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Experimental analysis of performance of HPHX by varying the input parameters for HVAC application

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Abstract: *A Research has been carried out to investigate the effect of HPHX (heat pipe heat exchanger) on energy recovery in air conditioning system. In this research first HPHXhas been designed and manufactured for heat recovery. In this research the wickless heat pipe have been investigated. The HPHX was designed, constructed and tested fortemperature range of 15 to 42^{O}C and relative humidity 50%. R134a was used as working fluid.An experimental results showsthat effectiveness increases with increase in air velocity &EBR (energy balance ratio) increases with increase of outdoor DBT.*
Keywords: *Heat pipe, Heat Exchanger, Energy recovery, HVAC.*

Nomenclature

C_{pc}	=	Specific heat of conditioned air stream at atmospheric pressure at T_4 ^{0}C(J/kg.^{0}C)
C_{pe}	=	Specific heat of outdoor air stream at atmospheric pressure at T_1 ^{0}C(J/kg. ^{0}C)
EBR	=	Energy balance ratio
HVAC	=	Heating ventilation and air conditioning.
HPHX	=	Heat pipe heat exchanger.
$\dot{m}$	=	Mass flow rate of air (kg/s).
T_1	=	Dry bulb temperature of inlet outdoor air before evaporator (^{0}C)
T_2	=	Dry bulb temperature of air after evaporator (^{0}C)
T_3	=	Dry bulb temperature of air before condenser (^{0}C)
T_4	=	Dry bulb temperature of air after evaporator (^{0}C)
V	=	Velocity of inlet outdoor air to heat pipe (m/s)
Qe	=	Heat absorbed at evaporator section (W)
Qc	=	Heat rejected at condenser section (W)
ε	=	Effectiveness

I. Introduction

As an efficient heat exchanger, heat pipe heat exchangers (HPHXs) are playing a considerable role in different fields like energy conservation, energy recovery and renewable energy based systems including air conditioning systems. A heat pipe heat exchanger is a heat transfer device, in which the latent heat of vaporization is utilized to transfer heat over a long distance with a corresponding small temperature difference.In order to reduce the energy consumption by central air conditioning system in tropical climate lot of literature is available by using the heat pipe heat exchangers.J.W. Wan et al.[1] carried out field work to investigate the effect of loop heat-pipe air-handling coil on energy consumption in a HVAC system with return air. The study indicates that the relative humidity has more impact than that of indoor temperature on energy consumption and effectiveness of HPHX. S. H. Noie et al. [2] carried out research on heat pipe using Methanol, Ethanol & Acetone as working fluid and three types of wick for the operating temperature range of 15 to 55^{0}C. After conducting series of experiments, it shows that lower effectiveness of HPHX was due to lack of fins, high pitch to diameter ratio and high air face velocity.Mostafa A. et al. [3] developed the heat pipe heat exchanger for the heat recovery applications to cool the incoming fresh air in HVAC system,where two streams of fresh and return air to investigate the thermal performance and effectiveness of heat recovery system. Y. H. Yau [18] investigated experimentally 8-row thermosyphon-based HPHX for tropical building. This research was an investigation into how the sensible heat ratio (SHR) of the 8-row HPHX was influenced by each of three key parameters of the inlet air state, DBT, relative humidity and air velocity. Y.H.Yau [4] carried out experimentation using thermosyphon HPHX with 8 rows with the angle of tilt 30^0 to examine the influence of condensate forming on the fins of the HPHXs and affecting its effectiveness, where the effect of gravitational force to enhance the drainage of any condensate forming on extended surfaces of evaporator was investigated.

Present work aims to investigate the performance of two phase heat pipe heat exchanger as heat recovery facility for air conditioning system.In this research the effect of input parameters such as the inlet door temperature range of 30 to 40^{0}C and air velocity range of 1 to 3.5m/son output parameters such as pressure drop, effectiveness and EBR were investigated.

II. Experimental apparatus

A schematic diagram of experimental setup is as shown in Fig. 1. The test setup consists of HPHX, air blower, cooling coil and ductwork. Heat loss to the surrounding by convection and conduction is minimized by providing insulation to the duct. The ratio of mass flow rates over evaporator and condenser of HPHX was kept constant. Wattmeter with desired power ranges with variac for precision control was introduced in heater circuit so that the outdoor air with required temperature can be supplied to evaporator section.The air blower was also introduced with variac control for changing air velocity.

