EXPERIMENTAL INVESTIGATION OF HYBRID NANOFLUID ON THERMOSYPHON TYPE WICKLESS HEAT PIPE HEAT EXCHANGER THERMAL PERFORMANCE

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ABSTRACT

Waste heat is heat which is produced in a process by way of fuel combustion or chemical reaction, and then dumped into the environment even though it can be still be reused for some useful and economic purpose. The essential quality of heat is not the amount instead of its value. The strategy of how to recover this heat depends in part on the temperature of the waste heat gases and the economics involved. Direct and indirect benefits are involved in heat recovery. Recovery of waste heat has a direct effect on the efficiency of the process and indirect benefits involve reduction in pollution, equipment size and auxiliary air consumption.

This paper focuses on investigation of thermal performance of wickless heat pipe heat exchanger by using hybrid nanofluid (CuO+CNT/H_20) as a working fluid. Hybrid nano fluid of 2% volume concentration with 75% of copper oxide (CuO) and 25% of carbon nano tube (CNT) was prepared. Several studies have performed on heat pipe heat exchanger using conventional fluids and nanofluids. Effectiveness of heat pipe heat exchanger charged with hybrid nanofluid will be compared with heat pipe heat exchanger effectiveness charged with conventional fluid.

Keywords: *Weak less Heat Pipe, Heat Pipe heat exchanger, Thermal performance, Hybrid nanofluid, CuO+CNT/H_20, Effectiveness.*

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1. INTRODUCTION

With increasing trend of energy demand, there are a lot of concerns over energy supply and it is a major issue for the policy makers. Universally, buildings consume about 40% of the total world annual energy consumption and most of this energy can be used for the purpose of heating, ventilation & air conditioning (HVAC) system. Therefore, Engineers and scientists try to find alternate energy recovery technologies to enhance the performance in terms of air quality and energy utilization level. Furthermore, increasing awareness of the environmental impact of CFC refrigerants, make the engineers to adopt environmentally friendly energy recovery technologies. Most of heat is wasted in many of the outputs like industrial, automobiles etc. There are many types of energy recovery system, but most commonly used are rotating wheels, plates, heat pipes & run around loops. This experiment considers the thermal design & the experimental testing of a heat pipe (Thermosyphon) heat exchanger for a relatively small commercially available waste heat. The purpose of the heat exchanger is to recover maximum heat from moist waste air stream to preheat the fresh incoming air. A significant amount of waste heat exhausted through the exhaust ducts of commercials & industrials exhausts.

Capturing the energy in that waste heat represents rich potentials for energy savings. The heat pipe heat exchanger heat recovery system is cost effective to install and operate could potentially recover wasted heat economically and be an effective addition to utility CIPs. This project was undertaken to design, develop, install and measure the effectiveness of a heat recovery system at a small temperature range. The design concept was to capture waste heat from exhaust duct and use that heat for the fresh air supply. The limiting factor against increasing the heat transfer performance of heat pipe depends on the working properties of the working fluid. The enhancement of liquid thermal conductivity is achieved by adding highly conductive solid hybrid nanoparticles inside the base fluid. The special characteristics of the nanofluid shows increment in the heat transfer coefficient, thermal conductivity and liquid viscosity.

1.1 Need of waste heat recovery

Waste heat is heat, which is generated in a process by way of fuel combustion or chemical reaction, and then dumped into the environment even though it could still be reused for some useful and economic purpose. The essential quality of heat is not the amount but rather its value. The strategy of how to recover this heat depends in part on the temperature of the waste heat gases and the economics involved. Direct and indirect benefits are involved in heat recovery. Recovery of waste heat has a direct effect on the efficiency of the process and indirect benefits involve reduction in pollution, equipment size and auxiliary air consumption.

