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Experimental Study of Fins Effect on Thermal Performance of HPHX for Air Conditioning System

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Abstract*—nowadays the use of heat pipes is one of the most effective technique of saving energy & preventing global warming. In heat recovery applications, the heat pipe heat exchangers are used to cool the incoming fresh air in air conditioning systems. Due to increasing in need of HPHx (Heat pipe heat exchanger) in heat recoveryapplication there is a challenge to achieve cost effective solution without compromising on its effectiveness. In this paper the experimentation was carried out to investigate the effect of HPHX on energy recovery in air conditioning system with different array of heat pipes in HPHX. In this experimental work, first one heat pipe was constructed& tested for temperature range 30 to 40ºC with R134a as a working fluid. Then multiple tests were carried out for HPHx without & with fin heat pipe arrangement in HPHx.The series of tests were conducted for multiple values of inlet air velocity from 1 to 5m/s& for different inlet outdoor air temperature varying from 32 to 40ºC based on Pune climatic condition.An experimental results shows that maximum effectiveness can be seen in staggered arrangement of finned pipes than finless pipes. Also results indicates that maximum effectiveness is possible to achieve at minimum velocity of inlet air & goes on increasing as outdoor inlet air temperature increases. This study indicates that due to the addition of fin on heat pipes in HPHx will increased its effectiveness significantly.*

Index Terms*— Energy recovery, Heat pipe heat exchanger, air conditioning application,Fin geometry, FPI, Effectiveness.*

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I. Introduction

The developing countries like India are indulged to maintain a certain progress rate for which energy is anelementaryfactor. With the rapid development of the economics and the improvement in living standard of ordinary people in India, the use of air-conditioning equipment has been increasing quickly in recent years. The ever increasing energy requirement puts a great burden on the further economic development. The lag between energy supply and demand is increasing every year as power sector is highly capital intensive. So, energy conservation is the approach of regulating and improving energy using systems and procedures to reduce energy requirements per unit of output without affecting socio-economic development [1]. Recently, due to global warming & greenhouse effects, ambient air temperature continuously raising every year. Hence controlling Heating, Ventilation and Air Conditioning (HVAC) system to maintain occupant's indoor thermal comfort is important to energy-efficient buildings and the development of smart cities. For decades, the design of HVAC systems has been focused on minimizing energy waste by enhancing the efficiency in heaters and coolers, or improving insulation of air ducts and exchangers [2].

The use of heat pipes for heat recovery represents an excellent way to a decrease of a waste heat that is rejected to the ambient. Also it has many advantages such as its heat recovery efficiency, lack of moving parts, compactness, light weight, economy, and minimumpressure drop on the air side [3]. Heat pipes applies in various different areas such as in the area of space craft cooling, electrical & electronic equipment cooling, medicine & human body temperature control and as a heat exchanger for heat recovery in air conditioning system. The research based on hphx'sapplication shows that the heat transfer rates to the evaporator section of a single heat pipe from the computer simulation is very close to the actual experimental results [4]. Hence the effectiveness of hphx is proven & cross verified. Thanaphol&Chaiyun investigated by their studies the effect of filling ratio of working fluid R134a & length of adiabatic section. The pipe material used was copper. The optimum filling ratio for each adiabatic length is 15% of heat pipe volume[5]E.Azad, F.Mohammadieh represents theoretical analysis of multi-stage heat pipe heat recovery system. They have developed the thermal performance & temperature profile in flow direction bothin evaporator& condenser sections. Similarly, they have done a theoretical study on the performance of a circular finned heat pipes in the longitudinal rowsto forecastits temperature distribution [6]. S.B. Riffat& G. Gan performed the work &represented results of effect of inlet air velocity on effectiveness. Air velocity was found to have a high impact on the effectiveness of heat recovery. The effectiveness decreased with increasing inlet air velocity & effectiveness also affected by shape of fins & pipe arrangement. By using CFD it was found that, for natural ventilation at low velocities the loss of pressure coefficient decreased with increasing air velocity, but the total pressure drop increased with the velocity. From the study it is recommended that, in naturally- ventilated low rise buildings, without the wind effect or solar energy, the design mean air velocity should be less than 1m/s [7]. Some authors represented review documents on HPHX's application, general design procedures, analysis tools based on the thermal network approach. Also this review study discussed about opportunities & challenges related to currentHPHX applications. [8] X.Yang, Y.Y.Yan& D. Mullen discussed in their paper the several methods& manufacturing methods to achieve the requirements of lightweight & high performance heat pipes. The application of light weight material helps to reduce 80% the weight of conventional heat pipes. [9].

