

Experimental Investigation and Fabrication of an Evacuate Tube Solar Collector

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Abstract: Use of renewable source of energy has now become of utmost attention. With increasing global pollution and subsequent decrement of global reserves of energy supply is a very crucial factor for environmental protection. Energy Generation from renewable sources like sun and utilization of generated one can optimize the global pollution. In this contrasts this paper presents one of the systems utilizing the solar energy to generate hot water for daily purpose and for industrial purpose. Evacuated U tube solar water heating system is one of the effective methods of solar thermal energy collection systems. The experimental observation is that when the mass flow rate of water as well as the tap angle movement increases then heat transfer rate also increases. It was also observed that when the setup was fixed in north west direction the heat transfer rate increases with respect to time and in south west direction it also increases but highest value of heat transfer rate is at 2 pm and another at 3pm.

Keywords: Energy, Solar Energy, Water Heating, Mass flow rate.

1. Introduction

1.1 Introduction to solar water heating system

Solar water heating is a solar thermal technology in which the energy from the sun, is captured by absorbing medium and used to heat water for any industrial or commercial application. In India there are mainly three weather like summer, winter rainy and some places mostly winter month for long time to 7 to 8 and above or below the range temperatures so the range temperatures so the people faces crucial condition for hot water. So it heated the water up to temperature.

A solar water heating system (SWHS) utilizes the incident solar radiation and converts it in to thermal energy for heating the water to use in various applications. The solar water heating system consists of solar thermal collectors, water tanks; inter connecting pipelines and the water, which gets circulated within the solar water heating system. The two popular devices that are used for water heating are flat plate collectors (FPC) and evacuated tube collectors (ETC). In the year 2008-09, ETC has constituted more than 30% of the total sales.

On July 1, 2009, there were 61 MNRE approved ETC suppliers and manufacturers. The arrival of evacuated tube collector has resulted in expanding the solar water heating supply chain significantly. Brunold et al. mentioned that evacuated tube solar collector are of 3 different designs- water in glass, heat pipe evacuated tube solar collector, evacuated U tube solar collector[2].

Ma L. et al reported that the heat pipe evacuated tubular solar collectors have some advantages, such as anti freezing, rapid start-up, resistance to high pressure, easy installation and maintenance etc. In practical application, maintain vacuum environment is very difficult because lots of non condensable gas will be produced in the heat pipe at the running process of the system. The thermal performance of

the heat pipe will be subject to serious influence because of the accumulation of non-condensable gas. So running life of evacuated tube is restricted which is a serious short coming. Currently U tube evacuated tube is used much more than heat pipe.

1.2 Solar Energy

Solar energy is a very large, inexhaustible source of energy. The power from the sun intercepted by the earth is approximately 1.8×10^{11} MW which is mainly thousands of times larger than the present consumption rate on earth of all commercial energy sources. Thus, in principle, solar energy could supply all the present and future needs of the world on a continuing basis.

Sun is a source of renewable energy, it is largely a sphere of hot gases. It's diameter is 1.39×10^6 km while that of earth is 1.27×10^4 km.

1.3 Solar Technologies

- 1.3.1 Active solar technologies
- 1.3.2 Passive solar technologies

1.3.1 Active solar technologies

Active solar technologies are employed to convert solar energy into another more useful form of energy. This would normally be a conversion to heat or electrical energy. The basic benefit of active systems is that controls can be used to maximize their effectiveness. Using sensors and pumps, a relatively small amount of energy can harvest a far larger amount of available thermal energy by switching on as soon as a useful temperature differential becomes present.

1.3.2 Passive solar Technologies

Passive solar technologies use sunlight without active mechanical systems. Such technologies convert sunlight into usable heat, cause air-movement for ventilating, or future use with little use of other energy sources.

Passive solar technologies include direct and indirect solar gain for space heating, solar water heating systems based on geyser pumps and phase change materials.

1.4 Advantages of Solar Collectors

- Thermal energy can be used to passively heat buildings through the use of certain building materials and architectural design, or used directly to heat water for house hold use.
- They use solar energy which is a free renewable source of energy
- We can build our own solar water heating systems.