Large quantity of hot flue gases is generated from Boilers, Kilns, Ovens and Furnaces. If some of this waste heat could be recovered, a considerable amount of primary fuel could be saved. The energy lost in waste gases cannot be fully recovered. However, much of the heat could be recovered and loss minimized. Depending upon the type of process, waste heat can be rejected at virtually any temperature from that of chilled cooling water to high temperature waste gases from an industrial furnace or kiln. Usually higher the temperature, higher the quality and more cost effective is the heat recovery. In any study of waste heat recovery, it is absolutely necessary that there should be some use for the recovered heat. Typical examples of use would be preheating of combustion air, space heating, or pre-heating boiler feed water or process water. With high temperature heat recovery, a cascade system of waste heat recovery may be practiced to ensure that the maximum amount of heat is recovered at the highest potential. An example of this technique of waste heat recovery would be where the high temperature stage was used for air pre-heating and the low temperature stage used for process feed water heating or steam raising.

1.2 Literature Review

Lerchai Yodraket 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.

S.H. Noie-Baghbanet 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 ± 55^0C) 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. Experimentation on heat pipe heat exchanger charged with conventional fluids like water, methanol & acetone shows Effectiveness of 0.16.

Zhang et al. [3] conducted a study on a thermodynamic model built with an air moisture removal system incorporated a membrane-based total heat exchanger to estimate the energy use annually. The outcomes suggested that the independent air moisture removal could save 33% of primary energy.

Wasim saman et al. [4] 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 thermosyphons 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 thermosyphons. 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 thermosyphons. 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.

Yau and Tucker et al. [5] mentioned that for many years, heat pipe heat exchangers (HPHEs) with two-phase closed thermosyphons, and have 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.

M.G.Mousa [6] 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. [7] 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 confirmed that the use of Cu–water nanofluids in the heat pipe could enhance the maximum heat removal capacity by 83%. It was confirmed 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.

1.3 Concluding Remark from literature review

1. Heat pipe heat exchangers are suitable for energy recovery, reduction of air pollution and environmental conservation
2. Heat pipe heat exchanger can be successfully employed to recover the exhaust heat from restaurant, surgery room etc.
3. Heat pipe heat exchanger with staggered arrangement is superior heat recovery technology for low temperature source applications.
4. Parameters affecting the performance of heat pipe heat exchanger are flow rate, exhaust gas temperature, flow condition, environmental conditions, working fluid in heat pipe, filling ratio and geometrical properties of heat pipe, arrangement of heat pipe in heat exchanger etc.
5. Nanofluid as working fluid in heat pipe, found to be suitable candidate for enhancement of heat transfer in heat pipe heat exchanger.
6. This review gives an idea that performance augmentation of heat pipe heat exchanger with hybrid nanofluid as working fluid can be suitably employed in heat recovery applications.

1.4 Objectives

Planned objectives to study performance of heat recovery wickless heat pipe (TPCT) heat exchanger charged using hybrid nanofluid,

1.With the avability of literature study on thermosyphon and waste heat recovery systems finding the possibility of introducing a heat pipe heat exchanger charges with hybrid nanofluid (CuO & CNT/H_2O).
2.To design a thermosyphon type wickless heat pipe heat exchanger charged with 2 % volume concentration of hybrid nanofluid.
3.To analyze effect of variable source temperature and mass flow rate on effectiveness of heat exchanger.
4. To analyze the effect of variation in source temperature and mass flow rate of air on convective heat transfer coefficient.
5.To analyze the effect of variation in source temperature and mass flow rate of exhaust gas on Nusselt number.
6.To compare the effectiveness of heat pipe heat exchanger charged with hybrid nanofluid to that of heat pipe heat exchanger charged with conventional fluid available from literature.

