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Waste heat recovery using nanofluid charged heat pipe heat exchanger (HPHE) for variable Source

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ABSTRACT

To meet the increasing world demand for energy, the rate of depletion of non-renewable energy sources must be reduced. 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. Nevertheless, efforts to recycle this waste energy could result insignificant energy savings.The objective of this research was to develop a heat pipe heat exchanger charged with nanofluid for effective waste heat recovery. The advantage of the system proposed in this work is that, it provides more useful energy transfer during simultaneous flow of cold supply and warm drain air. Superior heat transport properties of nanofluid were effectively utilized in two phase closed thermosyphon (TPCT) heat pipe heat exchanger to obtain efficient heat exchange between two air streams.Experiments were carried out to determine the effect of mass flow rate of air and variable source temperature on effectiveness, evaporator and condenser side heat transfer coefficient of a heat pipe heat exchanger charged with nanofluid. By replacing the conventional fluid in heat pipe with boron nitrate water based (BN/H20) nanofluid (2% volume fraction) of the heat pipe heat exchanger good performance can be obtained. The maximum effectiveness obtained for proposed TPCT BN/H20 charged nanofluid heat exchanger is 0.28 (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 two phase closed thermosyphon heat pipe heat exchanger exhibits same pattern as that of conventional working fluid. The maximum enhancement in effectiveness obtained is 38%.Thus the nanofluid as working fluid in TPCT enhances the effectiveness of heat exchanger.

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I. Introduction

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.Low temperature waste heat recovery faces challenges due to the relatively small temperature difference between the higher energy exhaust gas and the lower temperature heat sink. This forces a heat exchanger with a large surface area to be implemented, which will not only require more space in the gas flow stream but have a higher initial cost to the customer. Another challenge in recovering the low temperature waste heat energy is finding a feasible use for the recovered energy.This work aim to investigate of thermal performance of waste heat recovery Two Phase Closed Thermosyphon (TPCT) heat exchanger charged with BN/H20 Nanofluid under variable source temperatures and mass flow rate. With broad perspective this study aims to investigate the feasibility of TPCT HRHX from low temperature waste heat source.

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

1.To implement a thorough literature study on thermosyphon and waste heat recovery systems, and explore the possibility of introducing a TPCT heat exchanger charges with nanofluid for the development of waste air heat recovery.

2. To design a wickless heat pipe heat exchanger charged with nanofluid and carry out a series of experiments which will lead to a full understanding of TPCT heat exchanger performance.

3. To investigate effect of variable source temperature on effectiveness of proposed heat exchanger under turbuent flow. To choose a different source temperature of waste heat recovery system which has a representative hot air usage pattern to which proposed TPCT HRHX might be applied for practical use. Some typical field data will be collected for further thermosyphon heat exchanger development.

4. To evaluate effect of variable mass flow rate on performance of proposed heat exchanger chrged with nanofluid.

II. LITERATURE REVIEW

F. Yang et al. studied the feasibility of using heat pipe heat exchangers for heating applying automotive exhaust gas. Practical heat pipe heat exchanger was set up for heating a large bus. Simple experiments were carried out to examine the performance of the heat exchanger. It was shown that the experimental results, which indicate the benefit of exhaust gas heating, are in good agreement with numerical results.Rittidech et al. stated that CEOHP airpreheater design employed cooper tubes: thirty –two set of capillary tubes with an inner diameter of 0.002 m, an evaporator and a condenser length of 0.19 m, and each of which has eight meandering turns. The evaporator section was heated by hot-gas, while the condenser section was cooled by fresh air. In the experiment, the hot-gas temperature was 60,70 or 80 0C with the hot-gas velocity of 3.3 m/s. The fresh air temperature was 30 0C. Water and R123 was used as the working fluid with a filling ratio of 50%. It was found that, as the hot-gas temperature increases from 60 to 80 0C, the thermal effectiveness slightly increases. If the working fluid changes from water to R123, the thermal effectiveness slightly increases. The designed CEOHP air-preheater achieves energy thrift.

