The Study of Solar Collector Using Closed Loop Pulsating Heat Pipe with Alumina as Working Fluid

Vinay Nikam[1], Maruti Khot[2], Mayur Mane[3]

[1, 2, 3]Department of Mechanical Engineering, Walchand College of Engineering, Sangli, Maharashtra, 416415, India

Abstract: ***Nowadays, flat plate collectors are used for water heating purpose. But there are problems of corrosion, scaling and reverse heat flowing. Flat plate collector also has low efficiency and it requires more size. It is not possible for collector to work early in the morning and also in rainy days due to low solar intensity. This might lead the collector to not work efficiently for the whole year. To overcome these difficulties we have turned to use heat pipe in the solar collectors. We know that the heat pipe is a device to absorb heat at one end and reject it at another end. In our project we have used this heat transferring device in solar collector. The project involves the design, construction and testing of a prototype model of a solar heat pipe collectors. In present study set up of flat plate collector using closed loop pulsating heat pipes is fabricated. The working fluid used in this setup is Al_2O_3 (Alumina) nanofluid. After taking readings and analyzing it we have found that there is enhancement in efficiency by 10 to 15% with the set up designed in comparison with conventional flat plate collector.***

Keywords: Closed loop pulsating heat pipe, Flat plate collector, Nanofluid- Alumina (Al_2O_3)

1. Introduction

In a conventional solar collector, water is used as working fluid. Tubes in which water is flowing are attached to absorber plate. The solar energy is absorbed by the working fluid and transferred to the storage tank either by natural or forced circulation. But it has some disadvantages. Because of natural circulation of fluid it requires more space, It requires pump, heat carrying capacity is limited, corrosion is also the problem.

Taking into consideration the problems of conventional solar collectors the research has done on using closed loop heat pipe systems with working fluid as nanofluid. In the experimental setup we have fabricated the model which has closed loop heat pipe system and Alumina (Al_2O_3) as working fluid. The analysis of obtained readings is also carried out. The graphs obtained by plotting the readings are promising the future of closed loop system.

For getting the standard data of solar intensity, weather parameter such as atmospheric temperature, global radiation and air flow rate is taken from C_WET Online Radiation and Meteorological Station which is installed at Govt. College of Engineering, Karad.

2. Literature Review

In the paper titled **"**Comparative study of heat pipes with different working fluids under normal gravity and microgravity conditions" (2008) by Savino, Raffaele & Abe, Yoshiyuki & Fortezza, Raimondo, the performance of heat pipes filled with water/alcohol binary mixture under normal gravity is checked and compared with the performances of different heat pipes, with composite wick or wickless, filled with pure water. The dimensions of heat pipes were different. They have diameter of 4mm (Composite wick) and 8mm (wickless) and length of 25cm. The liquid volume in the wickless pipe was 20% of the inner volume. For the composite wick pipe different filling ratio i.e. 10% and 20% are used. Tests are carried out in both horizontal and vertical configuration. Results shows that the heat pipes with binary mixture were more efficient as compared to pure water filled heat pipe. **[1]**

In the paper titled "An investigation of Thermal performance of heat pipe using Di-water" by R. Manimaran, K. Palaniradja, N. Alagumurthi , K.Velmurugan (2012), study of solar collector is done by using water as working fluid. Parameters like solar intensity, filling ratio and angle of inclination are varied and thermal performance of heat pipe is analyzed. It is concluded that as the angle of inclination increases, thermal resistance decreases and reaches minimum when solar collector is in vertical position. Highest efficiency is obtained with angle of inclination 30^0 and 75% filling ratio. **[2]**

In the paper titled "Analysis of flat plate solar collector" by Fabio Struckmann (2008) Description of thermal performance of flat plate collector is given. As per this paper the most important measure is collector efficiency. There are also other important factor like overall heat loss coefficient and heat removal factor. **[3]**

In the paper titled "Performance enhancement of two phase thermosyphon flat plate solar collectors by using surfactant and nanofluid" by Sandesh S. Chougule, Santosh Kumar Sahu, Ashok Pise (2013) , performance of three different wickless heat pipe solar collector were investigated. They have used pure water, water surfactant and CNT-water nanofluid as working fluids. They have concluded that 2-ethyl-hexanol surfactant with water as coolant gives better performance as compared to pure water and CNT-water nanofluid. **[4]**

