Thermal Performance of Waste Heat Recovery by using TPCT Heat Exchanger Charged with Nanofluid

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Abstract— Hot air plays an import role in modem life. The consumption of hot air represents a significant part of the nation's energy consumption. One way of reducing the energy consumption involved, and hence the cost of that energy, is to reclaim heat from the waste warm air that is discharged to the sewer each day. The potential for economic waste air heat recovery depends on both the quantity available and whether the quality fits the requirement of the heating load. To recover heat from waste air in residential and commercial buildings is hard to achieve in quality because of its low temperature range. Nevertheless, efforts to recycle this waste energy could result insignificant energy savings. The objective of this research was to develop a two phase closed thermosyphon heat exchanger charged with nanofluid for a waste air heat recovery system. The advantage of the system proposed in this work is that it provides useful energy transfer during simultaneous flow of cold supply and warm drain air. While this concept is not new, the design of the TPCT heat exchanger with nanofluid for the present study is significantly different from those used previously. Component experiments were carried out to determine the performance characteristics of a heat pipe heat exchanger charged with nanofluid. By replacing the conventional fluid in heat pipe with CuO/H2O nanofluid (2% volume fraction) of the heat pipe heat exchanger good performance can be obtained. The maximum effectiveness obtained for proposed TPCT CuO/H2O charged nanofluid heat exchanger is 0.2862 (2% volume fraction compared with effectiveness 0.16 obtained with conventional heat pipe working fluid. The influence of mass flow rate and source temperature on effectiveness of TPCTHX exhibits same pattern as that of conventional working fluid. The maximum enhancement in effectiveness obtained is 35%.Thus the nanofluid as working fluid in TPCT enhances the effectiveness of heat exchanger.

Key words: TPCT, Nanofluid

I. Introduction

Hot air plays an import role in modem life. The consumption of hot air represents a significant part of the nation's energy consumption. One way of reducing the energy consumption involved, and hence the cost of that energy, is to reclaim heat from the waste warm air that is discharged to the sewer each day. The potential for economic waste air heat recovery depends on both the quantity available and whether the quality fits the requirement of the heating load. To recover heat from waste air in residential and commercial buildings is hard to achieve in quality because of its low temperature range. Nevertheless, efforts to recycle this waste energy could result insignificant energy savings.

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Component experiments were carried out to determine the performance characteristics of a heat pipe heat exchanger charged with nanofluid. By replacing the conventional fluid in heat pipe with CuO/H20 nanofluid (2% volume fraction) of the heat pipe heat exchanger good performance can be obtained. The maximum effectiveness obtained for proposed TPCT CuO/H20 charged nanofluid heat exchanger is 0.2862 (2% volume fraction compared with effectiveness 0.16 obtained with conventional heat pipe working fluid. The influence of mass flow rate and source temperature on effectiveness of TPCT HX exhibits same pattern as that of conventional working fluid. The maximum enhancement in effectiveness obtained is 35.6%. Thus the nanofluid as working fluid in TPCT enhances the effectiveness of heat exchanger.

II. Literature Survey

Yodraket et al. [1] studied heat recovery system at Furnace in a Hot Forging Process; he concluded that the experiment findings indicated that when the hot gas temperature increased, the heat transfer rate also increased. If the internal diameter increased, the heat transfer rate increased and when the tube arrangement changed from inline to staggered arrangement, the heat transfer rate increased. The heat pipe air-preheated can reduced the quantity of using gas in the furnace and achieve energy thrift effectively.

Noie-Baghbanet et al. [2] carried out the research on the theory, design and construction of heat pipes, especially their use in heat pipe heat exchangers for energy recovery, reduction of air pollution and environmental conservation. A heat pipe heat exchanger has been designed and constructed for heat recovery in hospital and laboratories, where the air must be changed up to 40 times per hour. In This research, the characteristic design and heat transfer limitations of single heat pipes for three types of wick and three working fluids have been investigated, initially through computer simulation. Construction of heat pipes, including washing, inserting the wick, creating the vacuum, injecting the fluid and installation have also been carried out. After obtaining the appropriate heat flux, the air-to-air heat pipe heat exchanger was designed, constructed and tested under low temperature (15±550C) operating conditions, using methanol as the working fluid. Experimental results for absorbed heat by the evaporator section are very close to the heat transfer rate obtained from computer simulation.

