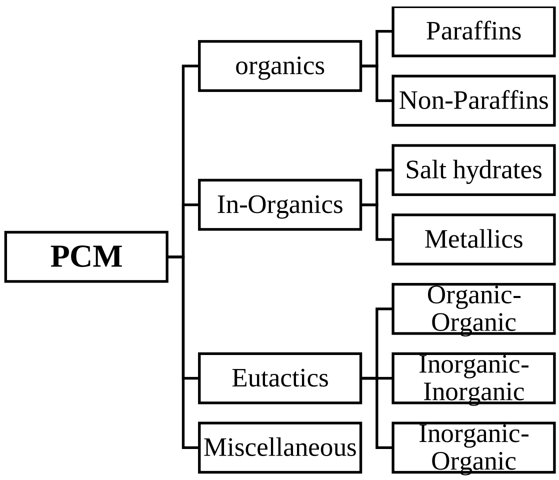

Fig.1. Classification of Phase Change Material

1.4.Nano Fluids

Nano fluids are the homogeneous solution of Nano particle size 1- 100nm in the base fluid. The nano particles are dispersed in base fluid and increase the convective heat transfer of the base fluid. Some preparation processes are employed finally we get the nano fluid. They are used to improve the heat transfer rate in solar flat plate collector. These fluids are mainly containing metal, oxides, and carbon nanotubes. The base fluid is taken as water, ethylene glycol etc. Thermo physical properties of nano fluids such as Thermal conductivity, density, viscosity, specific heat, volume fraction is playing a main role in the heat transfer in solar collector. The mass flow rate of nano fluids is also taking into consideration for heat transfer. So, in this work, we will discuss in detail about the effect of various Nano fluids and various thermo physical properties of nano fluid in solar flat plate collector system. [11-14].

1.5. Specifications of Nano fluids

Table.1. Specifications of Nano fluids

Nano particles	Particle size (nm)	Working fluid	Fraction	Thermal enhancement (%)
Metals				
Ag	<100	water	0.3-0.9 vol%	30 at 50°C
Ag	100-500	Ethylene glycol	0.1-1.0 vol%	18
Cu	50-100	Water	0.1 vol%	24
Cu	<10	Ethylene Glycol	0.01-0.55 vol%	41
Fe	10	Ethylene Glycol	0.1-0.55vol%	18
Metal Oxides				
Al_2O_3	9	Water	2-10 vol %	29
Al_2O_3	28	Water/ethylene glycol	3-8 vol %	41
Al_2O_3	650-1000	Transformer oil	0.5-4 vol %	20
CuO	100	Water	7.5 vol %	52
TiO_2	15	Water	0.5-5 vol %	30

1.6. Phase Change Material, Nano Powder and its properties

In this present work Zinc Nitrate Hexa,hydrate an Inorganic Phase Change Material from salt hydrates is used due to its high heat of fusion, Good thermal conductivity, Cheap and non-flammable. In this process, thermal energy transmission happens. Phase change material absorb and release heat at a constant temperature**.** Aluminium oxides mixed with water is used as an heat extracting agent used in the flat plate collector due to higher efficiency at low wall temperature than the base fluid(water), high thermal conductivity and heat transfer rate with low volume concentration 0.1-0.3%easy to dissolving in water.

Fig 2. (a) Zinc Nitrate hexa hydrate, (b) Aluminium oxide

Table.2. Phase Change Material, Nano Powder and its properties

Outer Casing: Wood	750mm×375 mm×140mm	No of Flow Tubes	12
Glass: Low Iron Tempered Glass	750mm×375 mm	Selective Coating	Flame coating
GlassCover Transmittance	0.91	Phase Change Material	Zinc Nitrate Hexahydrate
Glass Thickness	3.2mm	Melting Point of the PCM	36.4^0C
Absorber Materials	Copper	Thermal Conductivity of the PCM	0.5W/mk
Dimension of the Absorber	750mm×375 mm	Latent Heat of the PCM	184 KJ/Kg
Thickness of the Absorber	0.35mm	Nano fluid	Aluminium oxide(Al_2O_3)
Thermal Conductivity of the Absorbers	50mm	Size of particles	20-30 nm
Tube Centre to Centre Distance	50mm	Shape of particles	Spherical particles
Copper Tube Diameter	50mm	Density	3700 kg/m3
Copper Tube Length	50mm	Surface area per unit weight	15-20 m2/g
Glass Tube Diameter	50mm	Crystal Form	Gamma
Glass Tube Length	50mm	Al_2O_3 Content	99.99%
Insulation	50mm	Melting point	2,072°c
Thermal Conductivity of the Glass Wool	50mm	Density	3.95g/cm3
Bottom Insulation Thickness	50mm	Thermal conductivity	30 w/mk
Side insulation Thickness	50mm	No of Flow Tubes	13

