Experimental investigation effect of input air property at efficiency of air condition systems with HPHE

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Abstract

The effect of input air properties on the efficiency of an air conditioning system with heat pipe heat exchanger (HPHE) has been investigated at pilot scale in this paper. Energy saving is the main purpose of using HPHE in this experimental air conditioning system. HPHE is a heat superconductor that acts with few temperature gradients between evaporator and condenser sections and with any heat pump. Mass flow, temperature & humidity are main design parameters of this air conditioning system. These parameters have effect on heat transfer coefficient & efficiency of the HPHE. The HPHE is used for pre-cooling and preheating. The experiments show that by using HPHE in an air conditioning system, we will save around 10-15% of energy in the evaporator and 40-65% in the condenser of the HPHE.

Key Words: Air conditioning, Heat pipe heat exchanger, Energy saving, Humidity.

1. INTRODUCTION

Whereas the human population is increasing, energy demand and consequently its price have increased. So energy saving today is one of the main subjects in the industry. Air conditioning plays a significant role in many industries which consumes a lot of energy. So we should consider reduction of energy waste in this field.

In air conditioning systems, to reduce humidity the input air is initially cooled to 10°C. Since this temperature is too low for the refreshing air subsequently the input air is heated up to 18°C. This procedure provides air with 18°C of temperature and 70% of humidity which is a pleasant condition for refreshing air [1].

Comfort conditions: As described, air comfort condition is of what 97% of people feel comfortable in it. It is very difficult to distinguish this, because comfort conditions depended on different climates people live in. For example, comfort conditions for people living in mountains, is different to people living in deserts [2].

There are three parameters that affect comfort conditions: air temperature, relative humidity and air velocity. American Society of Heating and Air Conditioning Engineers (ASHRE) after several years of study have been able to correlate these three parameters. During their study the reaction of people at summer & winter were different; this means that the definition of comfort condition also depends on the season we are in [3]. 98% of the studied people expressed that 25°C temperature & 50% relative humidity is suitable for summer and 22°C temperature and relative humidity under 50% is suitable for winter [2].

Refrigerant systems: Refrigerant systems are the best known technology in air conditioning systems. This cycle consist of four sections: Evaporator, Condenser, Expansion Valve and Compressor. Because of its low boiling point the working fluid in this cycle usually is Freon (Recently scientists have found that this liquid harms ozone layer, so they prefer using alternative liquids [3]).

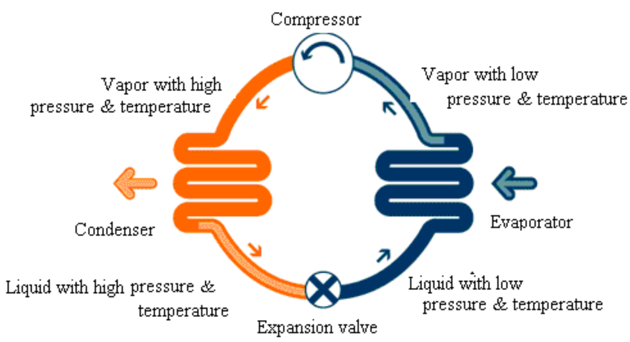

Figure 1. Refrigerant cycle

As shown in Figure 1, working fluid with low pressure and temperature enters the compressor where in its temperature and pressure are increased, followed by passing through the condenser section giving its heat to the environment and changing into liquid with high temperature and pressure. Then it enters The Expansion Valve where we have liquid with low temperature and pressure, and finally it goes through the evaporating section and takes heat forms the environment and cooling happen. These systems are preferred because of their temperature control and suitability for all types of climates especially humid places however high energy wastage is disadvantage of these systems [3].