The research has been done by J.A. Kute to explore the effect of HPHX on energy recovery in HVAC application. Thermosyphon type of heat pipe is investigated for this research. The relative study of inline & staggered arrangement has been carried out for different outdoor temperature and velocity in the article. The study indicates staggered arrangement is more effective than inline based on the thermal performance parameter. [11]. Y.H.Yau [13] carried out experimentation using thermosyphon HPHX with 8 rows with the angle of tilt 300 to examine the influence of condensate forming on the fins of the HPHXs and affecting its effective-
Ness.

On the basis of available research review, it has been found that experimental study has not been done for finned heat pipes arranged in staggered array used to enhance the performance of HPHx in air conditioning system. Hence this article proposes experimental & comparative study of the thermal performance of the HPHx in both the cases in which, pipes are used with & without fins.

<u>Abbreviations</u>	
HVAC	Heating ventilation and air conditioning.
HPHX	Heat pipe heat exchanger
EBR	Energy balance ratio
FPI	Fins Per Inch
DBT	Dry Bulb Temperature
<u>Symbols</u>	
$\dot{m}$	Mass flow rate of air (kg/s).
T_1	DBT of inlet outdoor air before evaporator (°C)
T_2	DBT of air after evaporator (°C)
T_3	DBT of air before condenser (°C)
T_4	DBT of air after condenser (°C)
C_{pc}	Specific heat of conditioned air at atmospheric pressure at T_4°C(J/kg. °C)
C_{pe}	Specific heat of outdoor air at atmospheric pressure at T_1°C(J/kg. °C)
V	Velocity of inlet outdoor air to heat pipe (m/s)
Q_e	Heat absorbed at evaporator zone (W)
Q_c	Heat rejected at condenser zone (W)
ε	Effectiveness

Working of heat pipe:

There are three sections of heat pipe, evaporative section, adiabatic section and condenser section as shown in fig.6. Heat gets added to the evaporator section. Due the heat supplied the working fluid present in heat pipe boils and get converted into vapour. As vapour has low density it travels to the condenser section. In condenser thevapour rejects its latent heat and gets condensed into liquid. Due to its weight the liquid moves downward andgets collected in evaporative section.

II. Experimental Apparatus

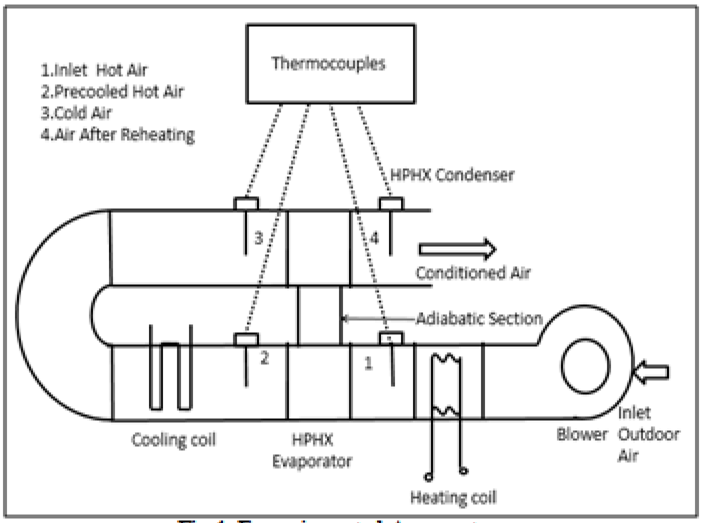


Fig.1 Experimental Apparatus

Construction of Test Rig:

The experimental set up is as shown in the fig.1. It consists of hphx, air blower, cooling coil, heating coil, sensors to read the temperatures & duct. To minimize the loss of heat to the surroundings by conduction and convection proper insulation is provided to the duct. The ratio of mass flow rate over evaporator & condenser were kept almost constant. To supply the heatto heating coil, wattmeter with desired power ranges with variac for precision control was included to heater circuit. Due to this, the outdoor air with pre-required temperature can be supplied to the evaporator section. For changing inlet air velocity, the another variac control is connected to the air blower.