2. Performance of solar collector using nano fluids

The performance of solar collector is defined as an energy balance, energy from solar incident radiation into energy absorbed. Here losses have considered a thermal energy loss to the surroundings from the collector by means of conduction convection radiation. The performance of solar collectors are analysed by ASHRAE standard. [12]The steady state thermal efficiency of flat plate collector is calculated from [13]

$$= \frac{Q_u}{A_c \mathrm{G}_T}$$

The amount of useful energy come out from the collector is the difference between the absorbed solar radiation and thermal losses

$Qu = A_c[S – U_L (T_p-T_a)]$

Where,

S - Solar energy absorbed by a collector

G_T- Incident solar energy

U_L- heat transfer coefficient

Tp- mean absorbed plate temperature

3. Theoretical calculation

3.1. Zenith angle

Cosθz = (sinδ×sin ()) + (cosω×cosδ×cos()) =0.954

3.2. Hour angle corresponding to sunrise or sunset on a flat surface:

ωs = Cos-1(-tanØ × tan δ) =82°39' (1.439)rad

3.3 Hour angle corresponding to sunrise or sunset on a tilt surface:

ωst = Cos-1(-tan (Ø - β) × tanδ) = 90°34' (1.580) rad

3.4. Tilt factor:

rb= 0.98

3.5. Monthly average hourly global radiation:

Ig/Hg = Io/Ho(a+bcosω)

Angle of refraction θ2 = $\sin^{-1}$ (sin θ1/1.52)

Assume, Reflective index = 1.52

3.6. Efficiency calculation

Without PCM

Energy absorbed by the working fluid

H=$\frac{v}{t}(t_2 - t_1) \times 4186.5$

Efficiency

η = $\frac{H - H_p}{H_i}$

Loss

L=$H_i + H_p - H$

Where,

H=energy absorbed by working fluid H_p=energy input by the pump

H_i=energy incident on the surface

L=losses

3.7. With PCM

Energy absorbed by PCM

Q = $m \times h_{fg}$ Energy

Absorbed by the working fluid

H=$\frac{v}{t}(t_2 - t_1) \times 4186.5$

Efficiency

η = $\frac{H - H_p}{H_i}$

Loss

L=$H_i + H_p - H$

4. Temperature measured on flat plate Collector to select the PCM

Table.3. Temperature measured on flat plate Collector to select the PCM

Sl.no	Voltage obtained (V)	Time taken (Min)	Temperature obtained (°C)
1	220	5	33
2	220	10	35
3	220	15	36
4	220	20	36
5	220	25	37
6	220	30	38

5. Design of flat plate collector

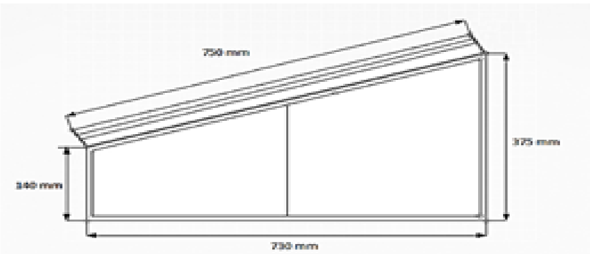

Fig.3: Design of Flat Plate Collector

Fig.4.(a) Cover Plate, (b) Copper tube, (c) Absorber Plate, (d) Wooden casing, (e) Glass Tubes, (f) Thermal insulation (g) Thermocouple

5.1. Cover plate

Toughened Glass is used as a cover plate due to shield the collector from natural calamities and to absorb maximum solar radiation, minimize heat loss other type of cover plates are as acrylic Polycarbonate plastics, Tedlar and Mylar plastic film, Selection: 0.32cm thick with high rigidity, it should be less air expansion and highly resist to mechanical stresses.

5.2. Copper Tube

It will act as an heat extracting region through flow of fluid which is closely soldered and brazed toward the absorber plate, it size range from 0.7 to 1.5cm

5.3. Absorber Plate

It is otherwise called as a heat source of an Collector with high thermal conductivity, high melting point, high specific heat, absorptivity ∞= 1 and ε= 0.0 and corrosion resistance properties push back steel and thermoplastic plate

5.4. Wooden Casing

Casing materials are wood and fibre. It has low thermal conductivity and the whole assembly is rest on the casing. It protects from weather, dirt, Insect etc.

5.5. Glass Tubes

It is placed over the Copper tube for filling the phase change materials and is sealed to avoid leakages during the phase transformation.

5.6. Thermal Insulators

Insulation is at the bottom and all sides to minimize the heat losses. 25 to 50mm thickness is usually placed behind the absorber plate to prevent the heat losses from rear surface. The insulation content is normally mineral wool or glass wool or fibre wool that is resistance to heat.