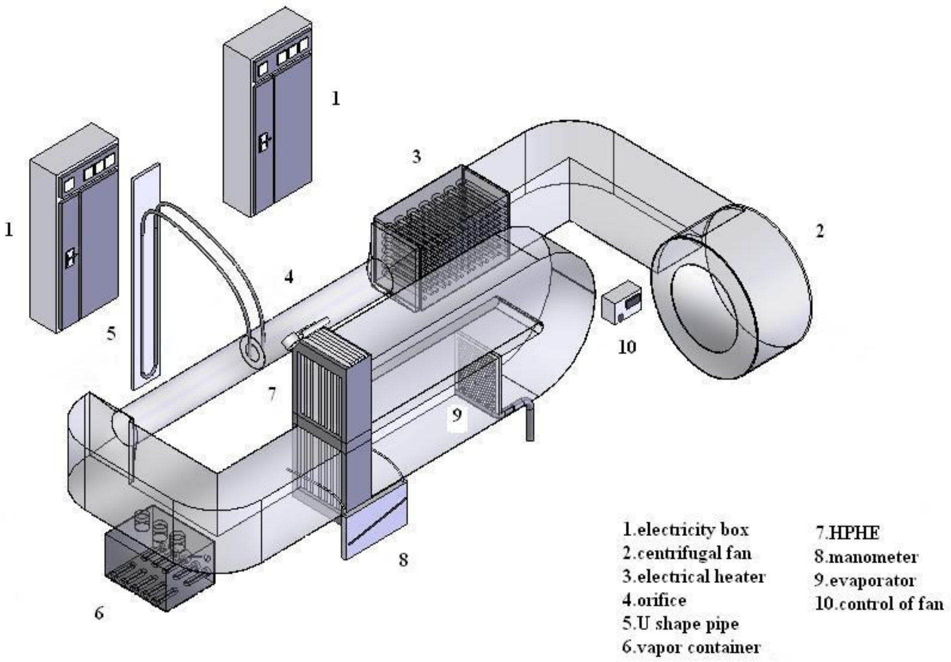

Figure 2.Schematic of the pilot

2. HOW HEAT PIPES WORK

Using heat pipes is the best way of energy saving. A heat pipe is a simple device which transfers heat between two medium rapidly. A heat pipe is a super conductor that has high heat capacity and wastes little amount of energy. A heat pipe consists of a vacuumed closed duct with wick which contains a working fluid in two phases (liquid and vapor) [4]. Heat pipes are divided into three sections, evaporator which is in contact with hot medium and removes heat from it and changes the working fluid from liquid into vapor, adiabatic section and condenser section which are in contact with cold medium and transfers the latent heat of the working fluid to it. During this cycle the wick has the role of recycling the working fluid in liquid phase from the condenser section to the evaporator, this helps heat pipes to work against gravity, meaning that the evaporator section can be placed above or at the same level of the condenser section, but thermosyphon is a kind of heat pipe without wick and working fluid flows from condenser to evaporator by gravity force. This is the advantage of heat pipes over thermosyphons [4]. One the applications of heat pipes that recently has been paid attention is in air conditioning systems, as dehumidifier to reduce the air of input air [5].

3. EXPERIMENTAL SETUP

In this paper the experiments were run in a pilot shown in Figure 2, which is consisted of ten different segments connected to each other with a canal and the specification of each part is as follow. Area of its muzzle is 50cm*60cm and its diameter is 2mm.

A centrifugal fan with specifications listed in Table 1.is used in this setup.

Table 1.Specifications of the fan

60cm	Muzzle length
80cm	Vane diameter
□phase	Kind of motor
2.2Kw	Power
5.3A	Current

The heating section consists of five 1kW powered electrical heaters which are shaped as U. These heaters are introduced to the setup in order to control the input air temperature. The fan is powered by 3-phase electricity and is controlled by the frequency of the input power. In this way of control air velocity can be reduced without reducing the power. The equation used for the orifice was the one for incompressible fluids as:

$$\dot{M} = C_1 Y A_0 \sqrt{2\rho_1 \Delta p} \qquad (1)$$

Where Y is the expansion coefficient, A_0 is the area of the orifice and ρ is the air density. Since the pressure drop is low and the expansion coefficient is one [6], equation (1) can be rewritten as:

$$\dot{M} = C\sqrt{\rho_1 \Delta p} \qquad (2)$$

The vapor container used is 45cm*40cm*70cm in size and is made of stainless steel sheets of 2 mm thickness. Thirty 1kW electrical elements heat water in the container and control mass flow of vapor. The HPHE used in this pilot has the specifications given in the Table 2.

Table 2. Specifications of the HPHE

Physical size	130cm*47cm*20cm
Size of a single pipe	14mm*15mm*130cm
Fin type	Aluminium Dimeter=0.4mm 300 No. per each 1 m of pipe
Pipe arrangement	In-line S_L=S_T= 30mm
Number of pipes	N_L=6 ,N_T=15 N=90
Working fluid and the material of pipes	Methanol & copper

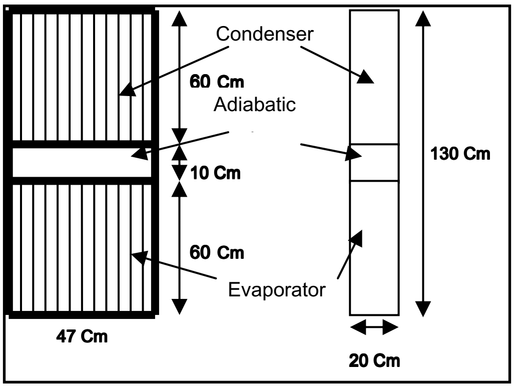

Figure 3. Schematic of the HPHE

The evaporator of refrigerating system in this pilot is made from copper pipes and aluminum fins. The size of this section is 45cm*45cm and operates with a compressor of 3kW power. The power of the refrigerating cycle is approximately 7 kW. A draining pipe is placed underneath the evaporating section for condensed water.

