ISSN 2395-1621

Design, Fabrication and Testing of Evacuated Heat Pipe Solar Collector using Nanofluids

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ABSTRACT

Solar heater is a device which is used for heating the water, for producing the steam for domestic and industrial purposes by utilizing the solar energy. Solar energy is the energy which is coming from sun in the form of solar radiations in infinite amount, when these solar radiations falls on absorbing surface, then they gets converted into the heat, this heat is used for heating the water. This type of thermal collector suffers from heat losses due to radiation and convection. Such losses increase rapidly as the temperature of the working fluid increases. To overcome this losses we use SWH using nanofluid system. This system include heat pipe using nanofluid. Because of that it absorbs maximum heat and also reduces heat losses. It also consumes the time required for heating water. In this paper we explained SWH using nanofluid and analysis of parameters using Taguchi Method. Initially we compared different parameters of nanofluid according to that we select CuO nanofluid having better properties. In this experiment we considered three parameters such as Diameter of heat pipe, Mass flow rate, Length of glass tube. By using these three independent parameters, with each having three set values in L9 orthogonal array, we find out optimum combination of parameters. In taguchi method we take analysis of variance, regression analysis and validation test. Analysis of variance gives us Mass flow rate has stronger evidence and hence it is more effective parameter.

Keywords – Thermosyphon, Nanofluid, Heat pipe, Orthogonal Array, Taguchi method

ARTICLE INFO

Article History

Received: 18th July 2019

Received in revised form : 18th July 2019

Accepted: 22nd July 2019

Published online : 22nd July 2019

I. INTRODUCTION

The solar energy is the most capable of the alternative energy sources. Due to increasing demand for energy and rising cost of fossil type fuels (i.e., gas or oil) solar energy is considered an attractive source of renewable energy that can be used for water heating in both homes and industry. Heating water consumes nearly 20% of total energy consumption for an average family. Solar water heating systems are the cheapest and most affordable clean energy available to homeowners that may provide most of hot water required by a family. Solar heater is a device which is used for heating the water, for producing the steam for domestic and industrial purposes by utilizing the solar energy.Solar energy is the energy which is coming from sun in the form of solar radiations in infinite amount, when these solar radiations falls on absorbing surface, then they gets converted into the heat, this heat is used for heating the water. This type of thermal collector suffers from heat losses due to radiation and convection.

Such losses increase rapidly as the temperature of the working fluid increases. Solar energy is considered nowadays as one of the most important sources of clean, free and renewable energy with minimum environmental effects. After industrial revolution (1970s) energy consumption increased sharply, so threat of energy shortages led scientists to find new sources of energy. The solar energy is widely believed to be the most sustainable form of energy among another renewable energy sources. By mid of the 21stcentury, renewable sources of energy could account for 60% of the world's electricity market and 40% of this market are come for fossil fuels. The solar energy can be defined as the energy which comes from the sun and can be converted into and heat. Solar energy is a natural result of electromagnetic radiation released from the Sun by the thermonuclear reactions occurring inside its core. It has produced energy for billions of years, so the utilization of solar energy has received significant attention especially in the last ten years. For example, some studies have indicated that about 1000 times from the global energy requirements can be achieved by using solar energy; however, only 0.02% of this energy is currently utilized. The main reasons of this huge attention in the solar energy applications are due to the increased demand of energy, limited availability of fossil fuels and environmental serious problems related with them especially the carbon dioxide emissions. From the other side, the huge increase in the human population can be considered as an extra serious problem. In fact, the sun radiates every day, enormous amount of energy and the hourly solar flux incident on the earth's surface is greater than all of human consumption of energy in a year. In spite of this huge amount of available solar energy, approximately 80% of energy used worldwide still significantly comes from fossil fuels. Recently, one of the future projections is to reduce global carbon dioxide (CO2) emissions by 2050 to 75% of its 1985 level if we can improve and use the solar energy equipment's such as the solar collectors. A number of systems have been developed to collect solar energy and convert it into an alternative form of energy, electricity, or to use the solar energy to perform work, such as in the case of a solar water heater. An important component of all these systems is the solar collector, which absorbs the solar radiation from the sun and transfers it to some transfer medium such as water, which delivers the heat as hot water to a house or to a heat storage unit. Among different types of solar collectors, one example of an advanced and highly effective type of solar collector is an Evacuated Tube solar Collectors (ETCs). Evacuated tube solar collectors are designed in such a way that heat loss to the environment is reduced. Heat loss due to convection cannot cross a vacuum, as it forms an efficient isolation Mech.