In the present work we use Evacuated tube solar collector heaters.

1.5 Application of Evacuated Tube Solar Collector

The technology is mainly employed in residential buildings where the demand for hot water is significant. This occurs when there is a large family, within laundry washing. The technology is also employed for heating the space in winter climate. Solar water heating systems are most likely to be cost effective for operations such as laundries or kitchens that demand large volume of hot water. Notable applications of evacuated U tube solar collectors are :

- In space heating
- In school, hospital
- Generally used in northern countries for heating purposes like swimming pool as per season.

1.6 Difference between Evacuated tube and solar collector

- Sun maxx plate collectors use a highly efficient flat absorber material called tinnox which transfers heat to a series of copper tubes which circulates a 50% glycol/water mix. The collectors themselves are in essence a sealed insulated box which captures the suns energy and transfers it via the tinnox, then through the pipes filled with glycol and into the storage tanks.
- Evacuated tube collectors are best used in northern climates where freezing can occur and can be utilized in areas where temperatures drop down to -60°F. Evacuated tubes are extremely efficient by virtue of the tubes themselves. Evacuated tubes can also be replaced if damaged, simply by plugging it in, no need to replace the whole unit.

2. Literature Review

2.1 About the present work

In literature review on the related topics is discussed. First a brief introduction of working principle of evacuated tube collector (ETC) system and advantages of the system. Solar water heater (ETC System) works on a simple principle „Black body heat absorption principle“. The principle says „black color absorbs maximum heat, more than any other color“. Solar water heating systems using vacuum tubes made of borosilicate glass with special coating to absorb the solar energy are called ETC systems.

Air between the gaps of two glass tubes is evacuated. It results in high level of vacuum, which acts as the best insulation to minimize the heat loss from inner tube. The black coating the inner tube absorbs the solar energy and transfers it to the water.

2.2 Thermosyphon systems

In this type water flows through the systems and when water gets warm it rises as cooler water sinks. The principle on which this system works is called „Thermosyphon“ the key point of these systems is that: the evacuated tube solar collector is always tilted because straightness of tube would not let flow of water within the tube.

As the sun rays pass through the outer glass tubes they are largely transmitted directly to the inner glass tubes due to vacuum presence. As the inner tube surface is heated up transfer of heat to the water takes place by means of convection inside the inner tubes.

The temperature of the water in the tubes rises making it less dense or lighter and hot and lighter water naturally moves up to the top of collector and through the evacuated collector tube goes to the outside and stored.

2.3 REDSUN Evacuated Tube Collector Solar Water Heater Features

- Powder coated GI stand
- Long lasting
- Vacuum jacket insulation
- Easy to install, operate and maintain

The working of evacuated solar water heater is based on a natural circulation of water within the system. The principle is called „Thermosyphon“ the key important point of these systems is that: the evacuated tube solar collector is always tilted a little because straightness of tube would not let flow of water within the tube.

2.4 Technical Specification of Various Elements of Evacuated U tube Solar Collector

In this section a brief idea about the design is discussed:

Table 1: Specification and nomenclature of evacuated tube solar collector

Material	Parameters	Size and other particulars	Unit
Outer Glass tube	Thickness	2	Mm
	Diameter	47	mm
	Conductivity	0.74	W/m k
	Transmissivity	0.92	
	Refractive Index	1.474	
	Length	1500	Mm
Inner Glass Tube	Diameter	37	Mm
	Thickness	2	mm
	Conductivity	0.74	W/m k
Copper Tube	Thickness	0.7	Mm
	Conductivity	398	W/m k
	Diameter	8	mm
Absorbing Coating	Absorptivity	0.92	
	Emissivity	0.08	

3. Design and Fabrication

3.1 Design of Equipment

3.1.1 Evacuated Tube

The design of evacuated tube is in U shape and made up of highly resistive borosilicate glass with Al-N. Each evacuated tube consists of two glass tubes made from extremely strong borosilicate glass. It consists of two glass tubes in between a vacuum is present. The outer tube is transparent allowing lights rays to pass through minimum reflection. The inner tube is coated with a special selective coating (Al-N/Al) which features excellent solar radiation absorption and minimum reflection properties.