2. Experimental Setup

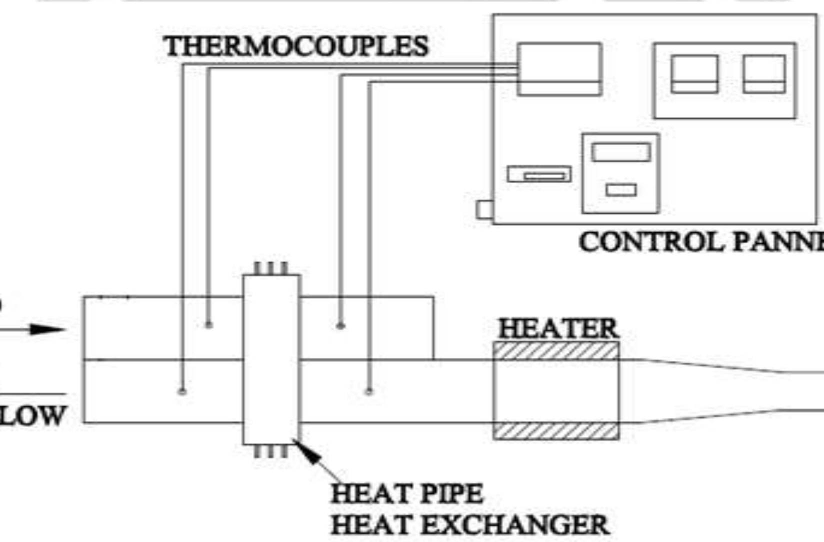

Fig.2.1. Experimental Setup

Heat pipe heat exchangers are devices that made the exchange of waste heat from a waste heat source to a colder source. Figure 2.1 shows the experimental layout of the test apparatus. The system is composed of three major parts: air heater (for waste air preparation), heat pipe heat exchanger and devices for measurement and control of parameters. In the installation there are two circulating fluids: the waste air in the lower chamber of the heat exchanger and the cold air in the upper chamber of the heat exchanger.

2.1 Test Methodology

Experiments are conducted to investigate Performance of heat recovery heat pipe heat exchanger by using hybrid nanofluid with variable source temperature. The heat is generated within the variable temperature source. An arrangement was made to measure and vary the heat input with the help of transformer, voltmeter and ammeter. The hot and cold air temperatures are measured with the help of RTD's mounted at different locations of ducts. Four RTD's are to be fixed inside of ducts at inlet and outlet of hot and cold air in order to measure temperature.

Fig.2.2 Actual Working Setup

Four thermocouples are used to measure temperatures of air on cold and hot side of heat pipe heat exchanger.

Effectiveness of heat pipe heat exchanger at any heat load and mass flow rate can be calculated as,

$$\text{Effectiveness, } \varepsilon = \frac{\text{Actual heat transfer}}{\text{Max.possible heat transfer}}$$

$$= \frac{\mathrm{m}\times C_p \times (\mathrm{T_{hi}} - \mathrm{T_{ho}})}{\mathrm{m}\times C_p \times (\mathrm{T_{hi}} - \mathrm{T_{ci}})}$$

Where,
m= mass flow rate of air in kg/s
C_p =Specific heat at constant pressure in kJ/kg-K
$\mathrm{T_{hi}}$ =Inlet temperature of air before heat exchanger in evaporator section in °C
$\mathrm{T_{ho}}$ = Outlet temperature of air after heat exchanger in evaporator section in °C
$\mathrm{T_{ci}}$ = Inlet temperature of air before heat exchanger in condenser section in °C

Test setup consists of two ducts or sections i.e. lower section is evaporator section where air heated by heater is flows over heat pipes arranged in series and upper section is condenser section where cold air flows over heat pipe and heat pipe gives away its heat to air. Hence we will get hot air at the exit of condenser section. The mass flow rate of air is control by blower provided at inlet of each section. Heat input to heater is varied from 250W to 1500 W in the step of 250W using 1500 W heater. Mass flow rate of air is varied from 100 cfm to 500 cfm at each heat load that gives us various values of effectiveness at each mass flow rate and heat loads. For measuring effectiveness of heat exchanger mass flow rate of air is maintain constant at both evaporator and condenser section. Temperature of air at inlet and exit of evaporator and condenser temperature were measured and with the availability of mass flow rate and temperature of air we can easily find out effectiveness of heat exchanger.