Jie Yi et al. carried out an experimental study for the heat transfer characteristics and the flow patterns of the evaporator section using small diameter coiled pipes in a looped heat pipe (LHP) by Two coiled pipes: the glass pipe and the stainless steel pipes were used as evaporator section in the LHP, respectively. Flow and heat transfer characteristics in the coiled tubes of the evaporator section were investigated under the different filling ratios and heat fluxes. The experimental results show that the combined effect of the evaporation of the thin liquid film, the disturbance caused by pulsation and the secondary flow enhanced greatly the heat transfer and the critical heat flux of the evaporator section.Wangnipparnto et al. investigated a numerical method to analyse the thermosyphon heat exchanger with and without the presence of electro hydrodynamics. The proposed model was capable of handling both balanced and unbalanced thermosyphon heat exchangers. For the balanced thermosyphon heat exchanger, the calculated results of heat transfer rate for water and R-134a agreed well with experimental data. For the unbalanced thermosyphon heat exchangers, it was found that the performance improvement increased with the ratio of Me/Mc when electro hydrodynamics was applied at the condenser alone.

M.G.Mousa et al. carried out an experimental study on an effect of nanofluid in Circular Heat Pipe. The nanofluid consisted of Al2O3 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 of the nanofluid increasing, then the thermal resistance of heat pipe decreased.

Shang et al. 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.

S. Kang et al. carried out an experimental study ofnanofluid is employed as the working medium for a conventional 211 lm wide 217 lm deep grooved circular heat pipe. The nanofluid used in this study is an aqueous solution of 35 nm diameter silver nanoparticles. The experiment was performed to measure the temperature distribution and to compare the heat pipe thermal resistance using nanofluid and DI-water. The tested nanoparticle concentrations ranged from 1 mg/l to 100 mg/l. The condenser section of the heat pipe was attached to a heat sink that was cooled by water supplied from a constant-temperature bath maintained at 40 0C. At a same charge volume, the measured nanofluid filled heat pipe temperature distribution demonstrated that the thermal resistance decreased 10–80% compared to DI-water at an input power of30–60 W. The measured results also show that thermal resistances of the heat pipe decrease as the silver nanoparticle size and concentration increase.

Yulong Ji et al. carried out an experimental study on an effect of Al_2O_3 particle on the heat transfer performance of an oscillating heat pipe Water was used as the base fluid for the OHP. Four size particles with average diameters of 50 nm, 80 nm, 2.2 lm, and 20 lm were studied, respectively. Experimental results show that the Al_2O_3 added in the OHP significantly affect the heat transfer performance and it depends on the particle size. As the particle size becomes smaller from 20 lm to 80 nm, the heat transport capability increases or the thermal resistance decreases, But if the particle size further decreases less than 50 nm, the thermal resistance cannot be further reduced. This means there exists an optimal particle size for the maximum heat transport capability. Among four particles of 20 lm, 2.2 lm, 80 nm, and 50 nm tested herein, it looks that 80 nm particles can result in the best heat transport capability for the OHP investigated herein.

Senthilkumar R. et al. carried experiment was carried out to study the Effect of Inclination Angle in Heat Pipe Performance Using Copper nanofluid the thermal efficiency enhancement as the working fluid. The average particle size of the copper is 40 nm and the concentration of copper nanoparticle in the nanofluid is 100 mg/lit. The study discusses about the effect of heat pipe inclination, type of working fluid and heat input on the thermal efficiency and thermal resistance. The experimental results are evaluated in terms of its performance metrics and are compared with that of DI water. The result show that if inclination angle increase then thermal efficiency increase and thermal resistance decrease.

III. DESIGN OF SYSTEM

As described earlier proposed work aims to investigate of thermal performance of waste heat recovery Two Phase Closed Thermosyphon (TPCT) heat exchanger charged with BN/H_20 Nanofluid under variable source temperatures and mass flow rate. With broad perspective this study aims to investigate the feasibility of TPCT HRHX 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 with following specifications.