In the paper titled "Performance analysis of elliptical heat pipe solar collector" by K. Sivakumar, N. Krishna Mohan and B. Sivaraman(2011), heat pipe with elliptical cross section is designed, constructed and tested. Collector angle

Licensed Under Creative Commons Attribution CC BY

11^0 with horizontal is used. Effect of condenser length/evaporator length (L_c/L_e) ratio of heat pipe, Mass flow rate, different inlet cooling water temperature is analyzed. Copper is used as container material and methanol is used as working fluid. Heat pipes were fixed and performance of elliptical cross section heat pipe solar collector has been studied and results obtained. For 0.1764 L_c/L_e ratio higher instantaneous efficiency is achieved. Also, 18 kg/hr water flow rate gives better performance compared to other flow rates.(24 kg/hr, 30 kg/hr, 36 kg/hr). [5]

In the paper titled "Experimental and theoretical study of two phase heat pipe" Journal of Engineering, Volume 19 (June 2008) by Dr.Karima Esmail Amori and Muhanad Latif Abdullah, thermal characteristics of a two-phase closed heat pipe were investigated experimentally and theoretically. A two-phase closed heat pipe with copper container and Fluorocarbon FC-72 (C6F14) as working fluid was fabricated. Effect of input heat flux range of 250-1253 W/m^2 ,70% filling ratio and different tilt angles is studied. Also temperature distribution along the heat pipe, output heat from condenser, input heat to evaporator section is monitored. [6]

In the paper titled, "Thermal performance measurement of heat pipe" by Patrik Nemec, Alexander Čaja, Milan Malcho (2011), explanation of construction of wick heat pipe is given and device to identify thermal performance is proposed. Ideal working position of heat pipe is vertical position because heat pipe maximum performance and maximum flow rate in this position. But wick heat pipe is able to operate at any other position and at horizontal position total heat transfer is not very different as at vertical position. [7]

3. Experimental Setup

By taking help from literature and with the help of seniors who have already worked in this field best suitable dimensions are taken to design experimental setup. The Pulsating heat pipe consists of a closed loop with two copper U-turns in the evaporator and condenser zones. Tube has ID and OD of 6 and 7mm respectively. The spacing between two parallel tubing is 120mm. A smaller copper tube (OD 7 mm/ ID 6 mm) is brazed on the main tube of the condenser section in order to connect the vacuum/filling valve. K-type of thermocouple is used to sense the temperature at inlet and outlet because of low cost. Arrangement of heat pipes is shown in fig. 1.

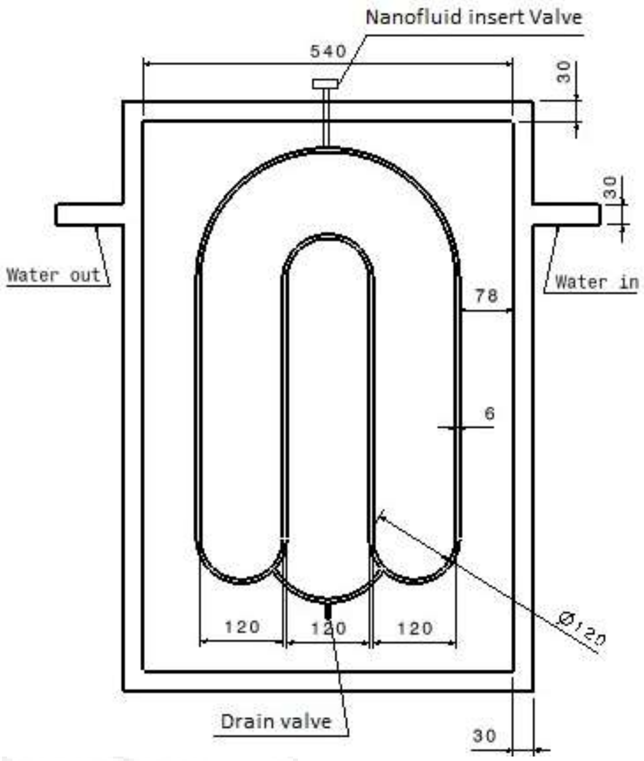

Figure 1: Arrangement of heat pipes

Picture 1: Experimental setup

Experimental setup is shown in pic.1. Detailed specifications are as follows:

1) Absorber plate

Area	0.1632mm^2
Length	510mm
Width	320mm
Thickness	3mm
Material	Copper

2) Thermocouple

Type	K type

3) Insulation

Material	Glasswool
Thickness	30mm
Density	48kg/m^3

Licensed Under Creative Commons Attribution CC BY
Paper ID: ART20183103 DOI: 10.21275/ART20183103