5.7. Thermocouples

A device in which the temperature difference between the ends of a pair of dissimilar metal wires is deuced from a measurement of the thermoelectric potentials developed along the wires. The presence of a temperature gradient in a metal or alloy contributes to the setting of an electrical potential gradient along the temperature gradient and differs from metal to metal. It is the fact that the thermoelectric emf is different in different metals and alloy for the same temperature gradient that allows the effect to be used for the measurement of temperature

6. Step by step fabrication

Step 1: insulating the wooden box.

Initially the wooden casing of the solar flat plate collector is insulated with the glass wool of thickness 2.5cm at the sides and 10cm at base.

Step 2: covering the insulation with aluminium foil.

The Aluminium foil of thickness 1mm covers the insulated glass wool.

Step 3: placing the copper tube on the absorber plate.

In this process, the copper tubes are fixed above the absorber plate of spacing 5cm gap between the tubes. The polymer flexible pipe joins the Straight Copper Tubes together.

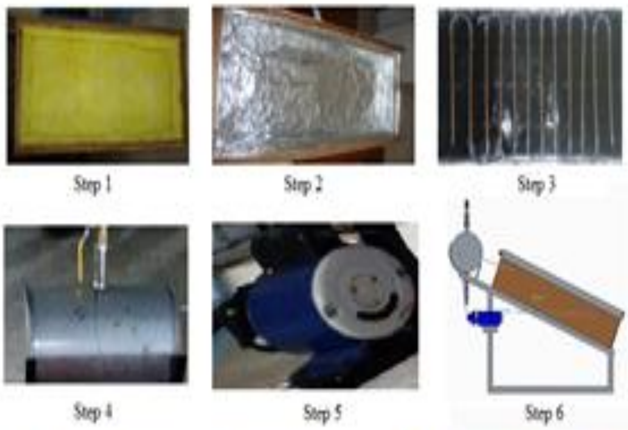

Fig.5: Step by Step Fabrication of Flat Plate Collector

Step 4: connecting the tank and motor to the collector.

Then the storage tank and the motor is connected with the collector in which the motor is used to circulate the water and tank is used to store the waterand the motor is controlled by the auto transformer

Step 5: placing the collector on the tilted channel.

Finally, the fabricated collector is placed on the tilted channel. The Titled angle is 21.56^0 for our location and the collector is placed to face the south.

7. Experimental arrangement

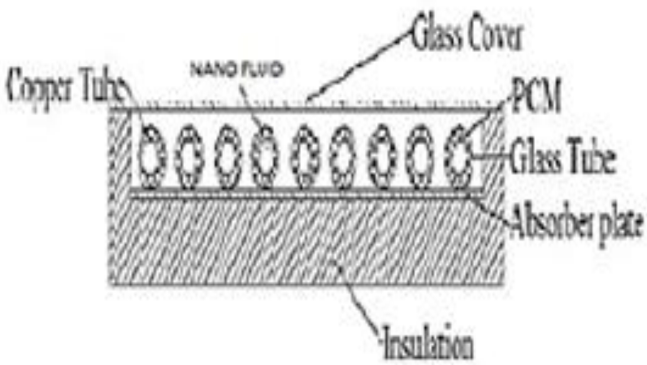

Fig.6: Arrangement of Flat Plate Collector with PCM and Nano Fluids

- A Translucent cover, which can be one or more sheets of plastic film or sheet transmitting glass orradiator.
- The tubes, fins, passages or channels that hold water, air or other fluid are integral to or attached to the collector absorber plate.
- The absorber plate is usually metallic or with a black surface, although it is possible to use a wide variety of other materials, particularly air heaters.
- Insulation, which should be given to Reduce heat losses on the back and sides.
- The shell or container that encloses and Protects the other components from the Weather.
- Glass tube, where the material for phase Change

8. Results

Table.4. Heat transfer at 0.1%

Density (ρ) kg/m^3	Heat capacity $((c_p)_{nf})$ j/kg k	Thermal conductivity (k)w/m k	Viscosity(μ) m^2 / sec	Area (A) m^2	Velocity (v) m/sec	Reynolds number (Re)	Prandtl number (Pr)	Nusselt number (Nu)	Convective heat transfer co-efficient (h) w/m^2 k	$(\Delta T)_{lm}$	Heat transfer (Q_{TH}) W	Heat transfer (Q_{act}) W	Q= $\frac{Q_{act}}{Q_{TH}}$ (%)
1001	4179	0.614	2.99×10^{-6}	2.827×10^{-5}	0.9	1813	0.02	4.44	455.38	3.6	0.05	0.01	25.32
1001	4179	0.614	2.99×10^{-6}	2.827×10^{-5}	0.9	1813	0.02	4.44	455.38	3.8	0.05	0.01	28.36
1001	4179	0.614	2.99×10^{-6}	2.827×10^{-5}	0.9	1813	0.02	4.44	455.38	3.5	0.04	0.02	38.42
1001	4179	0.614	2.99×10^{-6}	2.827×10^{-5}	0.9	1813	0.02	4.44	455.38	3.4	0.04	0.02	46.03
1001	4179	0.614	2.99×10^{-6}	2.827×10^{-5}	0.9	1813	0.02	4.44	455.38	3.6	0.05	0.02	48.48