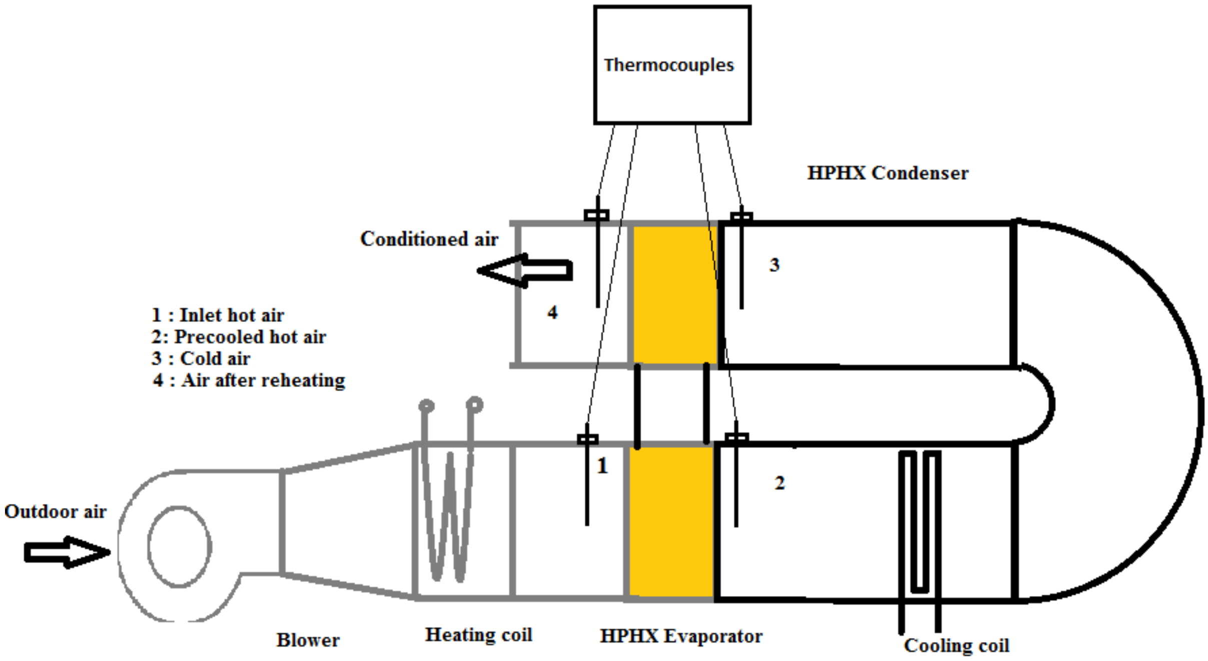

Fig.1 Experimental set up.

III. Design of heat pipe and manufacturing

The working of heat pipe is very simple it can be demonstrated with help of Fig. 2. Although the working of heat pipe is very simple, its accurate design and manufacturing is very complicated. Since there are numerous parameters required to be considered. For this research there was constrain on the operating temperature range (15 to 42^{0}C) and the application for which it is going to be used of heat pipe.

For most of HVAC applications the vertical orientation of heat pipe is suitable, where for vertical orientation the gravity assisted heat pipe (wickless heat pipe) are preferred. For design and manufacture of gravity assisted heat pipe heat exchanger, there is no need to select wick.

The design of and heat transport limitation for three types of working fluid (R11, R22, R134a) were checked theoretically, but the R134a has advantage over other two as it is ecofriendly. Initially heat pipe material (Copper), compatible working fluid and length of heat pipe were selected. The fluid inventory in heat pipe has remarkable impact on performance of heat pipe. Both under filled and overfilled liquid inventory have impact on performance of heat pipe. In the present work the filling ratio of 70% was taken.

The detailed specifications of heat pipe heat exchanger are shown in Table 1

3.1. Heat pipe manufacturing [5]

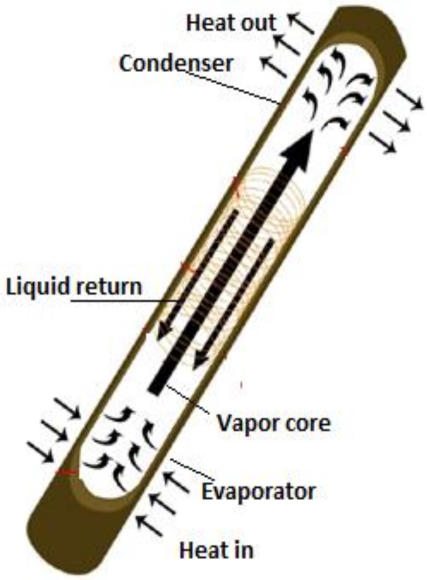

Fig. 2 Heat pipe

Table 1 Heat pipe heat exchanger specifications

Heat Pipe Specifications	Description
Type	Gravity assisted heat pipe
Refrigerant	R134a
HP material	Copper
Length of heat pipe	720mm
Length of evaporator section	300mm
Length of Adiabatic section	120mm
Length of Condenser section	300mm
Outer diameter	15.5mm
Inner diameter	13.5mm
Heat capacity per pipe	100W
No of heat pipe	33 Nos
Working medium conditions	Air to air heat exchanger
Overall dimension of heat exchanger (HxWxB)	720 x 225 x 180 mm^3
Tube pitch	S_T = 34mm, S_L = 33mm

After calculating different parameters like figure of merit, priming ability and limits on heat transport (sonic, entrainment, viscous and degree of superheat) the heat pipe were manufactured.