3. HEAT LOAD CALCULATION

While designing the heat pipe heat exchanger, we have to calculate the total heat load for proposed heat pipe heat exchanger. From lietureture available, Amount of heat required to raise temperature from 25°C to 30°C with proposed mass flow rate of air is 0.12 kg/sec. The heat load on heat exchanger can be calculated as follows,

Heat Load (Q) = m.C_p.ΔT …………………………… (1)

Where, m= mass flow rate of air in kg/s
C_p= specific heat at constant pressure kJ/kg-k
ΔT= difference in temperature of air in evaporator section in °C

= 0.12 X 1000 X (30-25)

Q= 600 W. Heat load on 8 heat pipes.

Assuming 10% loss in duct of total heat generated.
Therefore, Q=600+60=660W

Heat Load on Single Heat Pipe ($Q_{\text{Heat Pipe}}$)

$$= \frac{Total\ Heat\ Load\ On\ Heat\ Exchanger}{No.of\ \ Heat\ Pipe}$$

$$= \frac{660}{8}$$

= 82.5 W heat load on single heat pipe

3.1 Design Procedure for Proposed Heat Pipe

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

3.1.1 Viscous limitation-

Viscous limit depends on the viscous pressure losses in vapor phase and the vapor pressure of the working fluid. The viscous limit is sometimes called the vapor pressure limit [2]

$$\mathrm{Q_{vp}} = \frac{\pi.\mathrm{r_v^4}.\mathrm{h_{fg}}.\rho_{\mathrm{v,e}}.\mathrm{P_{v,e}}}{12.\mu_{\mathrm{v,e}}.\mathrm{l_{eff}}} \dots\dots\dots\dots\dots..(2)$$

3.1.2 Sonic limitation-

The sonic limit is due to the fact that at low vapor densities, the corresponding mass flow rate in the heat pipe may result in very high vapor velocities, and the occurrence of choked flow in the vapor passage may be possible [2]

$$\mathrm{Qs} = 0.474\mathrm{A_v}.\mathrm{h_{fg}}.(\rho_{\mathrm{v}}.\mathrm{P_v})^{0.5} \dots\dots\dots\dots\dots..(3)$$

3.1.3 Entrainment limitation-

The entrainment limit refers to the case of high shear forces developed as the vapor passes in the counter flow direction over the liquid saturated wick, where the liquid may be entrained by the vapor and returned to the condenser. This results in insufficient liquid flow of the wick structure [2]

$$\mathrm{Q_e} = \mathrm{A_v}.\mathrm{h_{fg}}.(\frac{\rho_{\mathrm{v}}.\delta_1}{2.\mathrm{r_{c,ave}}})^{0.5} \dots\dots\dots\dots\dots\dots..(4)$$

3.1.4 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 [2]

$$\mathrm{Q_b} = \frac{4\pi.\mathrm{l_{eff}}.\gamma_{\mathrm{ef}}.\mathrm{T_v}\sigma_{\mathrm{v}}}{\mathrm{h_{fg}}.\rho_{\mathrm{v}}.\ln\frac{\mathrm{r_i}}{\mathrm{r_e}}}\left(\frac{1}{\mathrm{r_n}} - \frac{1}{\mathrm{r_{c,e}}}\right) \dots\dots\dots\dots\dots (5)$$

3.1.5 Various heat pipe limits-

The various heat pipe limits calculated considering the operating temperature and parameters related to heat table 01. For heat pipe parameters mentioned above the axial heat flux under variable operating temperatures are calculated for different mentioned above i.e. viscous limit, boiling limit, entrainment limit and sonic limit.

Table 3.1 Various limits of heat pipe

Temp(°C)	Sonic Limit (Watt)	Viscous limit (Watt)	Entrainment Limit (Watt)	Boiling Limit (Watt)
20	103.41	92.09	111.01	132.45
30	182.90	119.89	106.87	125.65
40	308.69	186.49	102.19	121.10
50	500.98	453.16	97.25	106.84
60	783.92	1111.27	91.92	94.32
70	1190.5	2049.01	86.66	89.32

4. Results and Discussion

4.1 Effectiveness Vs. Mass flow rate

Fig.4.1 shows as air velocity increase for given heat load, effectiveness of heat pipe heat exchanger decreases. The minimum effectiveness obtained from experimental result is 0.21, which is higher than the effectiveness of heat pipe heat exchanger charged with conventional fluid which is 0.16, available from literature survey.