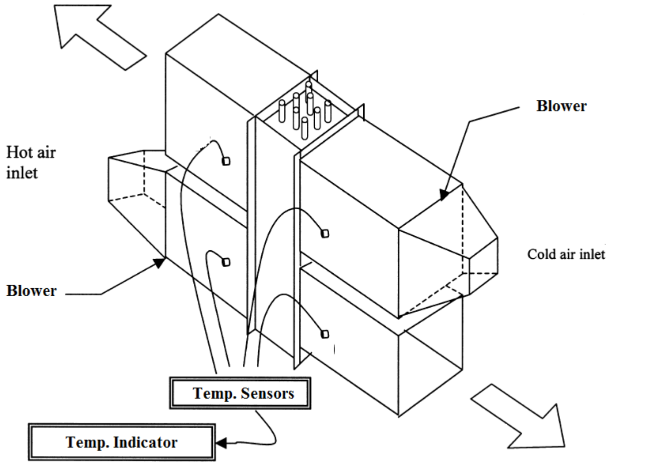

Fig. 1 representation of experimental system.

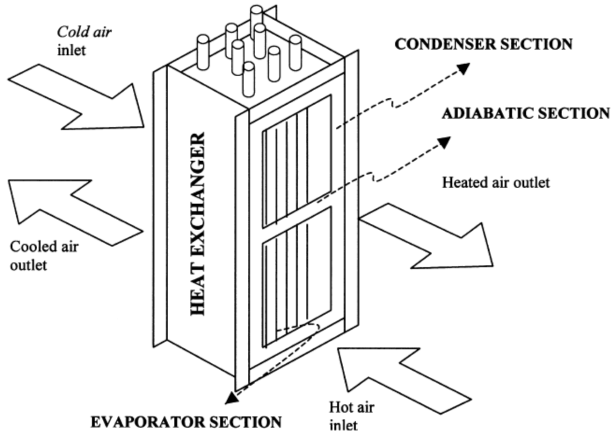

Fig. 2 Schematics of the Heat Pipe Heat Exchanger.

3.1 Specifications of experimental system

3.1.1 Heat Pipe Heat Exchanger

HPHE contains eight individual heat pipes under staggered arrangement and specifications of unit are

- Three rows of heat pipe
- BN/H_20 nanofluid as working fluid (Volume concentration 2% each)
- Hard drawn copper pipes with diameter 15mm
- Equal evaporator and condenser length (300 mm each)
- Overall dimensions HPHX unit are 150 x 600 x 150 mm.

3.1.2 Duct details

- Duct for hot air inlet to HX :- 0.150 (W) x 0.300 (H) x 2 m (L)
- Duct for hot air outlet to HX :- 0.150 x 0.300 x 1 m
- Duct for cold air inlet to HX :- 0.150 x 0.300 x 1 m
- Duct for cold air outlet to HX :- 0.150 x 0.300 x 1 m

3.1.3 Air heater

- Three finned tube air heaters with 500 W capacities each (Total 1500 W)
- Length :-12’’
- 500 W, Single phase AC

3.1.4 Dimmerstat for heater

- 10 A, Single Phase,230 V ,AC

3.1.5 Blower

- Centrifugal blowers (2 Nos.) for hot and cold air supply to HPHX
- Capacity :- 500 CFM
- Pressure head :-50 mm of H20
- 180 W,230 V AC Single Phase,1.5A
- 2880 rpm,50 Hz

3.1.6 Dimmerstat for blower

- A, Single Phase,230V

3.1.7 Temperature Sensor

- PT-100 type
- Range :-0-250 0C
- Length :-160 mm
- Temperature Indicator
- Four channel
- Three and half digit

3.1.8 Digital Ammeter

- Two and half digit
- 0-10 A
- Power required 230 V, AC ,50 Hz

3.1.9 Digital Voltmeter

- Three digit
- 0-1000 V, AC
- Power required 230 V, AC ,50 Hz

3.1.10 Insulating material

- R.B. Slab (Rock wool)

IV. NANOFLUID THERMAL FLOW PROPERTIES

The thermal and flow properties of nanofluid are calculated using different available correlations as below:

Thermal conductivity using Timofeeva correlations as below:

$$K_{nf} = [1 + 3\phi]K_w$$

Viscosity of nanofluid using Drew and Passman correlations as below:

$$\mu_{nf} = [1 + 2.5\phi]\mu_w$$

The density and specific heat using Pak and Cho correlations as below

$$\rho_{nf} = \phi\rho_{np} + (1-\phi)\rho_w$$

$$Cp_{nf} = \phi Cp_{np} + (1-\phi)Cp_w$$

V. DESIGN PROCEDURE FOR 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.

5.1 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

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

5.2 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.