Nomenclature

ETC	Evacuated Tube Solar Collector
SWH	Solar Water Heater
BTP	Building Technology Programme
WH	Water Heater
ICS	Integral Collector Storage
CNT	Carbon Nanotube
PCM	Phase Change Material
TPCT	Two Phase Closed Thermpsyphon
OHP	Oscillating Heat Pipe
CHP	Convectional Heat Pipe
HPC	Heat Pipe solar Collector
d	Diameter of Heat Pipe
l	Length of Heat Pipe
Cp	Sensible Heat Of Nanofluid
ΔT	Temperature Difference
Q	Heat Transfer Rate

II. WORKING PRINCIPLE

- In this project sun rays strike on a solar insulation then the solar insulation absorb heat and transfer heat from evacuated glass tube.
- After that Nano fluid vaporize in the heat pipe and transfer heat from heat pipe to cooling fluid water.
- Then the water is heat in minimum time 30 min and this hot water using for different application like Boiler, Heat exchanger, RAC System.

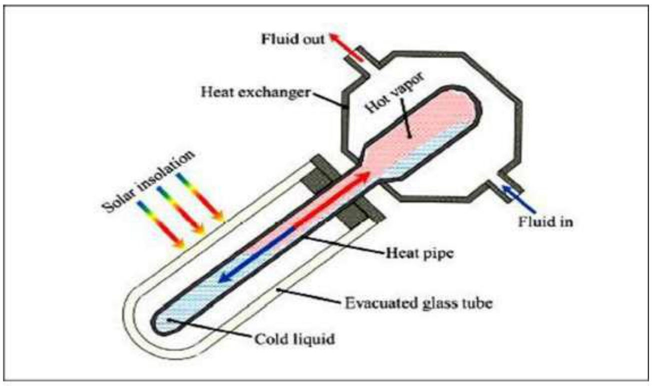


Fig .Heat pipe working cycle

III. SELECTION OF NANOFLUID

- As listed below some of the alternatives of the nanofluid that we can use for manufacturing of SWH. From these we have selected nanofluid.
- While selecting nanofluid we have considered various factors such as Density, Melting Point, Molar mass and Cost.

Table: Properties of Nanofluid.

Nanofluid	CuO	Al_2O_3	ZnO
Melting Point (^{0}C)	1201	2977	1975
Density (kg/m^3)	6.319	3.69	5.606
Molar Mass (gm/mol)	79.55	101.96	81.38
Rate (Rs/gm)	40	40	182

- We requires following properties of nanofluid for best results,
  I. High Density
  II. Low melting point
  III. Low Cost
- Our requirements match with the properties of the Nanofluid CuO, Hence Cuo is selected for further processes.
- Vendor for the nanofluid – Gandhi Research Lab, Raviwar peth, Pune.

IV. EXPERIMENTAL SETUP

- According to experiment of study to execute the experiment we have to consider three known parameters.
- In our experiment Diameter of heat pipe, mass flow rate and length of glass tube these three parameters are consider for the observation.
- Nine combinations of above parameters are taken from the study of experiment which are listed below, Amongst these combinations our aim to select best combination which gives highest heat capacity.