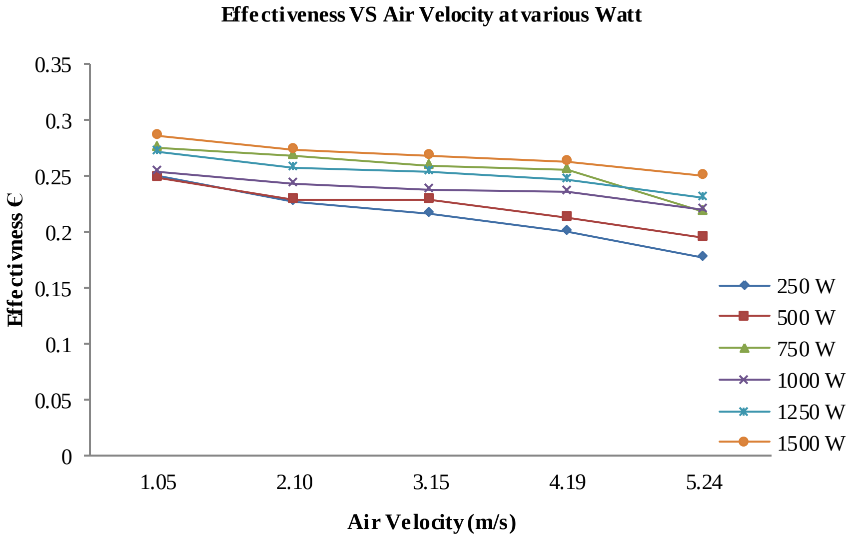

Fig.4.1. Effect of variation in air velocity at different heat load on effectiveness of heat exchanger

4.2 Convective heat transfer coe. (h) Vs. air velocity at evaporator section

Fig. 4.2 shows as mass flow rate and heat load increases convective heat transfer coefficient also increases. This is due to increase in heat transfer rate between heat pipe and surrounding air.

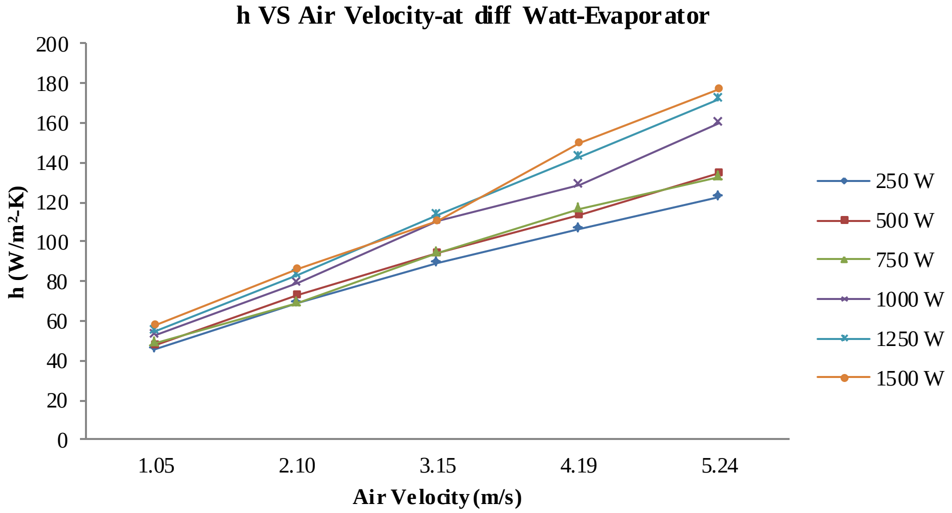

Fig 4.2 Effect of Variation of air velocity in evaporator section at different heat loads on convective heat transfer coefficient