Saman et al. [9] examined the possible use of a heat pipe heat exchanger for indirect evaporative cooling as well as heat recovery for fresh air preheating. Thermal performance of a heat exchanger consisting of 48 thermosyphon arranged in six rows was evaluated. The tests were carried out in a test rig where the temperature and humidity of both air streams could be controlled and monitored before and after the heat exchanger. Evaporative cooling was achieved by spraying the condenser sections of the thermosyphon. The parameters considered include the wetting arrangement of the condenser section, flow ratio of the two streams, initial temperature of the primary stream and the inclination angle of the thermosyphon. Their results showed that indirect evaporative cooling using this arrangement reduces the fresh air temperature by several degrees below the temperature drop using dry air alone. Humidity control is a never-ending war in tropical hot and humid built environment. Heat pipes are passive components used to improve dehumidification by commercial forced-air HVAC systems. They are installed with one end upstream of the evaporator coil to pre-cool supply air and one downstream to re-heat supply air. This allows the system's cooling coil to operate at a lower temperature, increasing the system latent cooling capability. Heat rejected by the downstream coil reheats the supply air, eliminating the need for a dedicated reheat coil. Heat pipes can increase latent cooling by 25-50% depending upon the application. Conversely, since the reheat function increases the supply air temperature relative to a conventional system, a heat pipe will typically reduce sensible capacity. In some applications, individual heat pipe circuits can be controlled with solenoid valves to provide improved latent cooling control. Primary applications are limited to hot and humid climates and where high levels of outdoor air or low indoor humidity are needed. Hospitals, supermarkets and laboratories are often good heat pipe applications.

Yauet et al. [10] mentioned that for many years, heat pipe heat exchangers (HPHEs) with two-phase closed thermosyphon, and has been widely applied as dehumidification enhancement and energy savings device in HVAC systems. Components used to improve dehumidification by commercial forced-air HVAC systems. They are installed with one end upstream of the evaporator coil to pre-cool supply air and one downstream to re-heat supply air. This allows the system's cooling coil to operate at a lower temperature, increasing the system latent cooling capability. Heat rejected by the downstream coil reheats the supply air, eliminating the need for a dedicated reheat coil. Heat pipes can increase latent cooling by 25-50% depending upon the application. Conversely, since the reheat function increases the supply air temperature relative to a conventional system, a heat pipe will typically reduce sensible capacity. In some applications, individual heat pipe circuits can be controlled with solenoid valves to provide improved latent cooling control. Primary applications are limited to hot and humid climates and where high levels of outdoor air or low indoor humidity are needed. Hospitals, supermarkets and laboratories are often good heat pipe applications.

Mousa et al. [17]carried out an experimental study on an effect of nanofluid in Circular Heat Pipe. The nanofluid consisted of Al_2O_3 nanoparticles with a diameter of 100 nm. The experimental data of the nanofluids were compared with those of DI water including the wall temperatures and the total heat resistances of the heat pipe. Experimental results showed that if concentration of the nanofluid increasing, then the thermal resistance of heat pipe decreased.

Shang et al. [18] investigated the heat transfer characteristics of a closed loop OHP with Cu–water nanofluids as the working fluid different filling ratios. The results were compared with those of the same heat pipe with distilled water as the working fluid. The experimental results are confirmed that the use of Cu–water nanofluids in the heat pipe could enhance the maximum heat removal capacity by 83%. It was conformed that directly adding nanoparticles into distilled water without any stabilizing agents had greater heat transfer enhancement compared to the case where a stabilizing agent was added to the distilled water.

III. DESIGN AND DEVELOPMENT OF EXPERIMENTAL SETUP

As described earlier proposed work aims to investigate of experimental performance of heat pipe heat exchanger charged with CuO/H20 Nanofluid under variable source temperatures and mass flow rate. With broad perspective this study aims to investigate the feasibility of heat pipe from low temperature waste heat source. In order to achieve the objectives stated above it has been decided to design and develop the experimental system as shown in following Figure 1. Heat pipe heat exchangers are devices that made the exchange of energy (waste heat) from a waste heat source to a colder source. Figure 1 shows the schematic diagram of the experimental system. The system is composed of three major parts: air heater (for waste hot air preparation), heat pipe heat exchanger and devices for measurement and control of parameters. In the installation there are two circulating fluids: the hot agent (waste air) in the lower chamber of the heat exchanger and the cold agent (cold air) in the upper chamber of the heat exchanger.