4. EXPERIMENTS

The centrifugal fan blows air into the canal with controlled mass flow rate and its velocity is measured by the orifice. Before the orifice the air is preheated by passing through electrical heaters, and then it is humidified inside the vapor container with a certain amount of vapor. This air will be pre-cooled when becomes in contact with the evaporator of the HPHE followed by a cooling in the evaporator section of the refrigerating cycle down to 10°C. In this stage, the humidity of the air has decreased and excess water is drained out of the system. And finally the air will go through the condenser of the HPHE and is preheated and ready to be blown into the requested area as refreshing air.

5. THEORY AND CALCULATIONS

The effect of temperature, humidity and mass flow rate of the input air into the evaporator of the HPHE on the energy saving were studied separately while the other properties were fixed. Since the power is a fixed specification of the refrigerating system, it is a bounding parameter in our experimental design.

First all experiments were run without HPHE in order of calculating the energy saving in the evaporator and the condenser of the HPHE.

Table 3. Operational and experimental data of temperature effect investigation

Mass flow Kg/s	Input Temperature to the HPHE Evaporator	Relative humidity	Output Temperature from the HPHE Evaporator	Output Temperature from the Main Evaporator	Output Temperature from the HPHE Condenser
0.122	30.9	71	27.5	10	13
0.122	35.4	68	30.5	9.9	13.8
0.122	40.6	69	34	10.4	15.4

Table 4. Operational and experimental data of humidity effect investigation

Mass flow Kg/s	Input Temperature to the HPHE Evaporator	Relative humidity	Output Temperature from the HPHE Evaporator	Output Temperature from the Main Evaporator	Output Temp. from the HPHE Condenser
0.122	39.9	51	34.4	9.6	13.7
0.122	40.4	60	34.9	10.1	14.3
0.122	40.2	72	34.6	9.7	13.9
0.122	40.5	84	34.9	10.4	14.8

Table 5. Operational and experimental data of mass flow rate effect investigation

Mass flow Kg/s	Input Temperature to the HPHE Evaporator	Relative humidity	Output Temperature from the HPHE Evaporator	Output Temperature from the Main Evaporator	Output Temp. from the HPHE Condenser
0.11	34.5	60	30.1	11	14.5
0.158	34	58	29.5	10.9	14.5
0.198	33.3	61	28.9	10.5	14.2
0.25	32.9	63	28.4	11.4	14.7

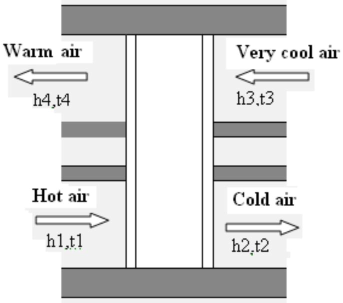

Figure 4. Streams to and from the HPHE

With input and output flows through the HPHE as shown schematically in Figure 4, we have [7]:

$$\varepsilon_e = \frac{h_1 - h_2}{h_1 - h_3} \quad (3)$$

$$\varepsilon_c = \frac{h_3 - h_4}{h_1 - h_3} \quad (4)$$

Where ε_e and ε_c are the efficiency of the evaporator and the condenser of the HPHE, respectively. While equation (3) can be rewritten as:

$$\varepsilon_e = \frac{h_1 - h_2}{h_1 - h_3} = \frac{m_1 c_p T_1 - m_2 c_p T_2}{m_1 c_p T_1 - m_3 c_p T_3} \quad (5)$$

Ideally we should have $\varepsilon_e = \varepsilon_c$, however because of energy wastage, always $\varepsilon_e < \varepsilon_c$ [7].

The temperature of the output air from the evaporator of the refrigerating system was controlled manually around 10°C, so at point 3 in Figure 4, we have saturated air at this temperature. According to the psychometric chart the absolute humidity at this point and the condensed water from refrigerating are calculated, hence the mass flow of the air into the condenser of the HPHE is known.