4) Cover plate

Area	$0.2394mm^2$
Length	630mm
Width	380mm
Thickness	4mm
No. Of Cover	Single
Material	Glass

5) Temperature Indicator

No. of temp. indicator	1
Range of indicator	$0\text{-}199.9^0C$
Accuracy	1^0C
Stability	< ± 2% change over a 1 year period
Response time	10 µs

6) Location

Sangli	16° 52' 3.4824" N 74° 34' 13.4004" E
Tilt angle	20°, 31.5°, 40°, 50°

In experimental setup inlet and outlet of solar collector is connected to inlet and outlet of solar collector respectively. Thermocouple sensors are attached at inlet and outlet to sense the temperature and this are in turn connected to digital temperature indicator to show the temperature. Vacuum pump is used to remove air from heat pipe. One direction valve is attached to heat pipe so that air cannot go inside as soon as vacuum pump is detached.

3.1 Calculations of closed loop pulsating heat pipe

It was decided to vary two parameters i.e. Tilt angle (20^0, 31.5^0, 40^0, 50^0) and Filling ratio i.e. ratio of amount of volume filled inside the heat pipe to the volume of heat pipe (40%, 60%, 80%). This angles and filling ratios are decide because as per the literature available, for one of this angles and filling ratio best efficiency has been found out. Calculations are as follows:

3.1.1 Calculation of volume of heat pipe

Total volume of heat pipe = volume of vertical pipe + volume of three small loops + volume of one large loop + volume of drain pipe

3.1.1.1 Total volume of vertical pipe

$= 4\times$ (volume of vertical pipe)
$= 4\times (\Pi r^2 h)$
$= 4\times (\Pi\times (3^2) \times 440)$
$= 12440.706\ mm^3$

3.1.1.2 Volume of three small loops

$= 3\times$ (volume of small loop)
$= 3\times (\Pi\times 9\times 63.5\times \Pi)$
$= 16921.436\ mm^3$

3.1.1.3 Volume of one large loop

$= \Pi\times 190.5\times \Pi\times 9$
$= 16921.436\ mm^3$

3.1.1.4 Volume of one drain pipe

$= (278.7735\times 42\times (\Pi/180)\times 9\times \Pi)+(9\times \Pi\times 60)$
$= 7474.3600\ mm^3$

Total Volume = (12440.706+16921.436+16921.436+7474.3600)
$= 53757.42\ mm^3$

Here, r = radius of heat pipe
h= height or length of heat pipe

3.1.2 Calculations of Filling ratio

- Volume for 40% Filling ratio = 40% × 53757.42 $= 21502.96\ mm^3$
- Volume for 60% Filling ratio = 60% × 53757.42 $= 32245.45\ mm^3$
- Volume for 80% Filling ratio = 80% × 53757.42 $= 43005.93\ mm^3$

Performance parameters of solar heat pipe collector were calculated as follows:

- Rate of solar energy input (Q_{in}),
  $Q_{in} = It \times A_{coll}$
- The rate of thermal energy gain (Q_g)
  $Q_g = m\, C_w\, (T_0 - T_i)$
- The instantaneous efficiency,
  $\eta = \frac{Q_g}{Q_{in}}$

4. Preparation of Nanofluid

In this work, two step methods is used for preparation of nanofluid of composition (0.3wt %). Al_2O_3 Powder of average size 50 nm and 99% pure water whose properties are listed in table no.1.

Table 1: Properties of fluids

Property	Water	Al_2O_3
Specific heat C(J/kg K)	4179	765
Density ρ(kg/m3)	997.1	3970
Thermal Conductivity k(W/m K)	0.605	40
Thermal Coefficient of expansion α (m^2/s)	1.47	1317

It can be seen that the primary Al_2O_3 nanoparticles are spherical and their size is widely distributed in a range of 1-100 nm. The BET surface area of the powder is found to be (30-50) m^2/g. From the table it can be seen that Al_2O_3 nanofluid has thermal conductivity and thermal coefficient of expansion is much higher than the water. So it is chosen as working fluid in this project.