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

5.3 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.

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

5.4 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.

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

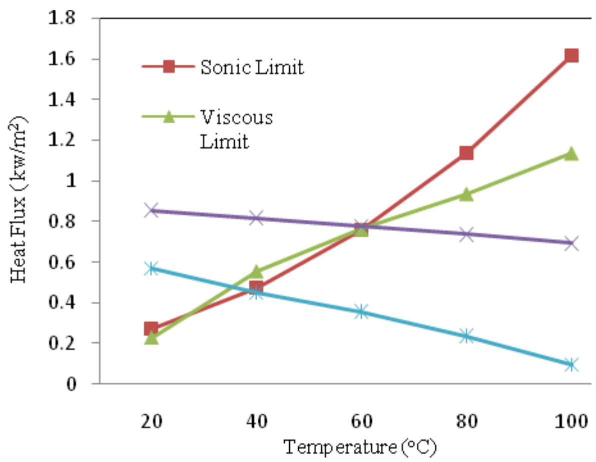

Fig 03 heat Pipe limit Calculation

VI. RESULTS 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 observations recorded the effectiveness of heat exchanger for particular heat input and mass flow rate of hot and cold air streams were calculated. The variation of effectiveness of heat exchanger with heat input i.e. source temperature and mass flow rate of air streams are represented graphically. The effect of mass flow rate on evaporator side temperature drop and condenser side temperature rise also represented graphically.

6.1 Effect of Heat Input on Effectiveness of TPCT Heat ExchangerThe effect of heat input on the performance of TPCT heat exchanger is studied by varying the heat input from 250 W to 1250 W and maintaining the flow rate of air stream from 0.047m^3/s to 0.236 m^3/s as mentioned earlier. The effectiveness of heat exchanger was calculated under conditions mentioned above and results are as follows.

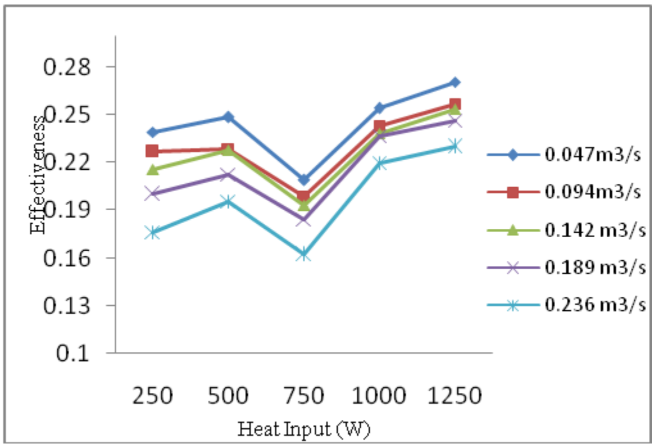

Figure 04 Variation in effectiveness of HX with heat input

Fig. 04 shows the variation in the effectiveness 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.

6.2 Effect of Air Stream Flow Rate on Effectiveness of TPCT Heat Exchanger

Figure 05 shows the variation in effectiveness with air stream flow rate under different heat input. It has been observed that effectiveness of heat exchanger decreases with increase in air stream flow rate of hot side and cold side and Table A13 gives its numerical values.