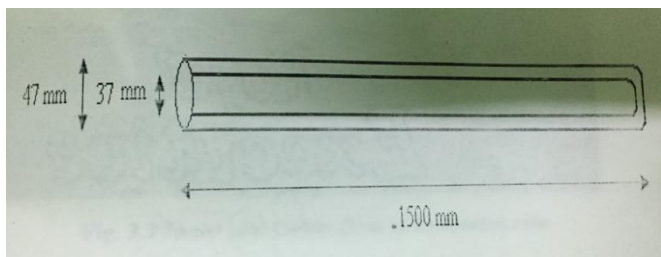


Figure 1: Evacuated tube along the length

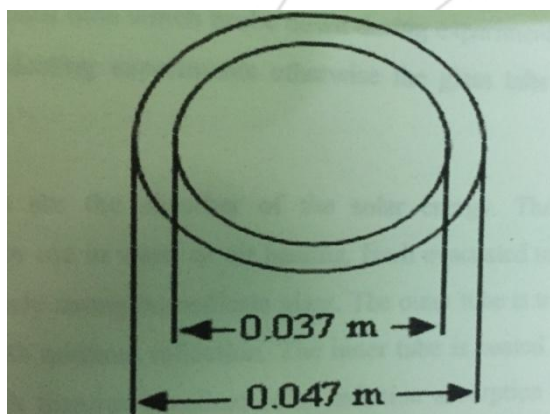


Figure 2: cross-section of glass evacuated tube

In order to maintain the vacuum between the two glass layers, a barium getter is used. During manufacture of the evacuated tube this getter is exposed to high temperatures which cause the bottom of the evacuated tube to be coated with a pure layer of barium. This barium layer actively absorbs any CO, CO₂, N₂, O₂, H₂O and H₂ out gassed from the evacuated tube during storage and operation, thus helping to maintain the vacuum. The silver colored barium layer will turn white if the vacuum is ever lost. This makes it easier to determine whether the tube is in a good condition or not.



Figure 3: Getter is located at the bottom of the evacuated tube

3.1.2 Header or Heat Exchanger

The outer body of the header is made up of the cast iron. It consists of a square pipe which is of steel. The pipe consists of 15 holes, 15 on each side in which the evacuated tubes are placed. Open end of the evacuated tubes are in these holes and the close ends are supported by the frame. Outer the square pipe, an insulation of glass wool material is used to stop the heat transfer from the header to the atmosphere. The header consists of a hollow pipe in the center of diameter 60mm through which air flows.



Figure 4: Header or heat exchanger

Inside the header a rectangular pipe of 1200mm is inserted centrally whose one end is closed and other end is opened to which a blower is attached. On rectangular pipe at an equal distance of 70mm and 15 holes are drilled on which 12mm inside diameters brass nuts are welded.

3.1.3 Frames

The frame was made up of cast iron having slots on both the arm. Header was fitted on the front portion of frame. The frame is made rigid for conducting experiments.



Figure 5: Testing data- load current (amperes)

3.1.4 Pen type Thermometer

Pen type thermometer is good for measuring water temperature and normal contract temperature testing. The meter is easy to operate. Just push out the probe cover and install the battery. Touch the object and press the ON button to measure the temperature.

3.1.5 Other Accessories

Some other needed accessories are:

- 1) Water tank
- 2) Inlet and Outlet Tap
- 3) Pipes and Stand
- 4) Water level measuring jar

3.2 Fabrication of Equipment

The experimental setup is developed at workshop for the conduction of experiment. Special care was to be taken to prevent the leakage from the tubes and joints. The leaks were tested using the soap bubble method by pressurizing it with air first.



Figure 6: Experimental setup

4. Results and Discussions

4.1 Experimental Results

When the full project is ready then the readings are noted down by the measuring equipments like thermometer, beaker and the angle movement of the outlet tap. The setup was prepared to run at 8 a.m in the morning and the experiments from 9 am to 4pm were calculated on day by day basis.