3.1.1. Container Material

Among all the most common materialsare copper, aluminum and stainless steel. Copper is suitable for low operating temperature range. In this research liquid filling provision was made by sealing at one end completely and other end with the non-return valve. For this application the heat pipe will work under normal atmospheric condition only leakage test was done, no need of pressure test.

3.1.2. Cleaning of container

Cleaning of pipe ensures that the working fluid will wet the pipe and that no foreign matter is present, which will affect performance of heat pipe and create incompatibilities. This was done by pickling processin acid solution followed by rinse in demineralized water.

3.1.3. Material out gassing

When outgassing is not done prior to filling, the gases may trap inside pipe that may affect the heat pipe performance. Outgassing is the process, where the pipe material is heated up to certain temperature under vacuum. Generally the outgassing does not appear to be a problem in low temperature heat pipe, only a vacuum is sufficient to remove the gases present in pipe.

3.1.4. Working fluid filling

Many of working fluids having affinity with airextreme care must be taken to avoid exposure to air. Before filling the vacuum of the order 10^{-3}torr must be made with the help of vacuum pump. The filling set up consist of vacuum pump with negative pressure gauge, working fluid container with cryogenic insulation, flow meter to measure quantity of working fluid filled and pressure gauge to measure the saturation pressure inside heat pipe.

IV. Experimental Results And Discussion

A series of experiments were carried out to investigate the performance of HPHX. The mass flow rateof air passing over evaporator and condenser were kept same. The inlet outdoor temperature was varied in between 30 and 40^{0}C. The air velocity was varied in between 1 to 3.5m/s. All other parameters like relative humidity and mass flow rate ratio were kept constant and unity respectively.

In the experimentation 10 set of temperatures (30,31,32….40^{0}C) and 6 (1,1.5,2…3.5m/s) set of inlet air velocity were taken.

With reference to inlet and outlet temperatures, the heat absorbed at evaporator and heat rejected at condenser section were calculated.

$$Qe = \dot{m}c_{pe}(T_1 - T_2) \quad (1)$$

$$Qc = \dot{m}c_{pc}(T_4 - T_3) \quad (2)$$

Heat pipe heat exchanger effectiveness can be calculated by using the ASHRAE standards for testing of air to air heat exchangers.The performance of the sensible energy transfer (DBT) and total energy transfer of an air-to-air heat recovery device is assessed by its effectiveness and EBR.[6]

$$\varepsilon = \frac{\text{Actual Heat transfer}}{\text{Maximum possible Heat transfer}} \quad (3)$$

EBR is the ratio of heat absorbed at the evaporator end to the heat rejected at condenser end, it must be closer to unity.The total pressure drops(ΔP) for air flow though the evaporator, cooling coil, condenser and duct were calculated with help of basic principles of fluid flow.

Fig.3, Fig. 4 and Fig. 5 shows the variation of effectiveness, EBR and pressure drop with change in inlet outdoor temperature and inlet air velocity.

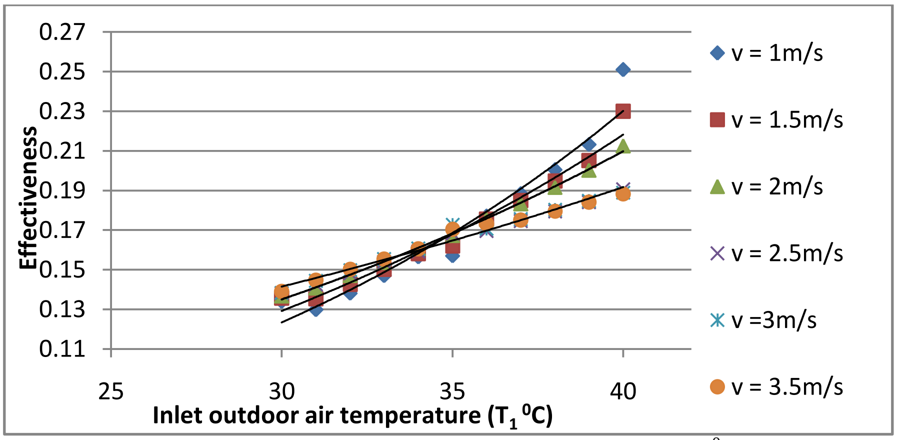

Fig. 3 Effectiveness vs. Inlet outdoortemperature (T_1^{0}C).