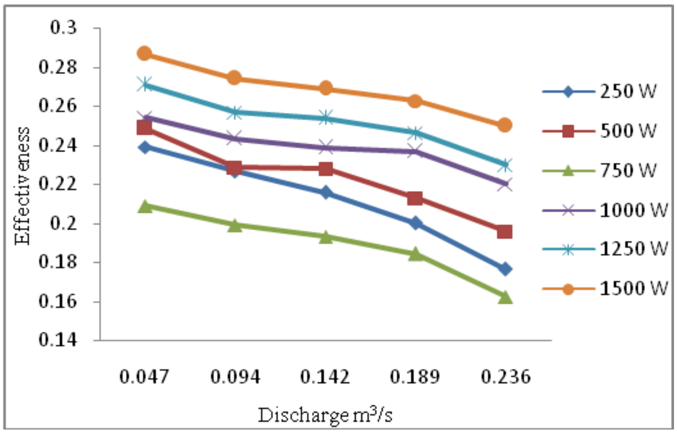

Figure 05 Variation in effectiveness of HX with stream flow rate

6.8 Effect of Heat Input on Heat Transfer Coefficient at Evaporator Section of TPCT Heat Exchanger

The effect of heat input on the heat transfer coefficient at evaporator section of TPCT heat exchanger is studied by varying the heat input from 250 W to 1250 W and maintaining the flow rate of air stream from 0.047 m^3/s to 0.236 m3/s as mentioned earlier. Fig 06 shows effect of heat input on heat transfer coefficient at evaporator section. The heat transfer coefficient at evaporator section of heat exchanger was calculated under conditions mentioned above and results are as follows.

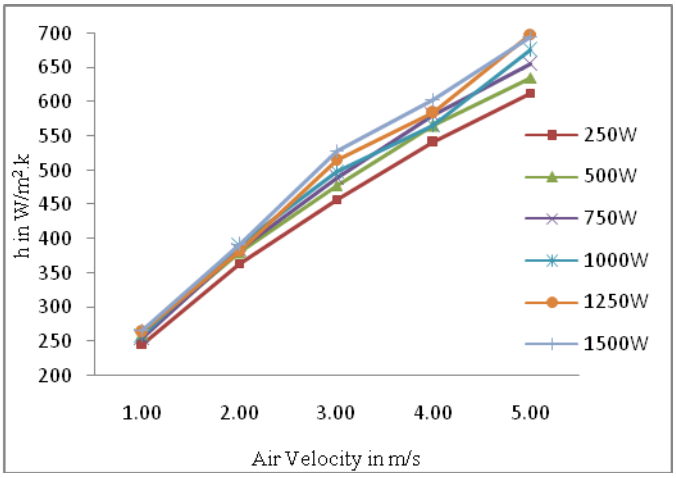

Figure 06 Variation in heat transfer coefficient of HX at evaporator section with heat input

Fig 06 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.

6.9 Effect of Heat Input on Heat Transfer Coefficient at Condenser Section of TPCT Heat Exchanger

The effect of heat input on the heat transfer coefficient at condenser section of TPCT heat exchanger is studied by varying the heat input from 250 W to 1250 W and maintaining the flow rate of air stream from 0.047 m^3/s to 0.236 m^3/s as mentioned earlier. The heat transfer coefficient at condenser section of heat exchanger was calculated under conditions mentioned above and results are as follows,

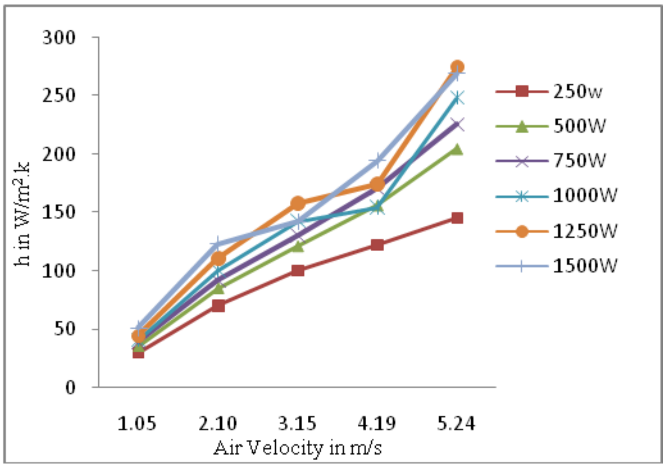

Figure 07 Variation in heat transfer coefficient of HX at condenser section with heat input

Fig 07 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.