4.3 Convective heat transfer coe. (h) Vs. air velocity at condenser section

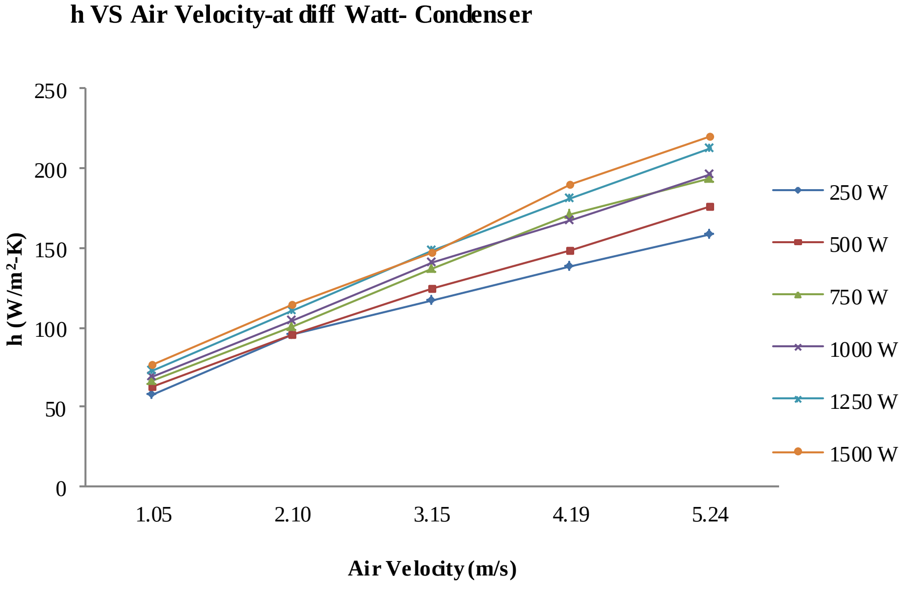

Fig 4.3 Effect of Variation of air velocity in condenser section at different heat loads on convective heat transfer coefficient

4.4 Nusselt Number (Nu) vs. air velocity at evaporator section

Fig. 4.4 shows as mass flow rate and heat load increases Nusselt number also increases. This is due to increase Reynolds number. Because at low air velocity Reynolds number is less and hence Nusselt number is also less. As velocity increases Reynolds number and Nusselt number also increases.

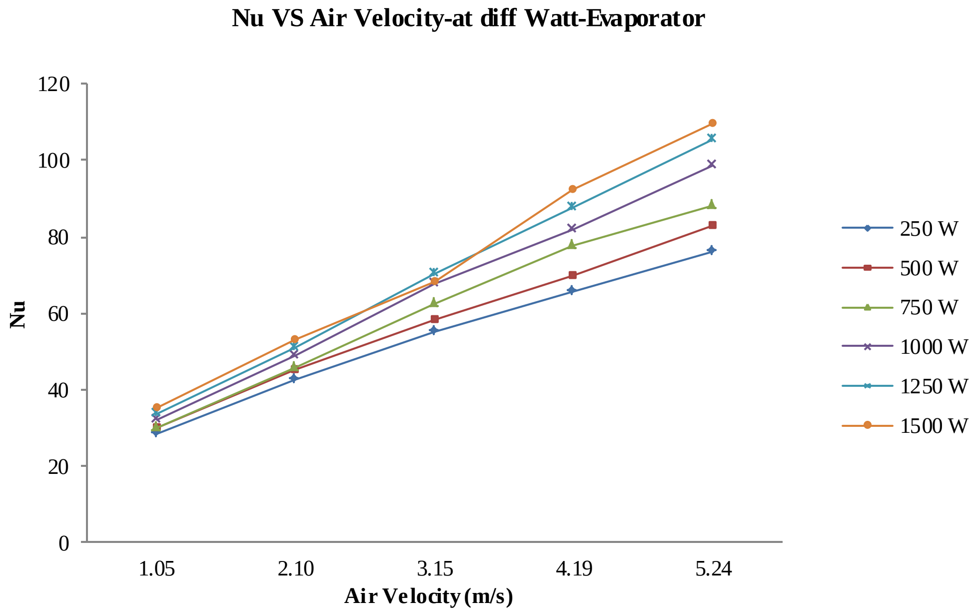

Fig.4.4. Effect of variation in air velocity on Nusselt Number at evaporator section