The main nine elements as per in the table are:

- 1) **Time:** Time taken and time interval are important variables.
- 2) **Angle:** Opening of angle is directly proportional to mass flow of water because mass flow rate of water is totally dependent on the opening and closing of outlet tap.
- 3) **Processing Time:** It is time taken to fill a beaker of 250ml.
- 4) **Mass flow rate of water (m):** Mass flow of water is important constraint.
- 5) **Inlet temperature of water (Ti):** Inlet temperature of water is important constraint.
- 6) **Outlet temperature of water (To):** Outlet temperature of water is important constraint.
- 7) **Difference between inlet and outlet temperature:** The difference is calculated by noting the Inlet and Outlet temperature of water.
- 8) **Specific heat at constant pressure (Cp):** Cp depends upon the temperature of water.
- 9) **Heat transfer rate (H):** The heat transfer rate is calculated using the basic heat transfer relation.

DAY 1:

Time	Angle	Processing Time	T_i	T_o	ΔT	\dot{m}	\dot{Q}
9:00 AM	30	22	0.0114	26.6	43.6	17	4.179 0.80989
9:00 AM	60	18	0.0139	26.6	43.8	17.2	4.179 0.999115
9:00 AM	90	16	0.0156	28.6	43.9	15.3	4.179 0.997444
10:00 AM	30	20	0.0125	30.6	44	13.4	4.179 0.699983
10:00 AM	60	16	0.0156	30.8	44.4	13.6	4.186 0.888102
10:00 AM	90	15	0.0167	30.8	44.5	13.7	4.186 0.957715
11:00 AM	30	22	0.0114	31.8	60.3	28.5	4.186 1.360031
11:00 AM	60	15	0.0167	31.8	60.4	28.6	4.186 1.999317
11:00 AM	90	10	0.025	31.8	60.7	28.9	4.191 3.027998
12:00	30	28	0.0089	34.1	72.1	38	4.191 1.417396
12:00	60	12	0.0208	34.2	72.2	38	4.191 3.312566
12:00	90	10	0.025	34.2	72.7	38.5	4.191 4.033838
1:00	30	27	0.0093	35.1	80.1	45	4.195 1.755608
1:00	60	12	0.0208	35.2	80.5	45.3	4.195 3.952697
1:00	90	10	0.025	35.3	80.9	45.6	4.195 4.7823
2:00	30	21	0.0119	37.1	81	43.9	4.195 2.191509
2:00	60	17	0.0147	37.1	81.2	44.1	4.197 2.720789
2:00	90	13	0.0192	37.2	83.5	46.3	4.197 3.730965
3:00	30	18	0.0139	32.5	77.7	45.2	4.197 2.636891
3:00	60	10.5	0.0238	32.5	77.5	45	4.197 4.494887
3:00	90	9	0.0278	32.3	77.1	44.8	4.197 5.227132
4:00	30	25	0.01	32.2	61	28.8	4.197 1.208736
4:00	60	11	0.0227	32.3	60.9	28.6	4.197 2.724776
4:00	90	10	0.025	32.3	60.8	28.5	4.197 2.990363

Figure 7: Observation table for day 1

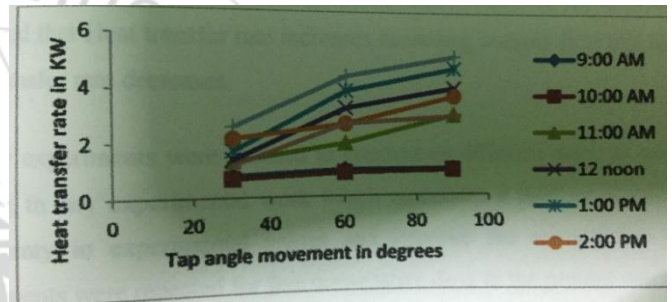


Figure 8: Experimental observation for heat transfer rate and tap angle movement for 9am-4pm(day 1)

Figure [8] shows the observations made on DAY 1 when the setup was tested for 8 hours. It was observed that when the outlet tap angles increases, the Heat Transfer rate increases. At each and every angle movement mass flow rate of water increases and heat transfer rate increases too. It was observed that the minimum flow rate was at 30 and maximum at 90. The maximum flow rate was at 3 pm.