Al_2O_3 nanofluid was prepared by the two-step method. Distilled water was used as the host liquid and sodium lauryl sulphate was used as dispersant to inhibit Al_2O_3 nanoparticles aggregation and break up clusters. SLS concentration used for stability is 0.015%. Required nanoparticle powder is mixed with distilled water and 0.015% SLS is added in the mixture. The mixture nanoparticle suspension was vibrated for 1 hour in overhead stirrer at 5000-6000 rpm. After

Licensed Under Creative Commons Attribution CC BY

vibrated in overhead stirrer the nanofluid mixture was agitated in ultrasonic agitator for 4 hour. Equipment mentationed above is available in PG laboratory of Government College of Pharmacy, Karad. Pic. 2. Shows the overhead stirring of Al_2O_3 nanofluid. Pic. 3. Shows the ultra-sonication process of nanofluid and Pic. 4. Shows prepared nanofluid.

Pic. 2: Overhead Stirrer

Pic. 3: Ultrasonic Agitator

Pic. 4: Prepared Nanofluid

5. Experimental Procedure

The experimental procedure for taking readings is as follows:

1) First it is necessary to remove complete air from heat pipe. So join the vacuum pump to nanofluid insert valve which is one directional valve. Start the vacuum pump and suck whole air from heat pipe.
2) Stop the vacuum pump. Take volume of nanofluid required according to filling ratio in test tube. Take one flexible tube and connect nanofluid insert valve and test tube. Because of vacuum inside the heat pipe, there will be pressure difference which helps to suck nanofluid inside the heat pipe.
3) Connect inlet of collector to the inlet tank. Initially keep the inlet water valve completely open, start the water supply and keep water flowing for some time until air is completely removed from the collector.
4) Once the condenser region is totally filled with water then adjust the flow rate as decided (2.4 Kg/hr.).
5) Attach all the sensors as per the requirement such as inlet sensor at inlet of the pipe, outlet sensor at outlet of the pipe, and absorber plate sensor to absorber plate. All sensors are connected to the temperature indicator.
6) For particular filling ratio and particular tilt angle take the readings from temperature indicator for whole day from 10 am to 4pm. Take readings after one hour.
7) Repeat the same procedure for total 12 combinations as follows:
   a) Filling ratio of 40% and tilt angle of 20^0
   b) Filling ratio of 40% and tilt angle of 31.5^0
   c) Filling ratio of 40% and tilt angle of 40^0
   d) Filling ratio of 40% and tilt angle of 50^0
   e) Filling ratio of 60% and tilt angle of 20^0
   f) Filling ratio of 60% and tilt angle of 31.5^0
   g) Filling ratio of 60% and tilt angle of 40^0
   h) Filling ratio of 60% and tilt angle of 50^0
   i) Filling ratio of 80% and tilt angle of 20^0
   j) Filling ratio of 80% and tilt angle of 31.5^0
   k) Filling ratio of 80% and tilt angle of 40^0
   l) Filling ratio of 80% and tilt angle of 50^0

6. Results and Discussion

After following the procedure, readings are taken for different angle and filling ratio. According to the readings graphs are drawn in Microsoft excel. Following graphs show the effect of tilt angle on efficiency at 3 different filling ratios (40%, 60%, and 80%) on performance of closed loop solar heat pipe collector.