4.5 Nusselt Number (Nu) vs. air velocity at condenser section

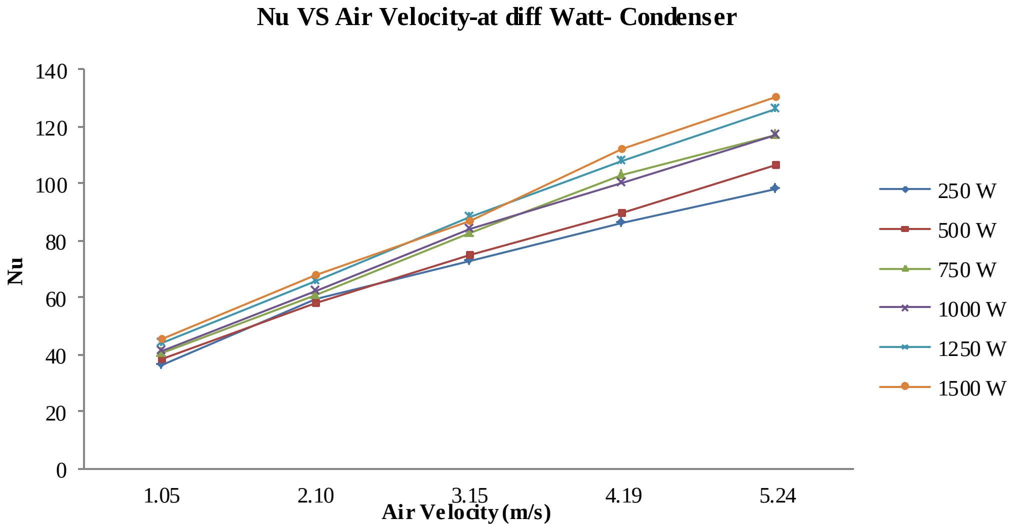

Fig 4.5 Effect of variation in air velocity on Nusselt Number at condenser section

5. CONCLUSION

In this study heat recovery by using heat pipe heat exchanger characteristics was investigated experimentally. The effect of variation in heat input and mass flow rate on various parameters has been investigated.

The following conclusions were drawn from this study.

1. Nusselt number of heat pipe heat exchanger increases as air velocity increases. Nusselt number ranges between 28.3 to 75.9 and 36.2 to 96.4 for condenser and evaporator section respectively
2. Heat transfer coefficient of heat pipe heat exchanger increases as air velocity increases. Heat transfer coefficient ranges between 45.9 to 123.5 and 58.1 to 158.1 for condenser and evaporator section respectively.
3. Nusselt number of heat pipe heat exchanger increases as heat input increases and hence it indicates more active convection.
4. Heat transfer coefficient of heat pipe heat exchanger increases as heat input increases.
5. Effectiveness of heat pipe heat exchanger decreases as air velocity increases. Effectiveness ranges in between 0.19 to 0.29.
6. Maximum effectiveness of heat pipe heat exchanger charged with conventional fluids like water methanol and acetone fluid is 0.16, which is less than effectiveness of heat pipe heat exchanger charged with hybrid (CuO+CNT/$H_2$0) nano fluid.
7. TPCT heat recovery heat pipe heat exchanger can be suitably employed for heat recovery from low source temperature.
8. Effectiveness of heat pipe heat exchanger decreases as heat input increases.
   Performance of HPHE charged with hybrid nanofluid gives better results than HPHE charged with conventional fluid

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