Table No. Study of experiment combinations,

P_1 (Dia of Heat pipe)	P_2 (Mass flow rate)	P_3 (Length of glass tube)
1	1	1
1	2	2
1	3	3
2	1	2
2	2	3
2	3	1
3	1	3
3	2	1
3	3	2

Experimental Setup

Working :

- In our Experimental setup heat pipe is inserted into the evacuated glass tube and sealed it with tape and both are mounted on frame.
- Cold water is stored into the tank, this water is pumped out and flows towards the inlet port of the heat pipe via rotameter. Mass flow rate of the water is controlled by using knob.
- In construction of heat pipe nanofluid is inserted into the upper part by brazing process.
- Cold water which is coming from rotameter flows around the upper part of heat pipe.
- When Sun rays strikes on the combination of heat pipe and evacuated glass tube, cold water gets the energy for heating which is evolved from evacuated glass tube as well as heat evolved by nanofluid and hence there is rapid increase of temperature of water. from the outlet port of the heat pipe water is again discharge to the tank.
- Now the same water is again feed to the inlet port of the same heat pipe. This process runs continuously for the specific interval of time.
- Inlet temperature of cold water and temperature after certain interval is listed for the combinations.

V. CALCULATION

A. Calculation of mass for Nano powder :

1. Volume of Tube.
2. Volume Fraction
3. Volume of Nano powder
4. Mass of Nano powder

According to the Comparative Study we conclude to the following dimensions:
Length of heat pipe- 400mm
Diameter of heat pipe- 25mm

1. Volume of Tube $=\pi/4.\ D^2.\ L$ ….(d= 0.025 m, l= 0.4 m)
$= 19.634 \times 10^{-5}\ m^3$
Total Volume of Single Heat pipe is $19.634 \times 10^{-5}\ m^3$
But from literature study it is seen that the thermal performance of TPCT is superior at filling ratio 50%.
Hence, 50 % of volume of tube = $9.81 \times 10^{-5}\ m^3$
2. Volume Fraction is selected 2%.
3. Volume Fraction $= \dfrac{\text{Volume of nanopowder}}{\text{Volume of Nanofluid}}$
$2/100 = \text{Volume of nanopowder} / 9.81 \times 10^{-5}$
Volume of Nanopowder = $1.962 \times 10^{-6}\ m^3$
4. Mass of Nanopowder
for single Heat pipe = Density of Nanopowder X Volume of Nanopowder
= 5.178gm ……. (considering density of nanopowder= 5609 kg/m cube)
Hence Total Mass of Nanopowder used in Heat Exchanger
= Mass of nanopowder of single heat pipe X Number of heat pipe.
= 10.356 gm.
Thus the 1.356 gm of nanopowder is added in the 923 ml of water in order to get nanofluid with 2% volume fraction.

B. Calculation for Heat Capacity (Q) :
Sample calculaton for 1st reading,
Mass flow rate (m)- 4 lpm – 0.048 kg/s
Temperature Difference- 10.5 K
Specific heat for water- 4187 J/kgK

Heat Capacity(Q) = $mCp\Delta T$
$= 0.048 \times 4187 \times 10.5$
$= 2110.248$ J/s

Observation table :

Parameter					
D(mm)	m(lpm)	L(mm)	$T_1(^0C)$	$T_2(^0C)$	Q(kJ/s)
25	4	600	30.3	40.8	2.11
25	5	1500	27.2	38.3	2.23
25	6	1800	29.4	41	2.914
27.5	4	1500	28.1	39.6	2.311
27.5	5	1800	27.5	37	2.386
27.5	6	600	29.5	39	2.743
30	4	1800	28.1	41.9	2.813
30	5	600	28.5	33.6	1.281
30	6	1500	29.2	42.7	4.061

VI. ANALYSIS

Typically the experiment would like to obtain some particular response from a product or a process; a higher average response is better, a nominal value is best, or a lower average response is better. Depending on the characteristic, different treatment conditions will be chosen to obtain satisfactory results. The lower the better response is used for situations where the target value is zero. Surface roughness measured on a part is one such response parameter used in this case. The higher the better response is used when the largest value is desired, such as Diameter of heat pipe, mass flow rate, Length of glass tube.