The heat pipe heat exchanger was equipped with eight heat pipes arranged vertically at an angle of 90 ° (Figure1). The working fluid used in heat pipe is CuO/H_2O nanofluid.

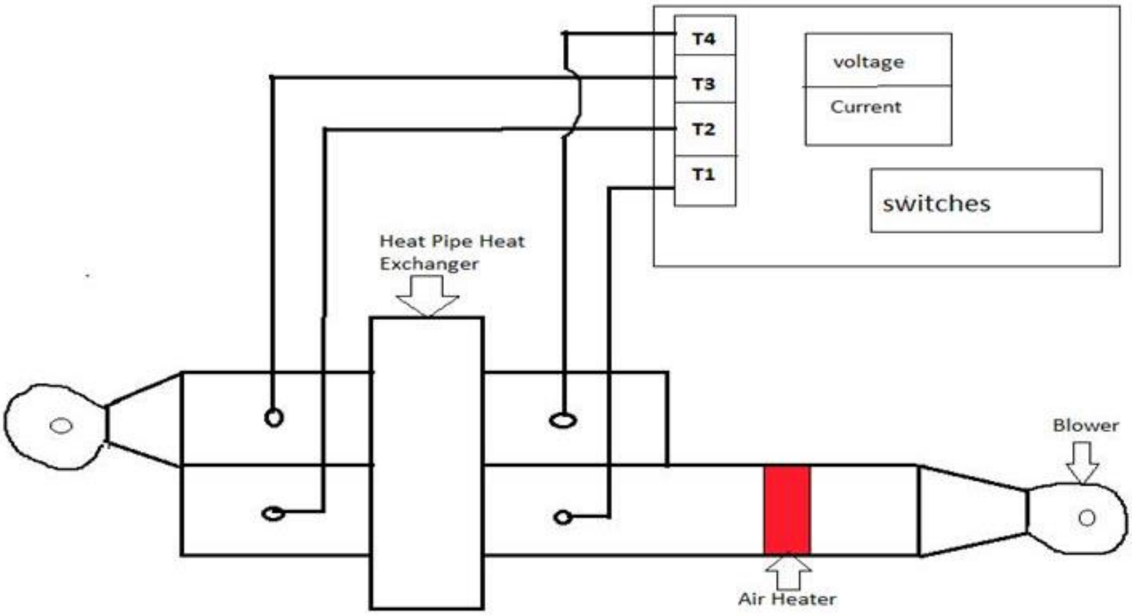

Fig 1: Schematic layout of proposed experimental system

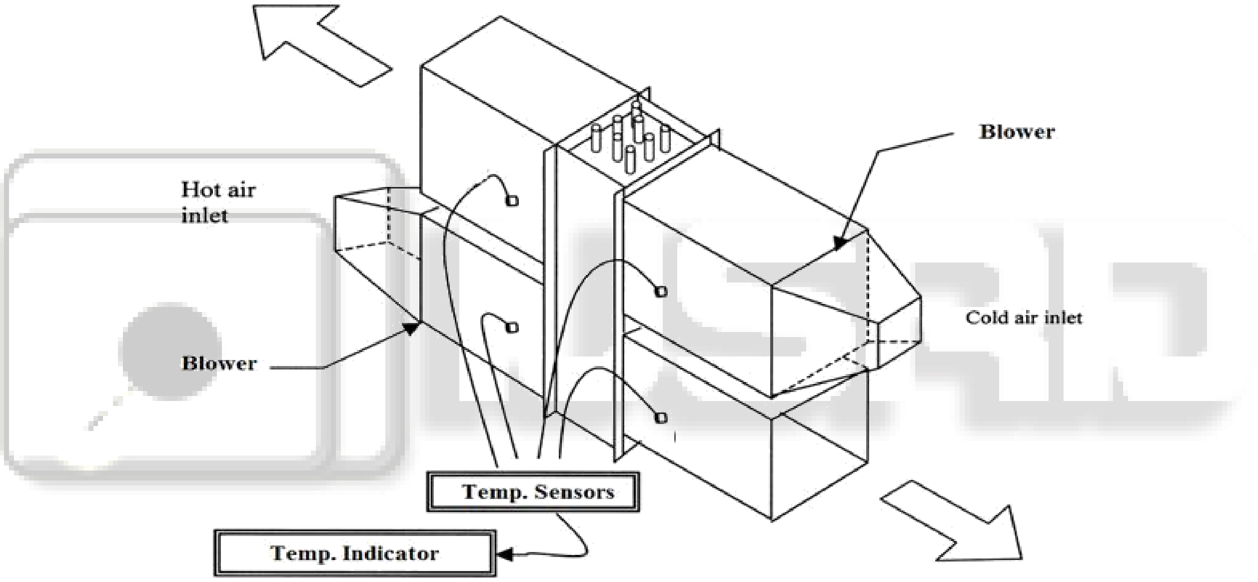

Fig. 2: 3D Representation of Experimental Set Up

IV. DESIGN AND DEVELOPMENT OF HEAT PIPE HEAT EXCHANGER

Heat pipe dimensions is choose as per below table. While designing heat pipe it has to be undergoes under limit checking. Thermal properties of CuO nanofluid are selected from various sources and it is used for calculation heat pipe limit. By using various correlations from literature survey heat flux under various limits is calculated for checking safety of design of heat pipe.

Sr. No	Parameters	Notation	Value	Unit
1	Evaporator Length	L_v	0.275	m
2	Adiabatic Length	L_{add}	0.05	m
3	Condenser Length	L_c	0.275	m
4	Total Length	L_t	0.6	m
5	Effective Length	L_{eff}	0.55	m
6	Inner Radius	r_i	0.007	m
7	Cross Section Area	A	0.0015	m^2
8	Axial Angle	Ø	90	O
9	Thermal Conductivity of Material (Copper)	λ_m	385	W/mk
10	Vapour Core Radius	r_v	0.007	m
11	Evaporative Section Radius	r_e	0.007	m
12	Condenser Section Radius	r_c	0.007	m

13	Nano Particle Volume Fraction	-	0.02	-
14	Density of Nanoparticle (CuO)	ρ_{np}	0.0021	kg/m^3

Table-1: Heat pipe parameters

A. *Heat Pipe Limit Calculation*

Heat pipes undergo various heat transfer limitations depending on the working fluid, the dimensions of the heat pipe, and the heat pipe operational temperature.

1) *Viscous limitation:*

The viscous limit occurs at low operating temperatures, where the saturation vapour pressure may be of the same order of magnitude as the pressure drop required driving the vapour flow in the heat pipe. This results in an insufficient pressure available to drive the vapour. The viscous limit is sometimes called the vapour pressure limit