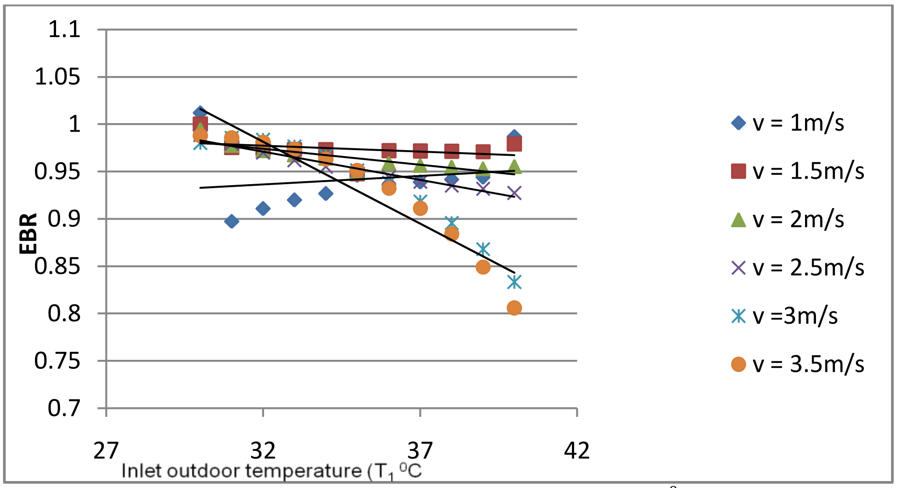

Fig. 4 EBR vs. Inlet outdoor temperature ($T_1{}^0C$).

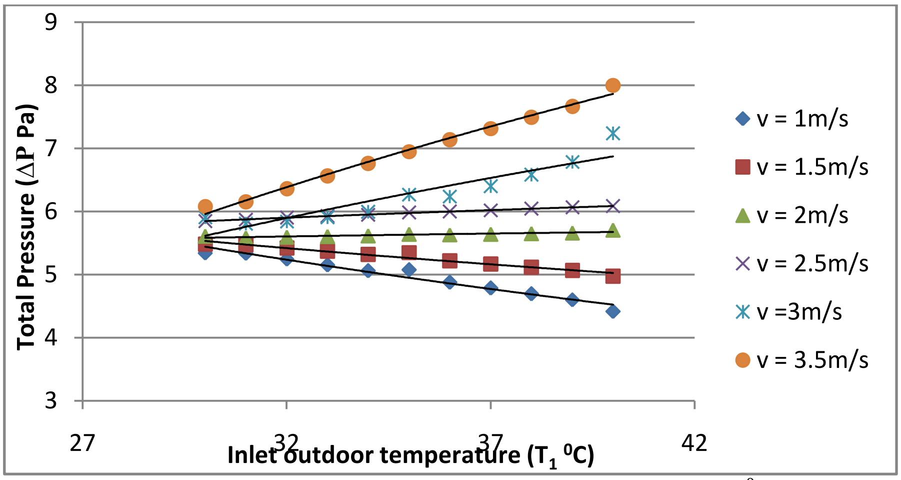

Fig. 4 Pressure drop (ΔP) vs. Inlet outdoor temperature ($T_1{}^0C$).

V. Conclusion

The heat transfer from outdoor air to evaporator and condenser to indoor air fromexperimentation was close to the theoretical model.

1. Fig. 3 shows the variation of effectiveness, with increase in inlet outdoor temperature, the effectiveness increases till 36^0C and further it decreases, with increase in air velocity the effectiveness increases till 36^0C and further it decreases.
2. Fig. 4 depicts the variation of EBR, it shows that with increase in both inlet outdoor temperature and air velocity, the EBR remains nearly constant close to unity till 36^0C further it decreases.
3. Fig. 5 shows the pressure drop that occurs during the travel of air from inlet to outlet of HPHX. It reveals that, with increase in indoor temperature the pressure drop decreases till the air velocity is below 2m/s and the pressure drop increases beyond 2m/s

From this results it may be concluded that the overall effectiveness for given HPHX is 0.17, EBR 0.95. As per the research data available the effectiveness range is 0.4 to 0.6, while EBR is 0.99. The possible reasons behind this are

a. Filling ratio was more(70%).
b. Fins were not provided.
c. Proper insulation must be provided to HPHX.

Acknowledgements

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