According to the taguchi method for orthogonal array, optimum combination having specification,

- Diameter of heat pipe – 30mm
- Mass flow rate – 6lpm
- Length of glass tube – 1500mm

Analysis of Variance -

Table No. 4.3.1 Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Dia	2	0.1508	0.07542	0.21	0.826
MFR	2	2.5064	1.25321	3.50	0.222
Length	2	1.1385	0.56925	1.59	0.386
Error	2	0.7155	0.35775		
Total	8	4.5113			

Table No. 4.3.2 Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.598119	84.14%	36.56%	0.00%

Sr no.	Diameter of heat pipe (mm)	Mass flow rate (lpm)	Length of glass tube (mm)	Temp. diff. (^{0}C)	Q_{th} (KJ/S)	Q_{act} (KJ/S)	% Difference
1	30	5	1500	13	2.811	2.61	7.1
2	25	6	1500	9	2.925	2.59	11.2

- As we know that, P-value gives Lower probabilities provide stronger evidence against the null hypothesis and F-value gives greater probabilities provide stronger evidence against the null hypothesis.
- But, MFR has Lower P-value and Greater F-value and hence it gives stronger evidence means it is more effective parameter.

Regression Analysis -

The applied diameter of heat pipe, mass flow rate, length of glass tube were considered in the development of mathematical models for the heat transfer rate. The correlation between factors (applied diameter of heat pipe, mass flow rate, length of glass) and Heat transfer rate were obtained by multiple linear regressions. The standard commercial statistical software package MINITAB was used to derive the models of the form:

HT = -2.01 + 0.060 A + 0.414 B + 0.000634 C

Where, A - Diameter of heat pipe
B – Mass flow rate of water
C – Length of glass tube

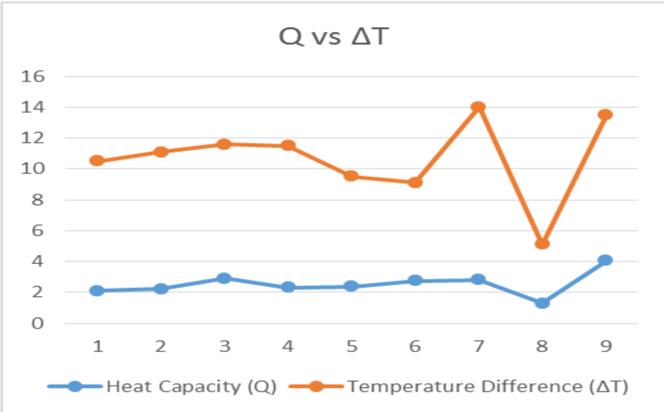
Validation Test for regression analysis

The experimental validation test is the final step in which the results are drawn based on Taguchi's design approach. Numbers of validation tests conducted are two and the observations are recorded below in Table