$$Q_{vp} = \frac{\pi . r_v^4 . h_{fg} . \rho_{v,e} . P_{v,e}}{12 . \mu_{v,e} . l_{eff}} \quad (4.2)$$

2) *Sonic limitation:*

The sonic limit is due to the fact that at low vapour densities, the corresponding mass flow rate in the heat pipe may result in very high vapour velocities, and the occurrence of choked flow in the vapour passage may be possible.

$$Qs = 0.474 A_v . h_{fg} . (\rho_v . P_v)^{0.5} \quad (4.3)$$

3) *Entrainment limitation:*

The entrainment limit refers to the case of high shear forces developed as the vapour passes in the counter flow direction over the liquid saturated wick, where the liquid may be entrained by the vapour and returned to the condenser. This results in insufficient liquid flow of the wick structure.

$$Q_e = A_v . h_{fg} . \left(\frac{\rho_v . \delta_1}{2 . r_{c,ave}}\right)^{0.5} \quad (4.4)$$

4) *Boiling limitation:*

The boiling limit occurs when the applied evaporator heat flux is sufficient to cause nucleate boiling in the evaporator wick. This creates vapor bubbles that partially block the liquid return and can lead to evaporator wick dry out. The boiling limit is sometimes referred to as the heat flux limit.

$$Q_b = \frac{4\pi . l_{eff} . \gamma_{ef} . T_v \sigma_v}{h_{fg} . \rho_v . ln\frac{r_i}{r_e}} \left(\frac{1}{r_n} - \frac{1}{r_{c,e}}\right) \quad (4.5)$$

Temp °C	Sonic Limit kW/m^2	Viscous limit kW/m^2	Entrainment Limit kW/m^2	Boiling Limit kW/m^2
20	0.57	0.5512	0.8549	1.05
40	0.7	0.75	0.8175	1.02
60	0.89	0.96	0.7779	0.95
80	1.1	1.13	0.7353	0.75

Table-2: Heat Pipes Limits for Various Operating Temperatures

It has been noticed that the amount of wattage to be transferred to which heat pipe is designed is below the maximum axial heat flux for variable temperature and thus design of heat pipe were observed to be successful.