Photograph of actual experimental set up

Heat Pipe-Manufacturing & Testing:

For HVAC application generally vertically oriented heat pipe is suitable. In this type of pipe, no need to select the wick as these pipes are gravity assisted pipes. Initially, the length of heat pipe, heat pipe material & compatible working fluid were selected. The material of pipe is selected as copper as it is cost

effective, thermally conductive& suitable to work at low temperatures. R134a was selected as a working fluid which is ecofriendly. This working fluid filled 60% in the pipe by sealing at one end completely & other end with the non-return valve. The working fluid should wet the pipe internally. Before filling the fluid into the pipe, outgassing is important process. If any gases were present in the pipe prior to filling, they may affect the performance of the heat pipe. The hphx set up is completely sealed properly by insulating material to avoid any kind of leakages.

The single heat pipe was tested with the help of thermocouples attached to different sections of heat pipe {i.e. evaporator, adiabatic & condenser}. After testing was done for single heat pipe, the setup of 35 number of heat pipes included in HPHx set-up.

Table. I. Dimensions of HPHx

Heat pipe specification	Dimension/Details
Type of heat pipe	Gravity assisted thermosyphon
Refrigerant	R134a (Tetrafluoroethane)
Pipe material	Copper
Total length of heat pipe	720.0 mm
Length of evaporator & condenser section	300.0 mm
Length of adiabatic section	120.0 mm
Outer diameter	19.1mm
Thickness of pipe	1.6 mm
Heat capacity per pipe	100 w
Working medium	air to air hphx
Tube pitch	ST = 40.0 mm, SL=80.0 mm
No. of Rows	7
No. of heat pipes	Staggered Array: 35

Fins Selection:

The relatively low heat transfer coefficients of flowing cooling air as compared to those of the products to be cooled or condensed may be partly compensated by a surface extension on the air side. This is realized by fin-pipe heat exchanger bundles. The surface extension is optimized on the basis of considerations of economy and manufacture. One criterion for the optimization is the specific performance increase in the heat transfer attainable per cost unit. Fin efficiency mainly depends upon following key parameters:

- Fin geometry: height, thickness, cross sectional shape
- Fin material: thermal conductivity coefficient.

The thermal rating first requires a reasonable adaptation of the means to be selected to the specified requirement. This implies a certain experience. Shape, size, finning, and fin-tube material must be suitable for the fluid to becooled or condensed and must be adapted to its physical properties.

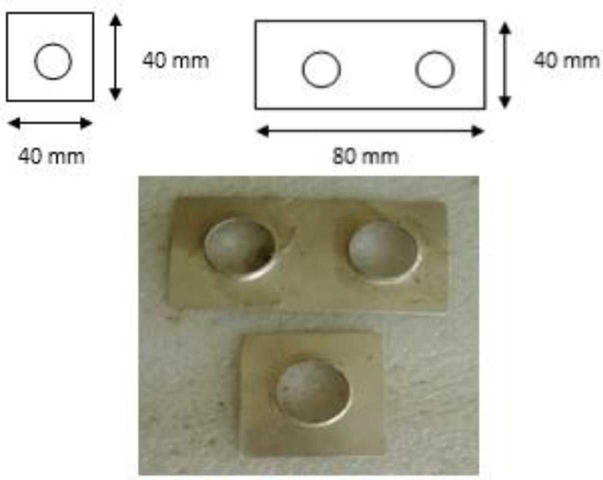


Fig. 2. Schematic of fin geometry

Generally, Fins are provided to increase the effective area for heat transfer. It is found from various studies that with the increase of FPI, surface per unit finned tube increases, but after increasing FPI more than 12, variation in surface per unit-finned tube is gradual. Literature shows that for rectangular plate fins the increase of FPI from 3 to 12 causes the increase of heat transferred about 50% (1.5 times). Moreover, increase of FPI from 12 to 15 causes the increase of heat transferred about 3%. Also, the increase of FPI from 3 to 12 causes only a minor increase in pressure drop about 1%, but there is a sharp increase between FPI=12 and FPI=15. Hence, according to the length of the evaporator & condenser section, rectangular plate fins with 8 FPI are selected for this study. Schematic of fin geometry is shown in Fig.2.