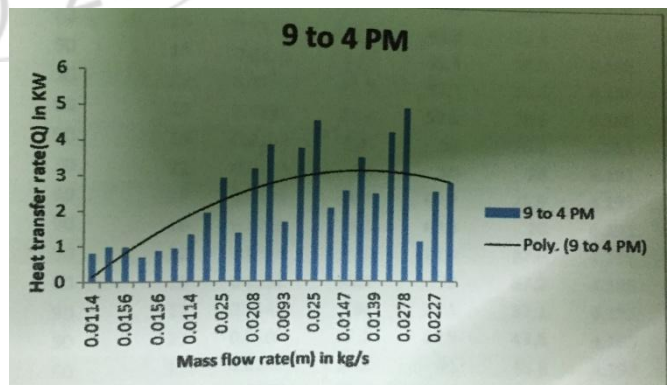


Figure 9: Experimental observation for comparison of mass flow rate and heat transfer rate for 9am – 4pm(day 1)

Figure [9] shows the observations made on DAY 1 when the setup was tested for 8 hours. It was observed that heat transfer rate increases according to the mass flow rate of water but after 3 pm heat transfer rate decreases.

DAY 2:

Time	Angle	Pro Time	m(kg/s)	Ti	To	To-Ti	Cp	Q(KW)
9:00 AM	30	22	0.0114	27.5	41.2	13.7	4.179	0.652676
9:00 AM	60	17	0.0147	27.6	41.3	13.7	4.179	0.841609
9:00 AM	90	15	0.0167	27.9	41.6	13.7	4.179	0.956113
10:00 AM	30	21	0.0119	29.2	43	13.8	4.179	0.686275
10:00 AM	60	18	0.0139	29.3	43.2	13.9	4.186	0.808777
10:00 AM	90	14	0.0179	29.7	43.4	14.2	4.186	1.063997
11:00 AM	30	23	0.0109	31.1	57.7	26.6	4.186	1.213689
11:00 AM	60	19	0.0132	31.3	57.9	26.6	4.186	1.469788
11:00 AM	90	15	0.0167	31.4	58	26.6	4.191	1.861726
12:00	30	21	0.0119	34	60	26	4.191	1.296695
12:00	60	18	0.0139	34.1	60.2	25.9	4.191	1.508802
12:00	90	16	0.0156	34.3	60.3	26	4.191	1.699869
1:00	30	22	0.0114	35.6	72.9	37.6	4.195	1.798145
1:00	60	19	0.0132	35.8	73	37.2	4.195	2.059913
1:00	90	17	0.0147	36	73.1	37.1	4.195	2.287227
2:00	30	23	0.0109	37.1	80.9	43.8	4.195	2.002777
2:00	60	17	0.0147	37.2	81	43.8	4.197	2.70228
2:00	90	15	0.0167	37.4	81.2	43.8	4.197	3.069938
3:00	30	20	0.0125	35.1	77.1	42	4.197	2.203425
3:00	60	18	0.0139	35	77	42	4.197	2.450209
3:00	90	15	0.0167	35	77	42	4.197	2.943776
4:00	30	22	0.0114	33	60.8	27.8	4.197	1.330113
4:00	60	19	0.0132	32.9	60.5	27.6	4.197	1.529051
4:00	90	16	0.0156	32.8	60.4	27.6	4.197	1.80706

Figure 10: Observation table for day 2

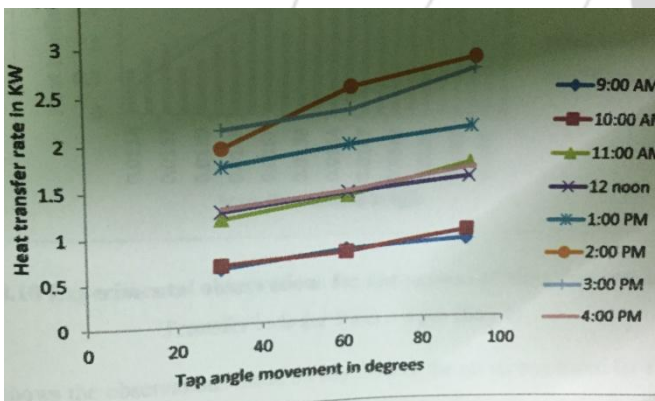


Figure 10: Experimental observation for comparison of mass flow rate and heat transfer rate for 9am – 4pm(day2)

Figure shows the observations made on DAY 2 when the setup was tested for 8 hours. It was observed that when the tap angles increases, the Heat Transfer rate increases. It was observed that the maximum flow rate was at 2 pm and minimum Heat transfer rate at 9 am.