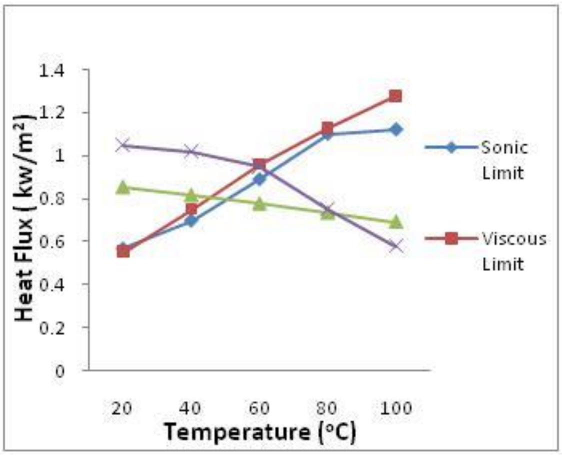

Fig. 3: Heat Pipes Limits for Various Operating Temperatures

V. EXPERIMENTATION

A. *Test Methodology:*

1) In order to investigate the thermal performance of TPCT heat recovery heat exchanger charged with nanofluid under variable source temperature and mass low rate, it has been decided to vary the heat input from 250 to 1000 W in the step of 250 W. The mass flow rate is varied from 100 cfm to 400 cfm in the step of 100 cfm.
2) For a particular heat input the mass flow rate of hot and cold air streams are varied from 100 to 400 cfm as mentioned above.
3) At steady state the hot and cold air stream inlet and outlet temperatures across heat pipe heat exchanger is measured.
4) The corresponding voltmeter and ammeter readings are noted and power supplied to electrical heater is calculated.
5) Air velocity is measured with the help of air vane anemometer.

B. *Test Parameters:*

Experimentation was carried on the TPCT HRHX. Working fluid is important parameter in the experimentation. CuO/H2O nanofluid was used as a working fluid. Other parameters and its description are as follows.

Parameter	**Description**
Heat load (W)	250 W to 1000 W
Source temperature	up to 65 ^{0}C
Mass flow rate (m)	0.0512 to 0.2749 kg/s
Discharge of Blower	100 to 400 cfm
Velocity	1.04 to 5.24 m/s

Table-3: Test Parameters

The heat input, effectiveness of heat exchanger is calculated by the following equations.

$$\text{Heat Input } (Q_{in}) = V \times I \ (W)$$

Where, V= Voltage, I=Current

Effectiveness of heat exchanger = Qactual/ Q max

Heat Exchanger effectiveness

$$(\varepsilon) = \frac{Thi - Tho}{Tco - Tci} \times 100$$

Heat transfer coefficient can be calculated by using equation Q= h A ΔT

VI. RESULT AND DISCUSSION

The experimental performance of heat pipe heat exchanger was experimentally evaluated. Experimentation was carried out to investigate the effect of heat input and mass flow rate of hot and cold air streams on the effectiveness of heat exchanger. On the basis of the observations recorded the effectiveness of heat exchanger for particular heat input and mass flow rate of hot and cold air streams were calculated.

For given heat input with increase in mass flow rate of air the temperature difference decreases. The numerical and graphical variation of the temperature difference is shown in Figure 04.

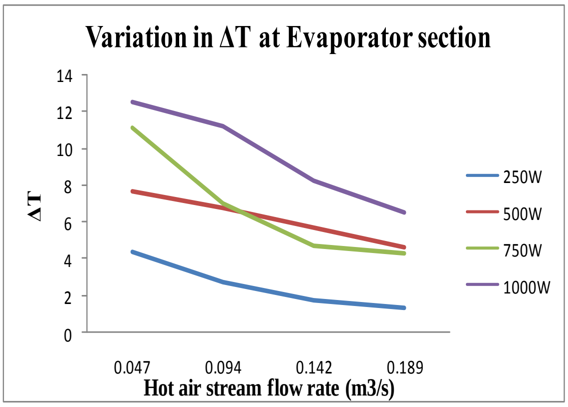

Fig. 4: Variation in ΔT at Evaporator Section

For given heat input with increase in mass flow rate of air the temperature difference decreases. The numerical and graphical variation of the temperature difference is shown in Figure 05.