The detailed specification of hphx is shown in table II.

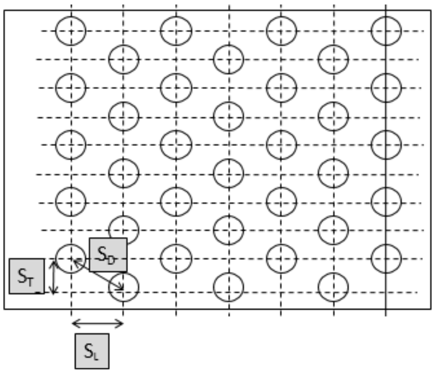
Table. II. Fin specification

Fins specification	Dimension/Details
Fin Material	Aluminum
Fin Geometry	Rectangular/Circular
Rectangular plate dimensions	40.0*40.0 mm & 80.0*40.0 mm
Gap Between Fins	3.0 mm
Fin Distribution	8 Fins Per Inch(300 mm of evaporator section & 300 mm of condenser section)

Heat pipe arrangement in HPHX:

Staggered array of heat pipes without fins:

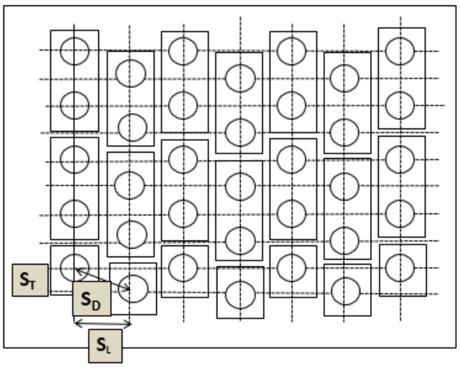
The pipeswere organized in the staggered manner as shown in the Fig.3. According to past study, staggered arrangement shown more effectiveness than inline arrangement [11].In this arrangement, no fins were provided to the pipes. Total 35 number of pipes were organized in 7 number of rows for this arrangement.



Fig,3. Staggered array of pipes without fins

Staggered array of heat pipes with fins:

The pipes were organized in the staggered manner as shown in the Fig.4. in this arrangement rectangular plate fins are provided on the pipes. The circular cut out of 2cm. diameter is taken out from the center of the plate. The heat pipe is passed through the hole of the plate & placed vertically as per shown in the photograph of actual finned pipe arrangement.The evaporator & condenser sections of the heat pipe are responsible for heat transfer, hence fins are provided over the length of evaporator & condenser section, as adiabatic section doesn't involve in any heat exchange activity.



Fig,4. Staggered array of pipes with fins

For the proper fitment of pipes& to avoid lateral movement of the pipes during working, wooden plates are provided in between the evaporator & condenser section. Due to this adiabatic region becomes isolated & no heat was transferred to that section from either of two ends of the pipe. The assembly of all 35 pipes become immovable & stand straight inside the duct during testing.

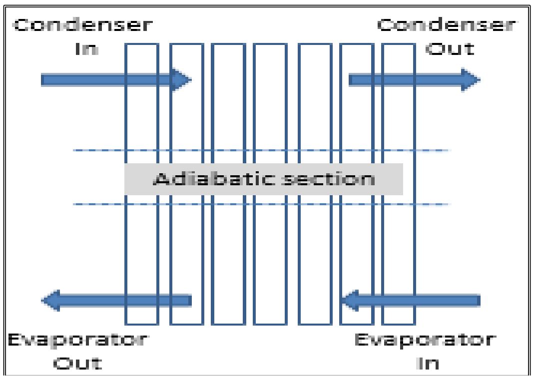


Fig.5.Air flow direction over heat pipe array

Photograph of actual finned heat pipes arranged in staggered array

III. Experimental Procedure

Following steps has been followed to conduct the experiment for all three set of heat pipe arrangement