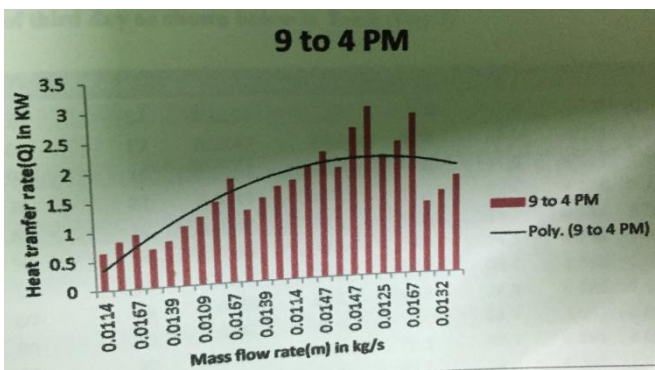


Figure 11: Experimental observation for comparison of

mass flow rate and heat transfer rate for 9am – 4pm(day2)

Figure [11]: shows the observations made on DAY 2 when the setup was tested for 8 hours. It was observed that heat transfer rate increases according to the mass flow rate of water but after 2 pm heat transfer rate decreases.

DAY 3:

Time	Angle	Pro Time	m(kg/s)	Ti	To	To-Ti	Cp	Q(KW)
9:00 AM	30	22	0.0114	28	43.5	15.5	4.179	0.738429
9:00 AM	60	17	0.0147	28.1	43.7	15.6	4.179	0.958328
9:00 AM	90	15	0.0167	28.3	43.8	15.5	4.179	1.081734
10:00 AM	30	21	0.0119	30.1	44.7	14.6	4.179	0.726059
10:00 AM	60	16	0.0156	30.2	44.9	14.7	4.186	0.959934
10:00 AM	90	14	0.0179	30.5	45	14.5	4.186	1.086476
11:00 AM	30	23	0.0109	32	60.7	28.7	4.186	1.309506
11:00 AM	60	18	0.0139	32.1	60.9	28.8	4.186	1.675739
11:00 AM	90	15	0.0167	32.3	61	28.7	4.191	2.008704
12:00	30	20	0.0125	34.2	72.5	38.3	4.191	2.006441
12:00	60	18	0.0139	34.3	72.7	38.4	4.191	2.236988
12:00	90	17	0.0147	34.4	72.7	38.3	4.191	2.359575
1:00	30	22	0.0114	35.5	74	38.5	4.195	1.841186
1:00	60	19	0.0132	35.6	74.2	38.6	4.195	2.137436
1:00	90	14	0.0179	35.8	74.5	38.7	4.195	2.96002
2:00	30	23	0.0109	37.4	82	44.6	4.195	2.039357
2:00	60	18	0.0139	37.5	82.5	45	4.197	2.625223
2:00	90	15	0.0167	37.7	82.7	45	4.197	3.154046
3:00	30	21	0.0119	32.7	77.5	44.8	4.197	2.237505
3:00	60	17	0.0147	32.5	77.4	44.8	4.197	2.763976
3:00	90	15	0.0167	32.4	77.2	44.8	4.197	3.140027
4:00	30	23	0.0109	30.5	60.8	30.3	4.197	1.386143
4:00	60	19	0.0132	30.3	60.5	30.2	4.197	1.673092
4:00	90	15	0.0167	30	60.4	30.4	4.197	2.130733