6.10 Effect of Heat Input on Nusselt Number at Evaporator Section of TPCT Heat Exchanger

The effect of heat input on the Nusselts Number at evaporator section of TPCT heat exchanger is studied by varying the heat input from 250 W to 1250 W and maintaining the flow rate of air stream fro 0.047 m^3/s to 0.236 m^3/s as mentioned earlier. The Nusselt number at evaporator section of heat exchanger was calculated under conditions mentioned above and results are as follows,

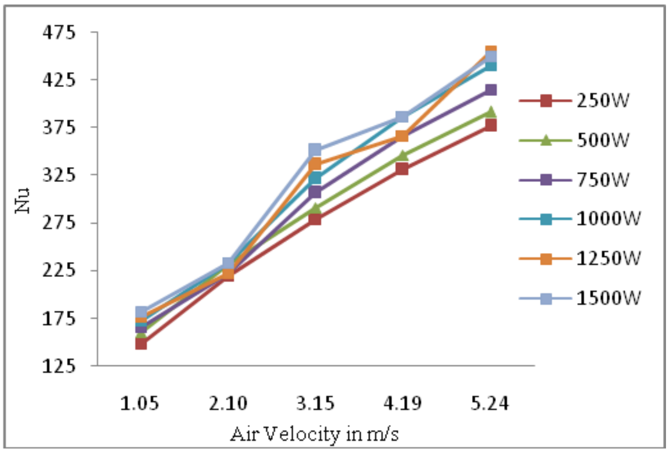

Figure 08 Variation in Nusselt Number of HX at evaporator section with heat input

Fig 08 shows the variation in the Nusselts 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.

6.11 Effect of Heat Input on Nusselt Number at Condenser Section of TPCT Heat Exchanger

The effect of heat input on the Nusselts Number at condenser section of TPCT heat exchanger is studied by varying the heat input from 250 W to 1250 W and maintaining the flow rate of air stream from 0.047 m^3/s to 0.236 m^3/s as mentioned earlier. The Nusselt Number at condenser section was calculated under conditions mentioned above and results are as follows, Figure 6.11 shows the variation.

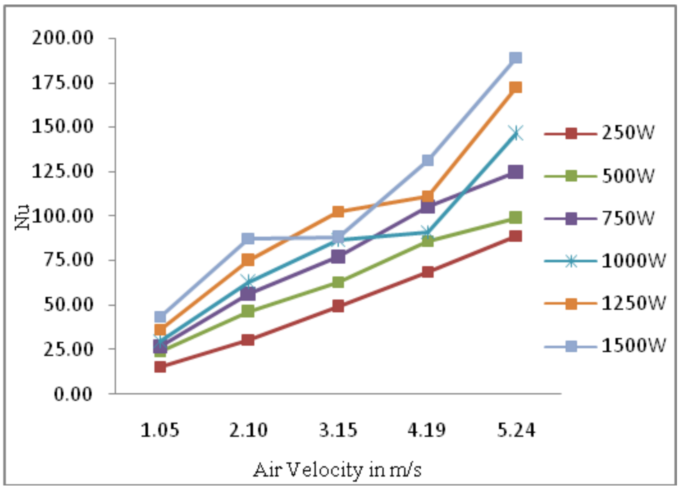

Figure 09 Variation in Nusselt Number of HX at condenser section with heat input

Fig 09 shows the variation in the Nusselt Number at condenser 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.

VII. CONCLUSIONS

The experimental investigation was carried out on two phase closed thermosyphon heat pipe heat exchanger charged with BN/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 1500 W and hot and cold air stream flow rate varied from 0.04719 m^3/s to 0.236 m3/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,

a) The performance of heat pipe heat exchanger charged with BN/H20 nanofluid increases with increase in source temperature.
b) Maximum effectiveness observed for proposed heat pipe heat exchanger is up to 0.28.
c) The results obtained for TPCT heat exchanger charged BN/H20 nanofluid are superior with that of TPCT charged with conventional fluid
d) Enhancement in effectiveness of heat exchanger for current study is about 35% compared with the available literature.

e) Improvement in effectiveness of two phase closed thermosyphon heat exchanger charged with nanofluid is due to thermal conductivity enhancement of nanofluid.
f) TPCT heat recovery heat pipe heat exchanger can be suitably employed for heat recovery from low source temperature.

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