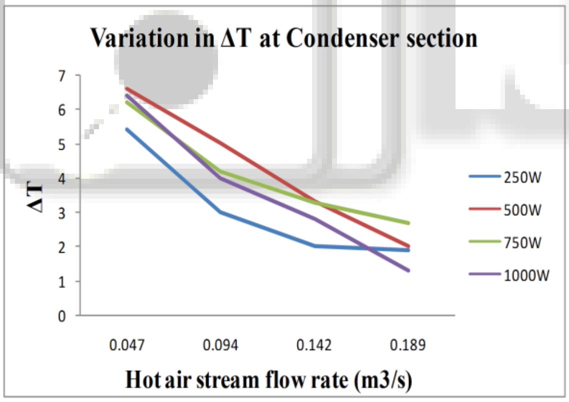

Fig. 5: Variation in ΔT at Condenser Section

Variation in inlet temperature at evaporator section is observed due to the heat input supplied to the fin tube heater with increase in heat input, temperature at inlet of evaporator section increases and Figure 06 shows the variations.

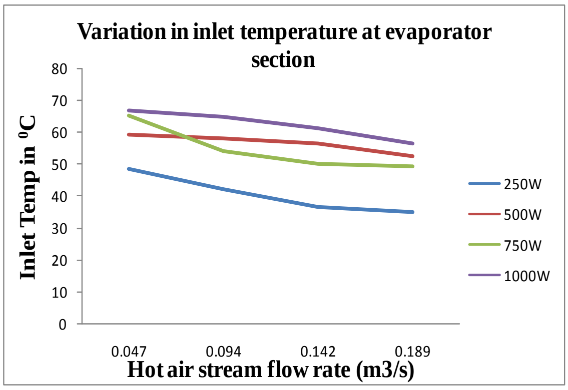

Fig. 6: Variation in Inlet Temperature at Evaporator Section

Variation in outlet temperature of evaporator section is observed due to the absorption of the heat by heat pipe working fluid during the phase change. At evaporator section working fluid absorbs the heat and it gets evaporated. So at the outlet of evaporation section temperature decrease and Figure 07 shows the variations.

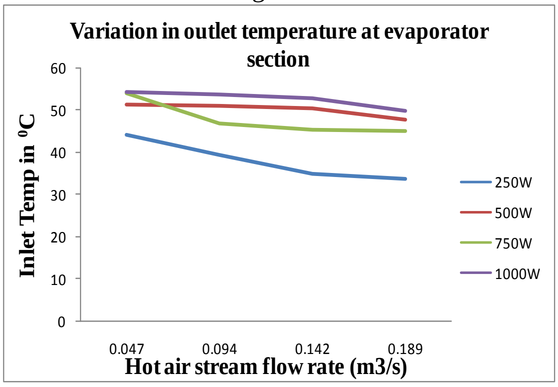

Fig. 7: Variation in Outlet Temperature at Evaporator Section

With increase in heat input the temperature at the outlet of condenser section increases. Figure 08 shows variation in outlet temperature at condenser section.

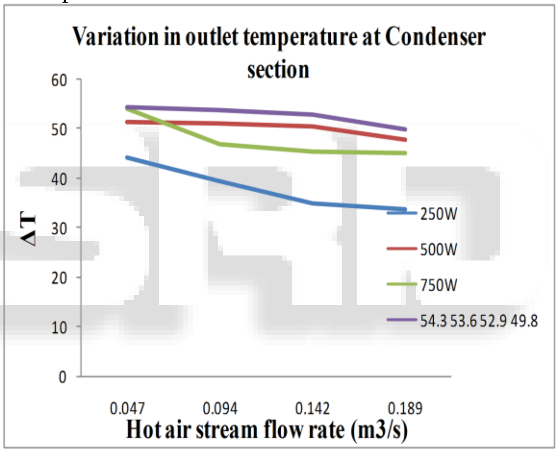

Fig. 8: Variation in Outlet Temperature at Condenser Section

Figure 09 shows the variation in the effectiveness at evaporator section of heat exchanger with variation in heat input. It is observed that the effectiveness of two phase closed thermosyphon charged with nanofluid increases with increase in heat input for a particular air stream flow.