1. A series of tests were conductedin the summer season considering Pune city's climatic conditions, where outdoor ambient temperature was 30-36°c. during the day period. The mass flow rate of air passing over evaporator & condenser were kept same.
2. For the decided input conditions first readings have been taken for staggered array heat pipes without fins & repeat the procedure for staggered array of heat pipes with fins.
3. The inlet outdoor temperature was varied in between 30°C and 40°C each step of 2 degrees. (32, 34, 36, 38, 40). The air velocity was varied between 1 to 5m/s, each step of 1.0 m/s (1,2,3,4,5).
4. Temperature & humidity data were collected through data logger during the working of HPHE in an air conditioning application &graphs were plotted

IV. Result and Discussion

Based on the inlet & outlet temperature of both evaporator & condenser zone, thermal performance of Hphx i.e. heat transfer rate, effectiveness& energy balance ratio was calculated

1. Heat absorbed at evaporator:

$Qe = \dot{m}\, cpe\ (T1 - T2)$ …. (1)

2. Heat rejected at condenser:

$Q_c = \dot{m}\, cpe(T_4 - T_3)$ … (2)

3. Thermal effectiveness:

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

4. Energy Balance Ratio:

$EBR = \frac{\text{Absorbed heat at evaporator zone}}{\text{Rejected heat at condenser zone}}$ … (4)

A. Effect of outside inlet air temperature & velocity on thermal performance of hphx without fin:

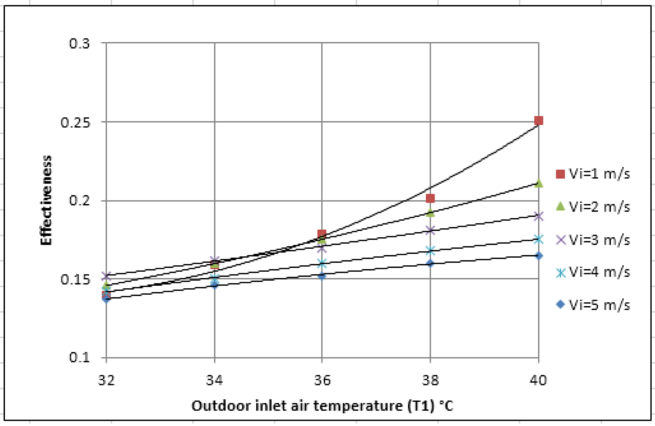


Fig.6. Effectiveness Vs Inlet temperature for Staggered Array of pipes without fins

Above fig.6. shows the effectiveness of HPHx is increases as inlet air velocity decreases & inlet outdoor air temperature increases.

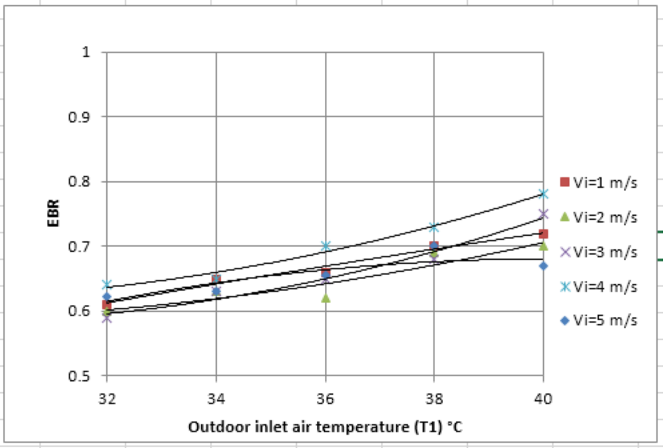


Fig.7. EBR Vs Inlet temperature for Staggered Array of pipes without fins

Fig.7. shows the EBR of HPHx is increases as inlet air velocity & inlet outdoor air temperature increases. The value remains almost constant for inlet air velocity 1 to 5 m/s.