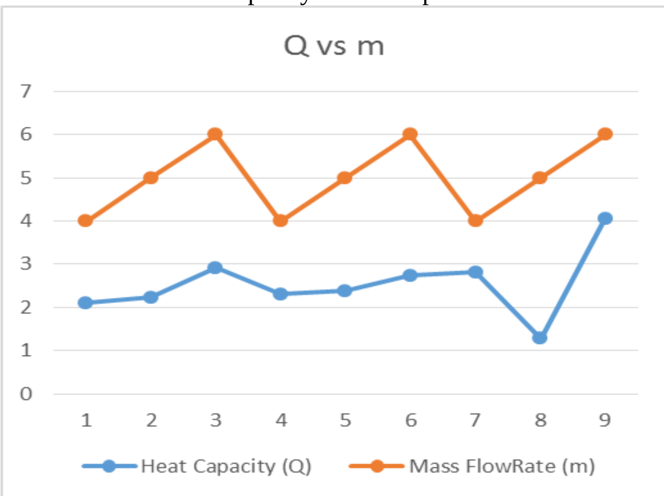
Table No. 4.5.1 Result of validation

VII.RESULT & DISCUSSION

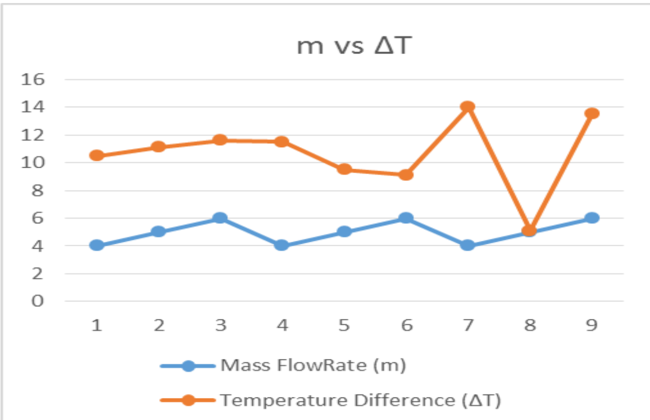
Experiments were carried out to investigate the thermal performance of heat pipe solar collector by using working fluids for heat pipes as water and copper-oxide nano fluid. The results are depicted in fig. . The variations of various parameters namely, inlet water temperature, outlet water temperature, mass flow rate of water, heat capacity for three different evacuated tube heat pipe solar collector shown in following figures.



Variation of Heat Capacity with Temperature difference



Variation of Heat Capacity with Mass flow rate



Variation of Mass flow rate with temperature difference

Main effects plot for mean -
A line connects the points for each variable. Look at the line to determine whether the main effect is present for a categorical variable. Minitab also draws a reference line at the overall mean. Interpret the line that connects the means as follows:

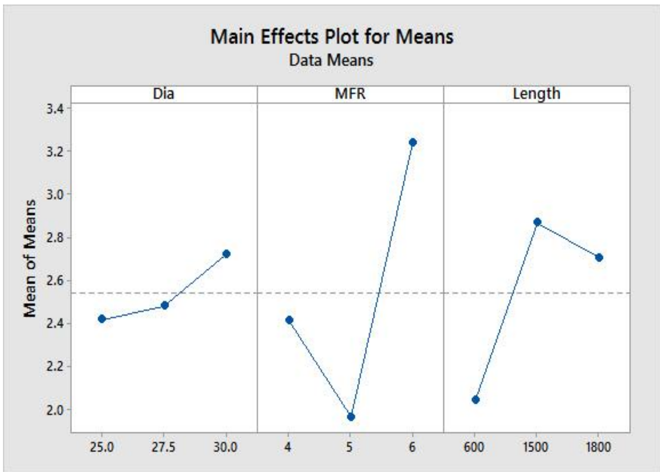


Fig No. 5.1.1 Main Effects Plot

- Diameter -
  The effect of parameters Diameter on the heat transfer rate values is shown above figure for mean of means. Its effect is increasing with increase in Diameter.
- Mass Flow Rate -
  The effect of parameters Mass flow rate on the heat transfer rate values is shown above figure for mean of means. Its effect is decreasing with increase in mass flow rate upto 5 rpm, and beyond that it is increasing.
- Length -
  The effect of parameters length of glass tube on the heat transfer rate values is shown above figure for mean of means. Its effect is increasing with increase in length of glass tube upto 1500mm, and beyond that it is decreasing. So the optimum length of glass tube is level 2 i.e. 1500mm.

VIII. CONCLUSION

An experimental study has been carried out to investigate the thermal performance of evacuated tube heat pipe solar collector by using different evacuated heat pipes for working fluid as pure water, CuO nanofluid.
Following conclusions are made from the experimental study and is detailed below,

- The thermal performance of evacuated heat pipe solar collector is higher by using copper oxide nanofluid.
- According to experiment of study, nine combinations of Dia. Of heat pipe, Mass flow rate of water, Length of glass tube are taken. From that we get better result of 4.061 KJ/s heat capacity for 30mm dia. Of heat pipe, 6lpm mass flow rate of water & 1500mm length of glass tube.
- It has been found that the optimal heat transfer rate for SWH ;
  Diameter – Heat transfer rate is increasing with increase in Diameter.
  Mass Flow Rate - Its effect is decreasing with increase in mass flow rate upto 5 lpm, and beyond that it is increasing.
  Length - Its effect is increasing with increase in length of glass tube upto 1500mm, and beyond that it is decreasing. So the optimum length of glass tube is level 2 i.e. 1500mm.
- A mathematical model for heat transfer rate response is identified by the Taguchi method considering Diameter of heat pipe, mass flow rate and length of glass tube.
- The extent of influence of the selected variable on heat transfer rate can be incerased quantitatively from the model.
- Regression equation of above model is given as,
  HT = -2.01 + 0.060 A + 0.414 B + 0.000634 C

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