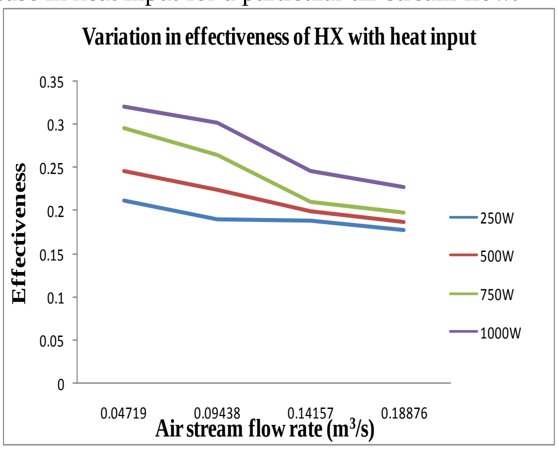

Fig. 9: Variation in Effectiveness of HX with Heat Input

Figure 10 shows the variation in the effectiveness of heat exchanger at condenser section with variation in heat input. It is observed that the effectiveness of two phase closed thermosyphon charged with nanofluid increases with increase in heat input for a particular air stream flow.

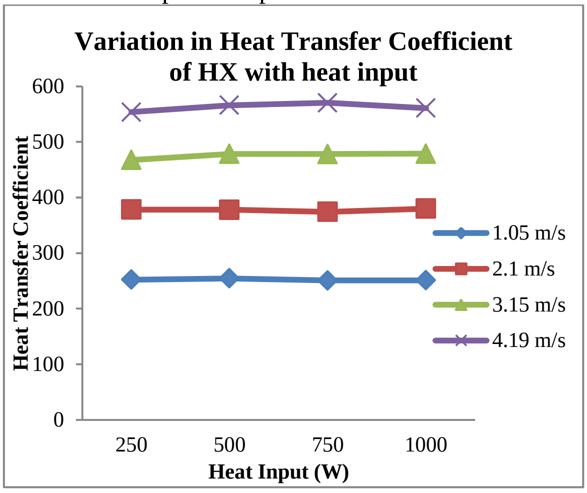

Fig. 10: Variation in Heat Transfer Coefficient of HX with Heat Input

Figure 11 shows the variation in the Nusselt Number at evaporator section of heat exchanger with variation in heat input. It is observed that the effectiveness of two phase closed thermosyphon charged with nanofluid increases with increase in heat input for a particular air stream flow.

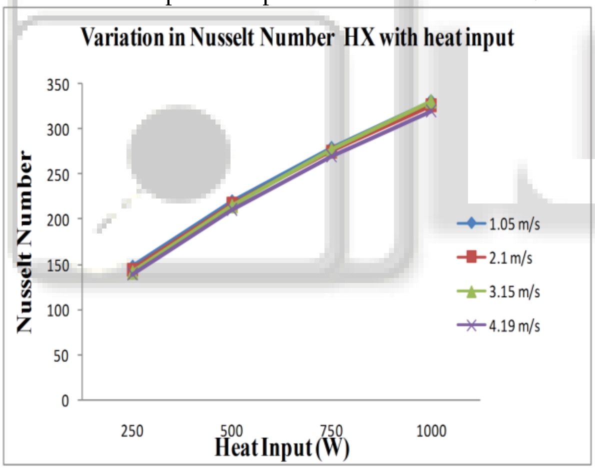

Fig. 11: Variation in Nusselt Number of HX with Heat Input

VII. CONCLUSION

The experimental investigation was carried out on two phase closed thermosyphon heat pipe heat exchanger charged with CuO/H20 nanofluid. The effect of source temperature and mass flow rate of hot and cold air streams on effectiveness of nanofluid charged TPCT heat exchanger was experimentally investigated. The heat input to finned tube air heater was varied from 250 W to 1000 W and hot and cold air stream flow rate varied from 0.04719 m^3/s to 0.236 m^3/s. The effect of variation in source temperature and mass flow rate of hot and cold air streams on effectiveness of heat exchanger was experimentally studied. The heat pipes used in heat exchanger was specially designed for heat recovery application. Conclusions from studied experiment are as follows,

1) The performance of heat pipe heat exchanger charged with CuO/H20 nanofluid increases with increase in source temperature.
2) Maximum effectiveness observed for proposed heat pipe heat exchanger is up to 0.32.
3) The results obtained for TPCT heat exchanger charged CuO/H20 nanofluid are superior with that of TPCT charged with conventional fluid.
4) Enhancement in effectiveness of heat exchanger for current study is about 35% compared with the available literature.
5) Improvement in effectiveness of two phase closed thermosyphon heat exchanger charged with nanofluid is due to thermal conductivity enhancement of nanofluid.
6) TPCT heat recovery heat pipe heat exchanger can be suitably employed for heat recovery from low source temperature.

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