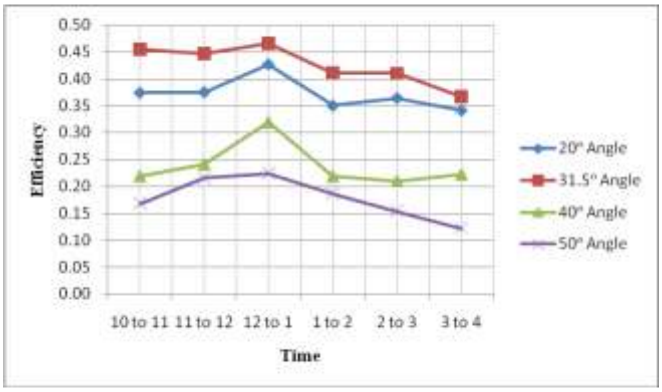

Figure 2: Efficiency vs. Time for filling ratio of 40%

Licensed Under Creative Commons Attribution CC BY

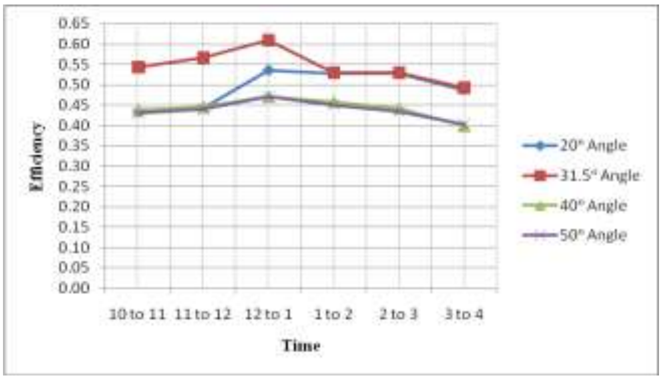

Figure 3: Efficiency vs. Time for filling ratio of 60%

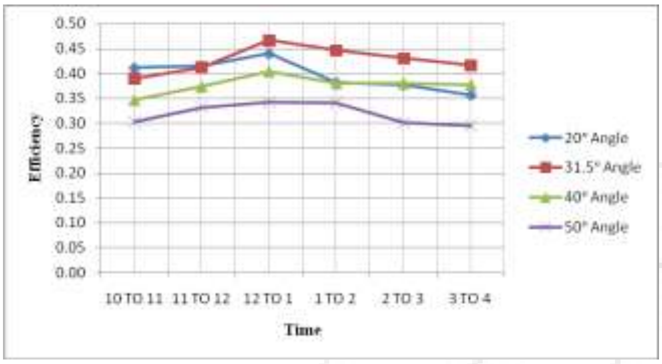

Figure 4: Efficiency vs. Time for filling ratio of 80%

These graphs are then compared with each other to find out the difference. It can be seen that for 40% filling ratio highest efficiency is obtained is 46.62% for 31.5^0 tilt angle and lowest efficiency for 50^0 tilt angle. In case of 60% filling ratio highest efficiency is obtained is 60.92% for 31.5^0 tilt angle and lowest efficiency for 40^0 and 50^0 tilt angles while for 80% filling ratio highest efficiency is 46.63% at 31.5^0 tilt angle.

7. Conclusion

From above discussion we can say that for 31.5^0 tilt angle and 60% filling ratio we get highest efficiency i.e. 60.92%. As we go on increasing tilt angle up to 31.5^0, efficiency goes on increasing but above that it is decreasing. For 31.5^0 tilt angle efficiency is almost doubled than existing one. From this discussion we can say that Solar heat pipe collector with use of alumina nanofluid gives better performance as compared to flat plate collector.

References

[1] Savino, Raffaele & Abe, Yoshiyuki & Fortezza, Raimondo. (2008). Comparative study of heat pipes with different working fluids under normal gravity and microgravity conditions. Acta Astronautica – ACTAASTRONAUT.63.2434.10.1016/j.actaastro.2007.12.037.

[2] Manimaran,R & Palaniradja, K & Natarajan, Alagumurthi & Velmurugan, K. (2012).“An Investigation of Thermal Performance of Heat Pipe Using Di-water.” Sci Technol. 2. 77-80. 10.5923/j.scit.20120204.04.

[3] Fabio Struckmann , “Analysis of a Flat Plate Collector” 2008 MVK 160 Heat and Mass Transport.

[4] Chougule Patil, Sandesh & Sahu, Santosh & Pise, Ashok. (2013). Performance enhancement of two phase thermosyphon flat-plate solar collectors by using surfactant and nanofluid. Front. Heat Pipes (FHP). 4.

[5] Sivakumar, N. Krishna Mohan and B. Sivaraman, “Performance analysis of elliptical heat pipe solar collector” Indian Journal of Science and Technology Vol. 4 No. 1 (Jan 2011)

[6] Dr.Karima Esmail Amori and Muhanad Latif Abdullah, “Experimental and theoretical study of two phase heat pipe.” Journal of Engineering, Number 6 Volume 19 (June 2013)

[7] Patrik Nemec, Alexander Čaja, Milan Malcho, “Thermal performance measurement of heat pipe” Global journal of technology and optimization Volume 2 (2011)

Author Profile

Mr. Vinay S. Nikam has completed Bachelors in mechanical engineering from Shivaji university and currently pursuing his M. Tech. in mechanical Design engineering from Walchand College of Engineering, Sangli.

Mr. Maruti M. Khot has completed his Bachelors in mechanical engineering from Shivaji University and M.Tech. and Phd in mechanical Design Engineering from Shivaji University.

Mr. Mayur S. Mane has completed Bachelors in mechanical engineering from Shivaji university and currently pursuing his M.tech. in mechanical Heat Power engineering from Walchand College of Engineering, Sangli.

Licensed Under Creative Commons Attribution CC BY