Figure 12: Observation table for day 3

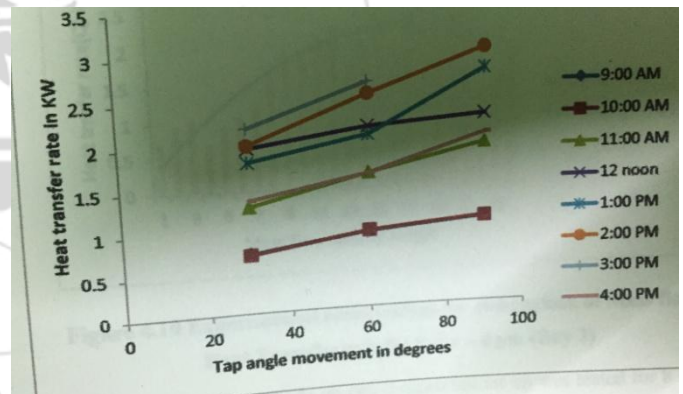


Figure 13: Experimental observation for comparison of mass flow rate and heat transfer rate for 9am – 4pm(day3)

Figure [13]: shows the observations made on DAY 3 when the setup was tested for 8 hours. It was observed that when the tap angles increases, the Heat Transfer rate increases. It was observed that the maximum flow rate was at 3 pm and minimum Heat transfer rate at 9 am.

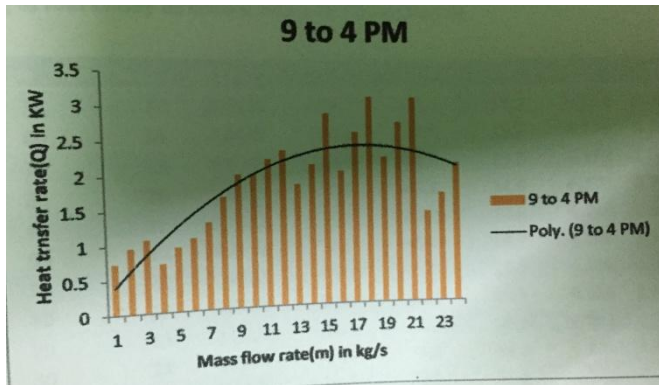


Figure 14: Experimental observation for comparison of mass flow rate and heat transfer rate for 9am – 4pm(day3)

Figure [14]: shows the observations made on DAY 3 when the setup was tested for 8 hours. It was observed that heat transfer rate increases according to the mass flow rate of water but after 2 pm heat transfer rate decreases.

4.2 Calculations

$$Q = m * Cp * (To-Ti)$$

Where,

m = Mass flow rate in kg/s

Q = Heat Transfer rate in KW

Cp = Specific Heat at constant pressure in kJ/kg k

To = Outlet temperature in degree Celsius

Ti = Inlet temperature in degree Celsius

5. Conclusion and Future Scope

5.1 Conclusion

From the experiment and research, it is clear that the evacuated tube solar collector possess 25% - 40% more efficiency than flat plate solar collector under same working conditions. Also, the cylindrical fin provides more efficiency than any other shape of absorber fin.

After concluding the experiments following conclusions were found:

- 1) The heat transfer rate increases first and then decreases from morning to evening, having its peak value at 2 pm in afternoon at 82 degree Celsius to 84 degree Celsius.
- 2) The project setup was fixed in South West direction at DAY 1. The temperature was maximum at 2 pm but the heat transfer was maximum at 3 pm.
- 3) The project setup was fixed in North West direction at DAY 2. The temperature and heat transfer was maximum at 2 pm.
- 4) The project setup was fixed in south west direction at DAY 1. The temperature was maximum at 2 pm and the heat transfer was comparable at 2pm and at 3 pm.
- 5) In total one can predict that the setup performed best around 2 -3 pm in terms of performance output.

5.2 Future Scope

The experimental setup performed extremely well in summers but it could not be performed in winters due to its

fabrication stage. The following modifications may be done to obtain good results in future:

- 1) The setup may be modified to follow the sun's movement using electronic circuitry.
- 2) If three to four setups are combined together, the setup can produce a large amount of hot water.
- 3) The reflector plate can be used for getting far better efficiency.
- 4) It can be used in power plant for pre heating the feed water.

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Kumar Shridhar received his Bachelors degree in Computer Science from India in 2015 and is currently pursuing his Masters degree in Germany. His endeavor lies in his belief to make the world a better place. He is also the co-founder of uliveeasy.com. Apart from

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