B. Effect of outside inlet air temperature & velocity on thermal performance of hphx with fin:

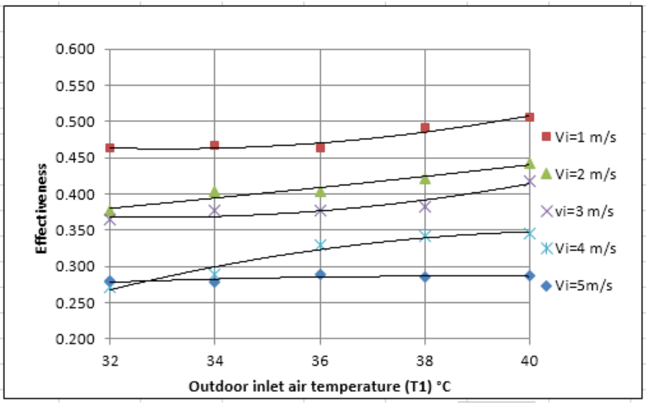


Fig.8. Effectiveness Vs Inlet temperature for Staggered Array of pipes with fins

Fig.8. shows the effectiveness of HPHx is increases as inlet air velocity decreases & inlet outdoor air temperature increases.

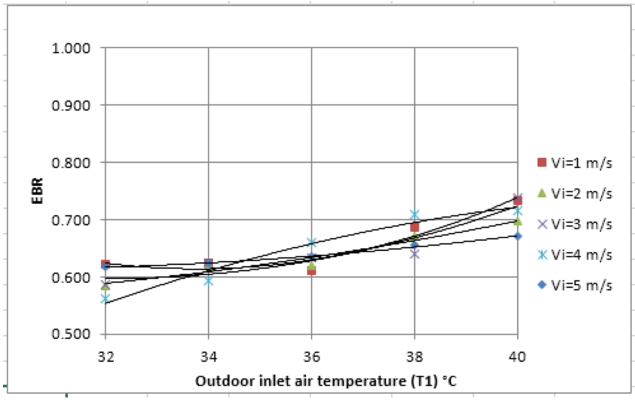


Fig.9.EBR Vs Inlet temperature for Staggered Arrayof pipes with fins

Fig.9. shows the EBR of HPHx is increases as inlet air velocity & inlet outdoor air temperature increases. The value remains almost constant for inlet air velocity 1 to 5 m/s.

Comparative assessment of Staggered array of heat pipes without & with fins attached arrangement.

Fig. 6 & fig. 8depicts drastic variation of with effectiveness across staggered array of heat pipe arrangements in without & with fins where staggered array with fins has higher effectiveness within the range 0.27 to 0.5, than the without finned heat pipe heat exchanger which lies in the range between 0.14 to 0.25.

Fig. 7& fig. 9 shows that EBR for three test attached. arrangements remain nearly constant within the range 0.6 to 0.7.

Table.III. Comparative assessment of both arrangements

Parameters	Staggered Array Without fin	Staggered Array With fin
Total No. of Heat Pipes	35	35
Total No of Fins	0	3948
Max. Effectiveness	0.506	0.357
Max. EBR	0.73	0.72

Table III shows the comparison of different thermal performance & geometric parameters of staggered arrangements of heat pipes without & with fins attached to them.

V. Conclusion

1. The effectiveness of HPHX increases with increase in outdoor air temperature while it decreases with increases in inlet air velocity for the staggered array of heat pipes without fins & with fins. The remarkable increment in effectiveness of HPHx has been observed in the second case i.e. when heat pipes are attached with fins as per prediction. The maximum value of effectiveness achieved is for staggered array with fins is having value of 50 to 52 %. Then comparatively less for staggered array without fins up to 25%.

2. Energy Balance Ratio of HPHX slightly increases with increase in outdoor air temperature for all three type of heat pipe array. The EBR value is almost constant for both the arrangementsstated withinthe range of 0.6-0.78.

3.By comparingboth the arrangements& their results obtained by experimentation, it can be concluded that the staggered array of heat pipe with fins attached is most thermally effective than the other two. By considering the no. of fins attached to the heat pipes in the first case, manufacturing cost of the finned pipes is much more than the fin less pipes. So, the only concern of the cost is pertaining to the finned heat pipes.

From this comparative study, one can adopt any of these arrangements according to its application in the area of air conditioning system for the provided input conditions.

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