Table.5. Heat transfer at 0.2%

Density (ρ) kg/m^3	Heat capacity $((c_p)_{nf})$ j/kg k	Thermal conductivity (k)w/m k	Viscosity(μ) m^2 / sec	Area (A) m^2	Velocity (v) m/sec	Reynolds number (Re)	Prandtl number (Pr)	Nusselt number (Nu)	Convective heat transfer co-efficient (h) w/m^2 k	$(\Delta T)_{lm}$	Heat transfer (Q_{TH}) W	Heat transfer (Q_{act}) W	Q= $\frac{Q_{act}}{Q_{TH}}$ (%)
1004	4175	0.167	5.98×10^{-6}	2.827×10^{-5}	0.9	875	0.04	4.22	433.9	4	0.05	0.02	48.37
1004	4175	0.167	5.98×10^{-6}	2.827×10^{-5}	0.9	875	0.04	4.22	433.9	4.7	0.06	0.03	50.17
1004	4175	0.167	5.98×10^{-6}	2.827×10^{-5}	0.9	875	0.04	4.22	433.9	5.8	0.07	0.04	50.77
1004	4175	0.167	5.98×10^{-6}	2.827×10^{-5}	0.9	875	0.04	4.22	433.9	5.4	0.07	0.04	52.6
1004	4175	0.167	5.98×10^{-6}	2.827×10^{-5}	0.9	875	0.04	4.22	433.9	5.1	0.07	0.04	53.4

Table.6.Heat transfer at 0.3%

Density (ρ) kg/m^3	Heat capacity $((c_p)_{nf})$ j/kg k	Thermal conductivity (k)w/m k	Viscosity(μ) m^2 / sec	Area (A) m^2	Velocity (v) m/sec	Reynolds number (Re)	Prandtl number (Pr)	Nusselt number (Nu)	Convective heat transfer co-efficient (h) w/m^2 k	$(\Delta T)_{lm}$	Heat transfer (Q_{TH}) W	Heat transfer (Q_{act}) W	Q= $\frac{Q_{act}}{Q_{TH}}$ (%)
1007	4172	0.619	8.977×10^{-6}	2.827×10^{-5}	0.8	563	0.06	4.09	421.27	5.7	0.08	0.04	54.57
1007	4172	0.619	8.977×10^{-6}	2.827×10^{-5}	0.8	563	0.06	4.09	421.27	6.2	0.09	0.05	55.6
1007	4172	0.619	8.977×10^{-6}	2.827×10^{-5}	0.8	563	0.06	4.09	421.27	6.3	0.09	0.05	53.7
1007	4172	0.619	8.977×10^{-6}	2.827×10^{-5}	0.8	563	0.06	4.09	421.27	6.6	0.1	0.05	50.19
1007	4172	0.619	8.977×10^{-6}	2.827×10^{-5}	0.8	563	0.06	4.09	421.27	7.1	0.11	0.06	50.2

Conclusion

The above work was adopted to use the solar water heater during the off-shine hours using phase change material that maintains heat even after sunshine. Therefore, during off sunshine hours it gives better performance. It is used for milk Pasteurization, domestic purposes, preheating the feed water, washing the fruits and vegetables, baking and in textile industry even in cloudy and after sunshine hours.The collector's performance can be enhanced by increasing the absorber plate area and increasing the size of the water tubes. The performance of the solar water heater with Phase Change Material can beimproved by selecting the appropriate Phase Change Material with the high thermal storage capacity. It is also improved by increasing the quantity of Phase Change Material and heat transfer area, by fixing the absorber at better performance. By using Aluminium Oxide (Al_2O_3) Nano fluid as a working fluid with 0.01% concentration, collector's instantaneous efficiency is enhanced from 0.93 to 3.38%, 0.1 to 3.45%, for 20 and 40 l/hr mass flow rates. Collector's thermal efficiency is enhanced from 1 to 2.85%, 0.05 to 1.88 for 20 and 40 & l/hr mass flow rates. It is possible to manufacturing a flat plate collector by easily available materials at low cost and the system can be easily installed and prepared in remote areas. Thus by conducting the experiment using the flat plate collector with phase change material and Nano fluids,the performance of the flat plate collector can be above the convectional level.

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