The energy saving at the evaporator and the condenser of the HPHE are calculated, respectively, as:

$$S_e = \frac{m_1 c_p (T_1 - T_2)}{m_1 c_p (T_1 - T_s) + m_{water} * \lambda_{water}} \quad (6)$$

$$S_c = \frac{m_3 c_p (T_4 - T_3)}{m_3 c_p (T_5 - T_s)} \quad (7)$$

Where T_s is the temperature at point 3 (after the evaporator of refrigerating system), and T_5 is the desired temperature of the refreshing which by standards, it should be 18°C [2].

In the dehumidifying process the evaporator section of the HPHE acts as a pre-cooler in which heat transfer may occur in both sensible and latent heat modes. If the surface temperature of the evaporator is lower than the dew point of the moist air, condensation may occur on the surface of the evaporator. Hence sensible and latent heat transfer will take place between the water film and the moist air. To express the effect of latent heat on total heat transfer, a condensing coefficient, η defined as the ratio of total heat to sensible heat, is introduced [8]:

$$\eta = \frac{h_1 - h_2}{c_p (T_1 - T_2)} \quad (8)$$

However, all experiments in this paper were in dry condition at the evaporating section of the HPHE. The conditions of all the experimental runs and their results are presented in Tables 6-8, wherein all variables are in SI units and the energy saving is expressed in percentage.

Table 6. Effect of input temperature on energy saving and efficiency of the HPHE

Input mass flow rate to the fan	Mass flow of wet air	Mass flow of dry air	Cp of wet air	Cp of dry & cool air	ε_e	ε_c	S_e	S_c
0.122	0.124	0.123	1.05	1	0.158	0.132	9	38
0.122	0.125	0.124	1.06	1	0.187	0.140	12	48
0.122	0.126	0.125	1.07	1	0.213	0.150	15	65

Table 7. Effect of input humidity on energy saving and efficiency of the HPHE

Input mass flow rate to the fan	Mass flow of wet air	Mass flow of dry air	Cp of wet air	Cp of dry & cool air	ε_e	ε_c	S_e	S_c
0.122	0.125	0.124	1.04	1	0.179	0.127	11.5	48
0.122	0.126	0.125	1.05	1	0.178	0.128	11.7	51
0.122	0.126	0.125	1.07	1	0.179	0.126	11.9	49
0.122	0.127	0.126	1.08	1	0.180	0.129	12.3	53

Table 8.Effect of input mass flow on energy saving and efficiency of the HPHE

Input mass flow rate to the fan	Mass flow of wet air	Mass flow of dry air	Cp of wet air	Cp of dry & cool air	ε_e	ε_c	S_e	S_c
0.11	0.112	0.111	1.04	1	0.183	0.138	7	49
0.158	0.161	0.159	1.04	1	0.19	0.144	9	49.7
0.198	0.201	0.2	1.04	1	0.189	0.152	10	48.3
0.25	0.255	0.252	1.04	1	0.203	0.142	9	49

6. RESULTS AND DISCUSSION

Whereas air conditioning is very important in many industries, which wastes a lot of energy, savings in energy seems vital in this area. HPHEs are the best choice for this aim. Therefore a pilot setup was prepared targeting the energy saving using HPHE.

The effects of the mass flow rate, humidity and temperature of the input air on the energy saving and the efficiency of the HPHE, are investigated in this paper. Since the efficiency is more important in calculation of the heat transfer coefficient, Figure 5 shows that by increasing the temperature of the input air, the efficiency of HPHE at evaporator and condenser sections increase. The reason is the direct effect of temperature on efficiency shown in equation 5.

Figure 6 shows that the efficiency of HPHE is almost constant with increasing humidity. This is because of negligible effect of humidity on the heat capacity.

The humidity will have effects on the efficiency of the HPHE where we have wet fin conditions and η›1 [8]. While all the experiments in this paper are in dry fin conditions.

Similarly, it is observed from Figure 7 that the efficiency is almost constant with increasing mass flow rates. This is because of little effect of mass flow rate ratios in equation 5.

Figure 8 shows that by increasing the input air temperature, energy savings of HPHE at evaporator and condenser increase. The reason is the importance and effect of temperature on energy saving in equations 6 and 7.

The effect of humidity on the energy saving is shown in Figure 9, which can be seen is almost nothing, because of negligible effect of humidity on heat capacity.

Figure 10 shows that energy saving of HPHE in also constant with increasing mass flow rate which is due to relatively constant mass flow rates on both side of the HPHE since the mass of condensed water in the refrigerating system is little and its effect on c_p in equations 6 and 7 is low.

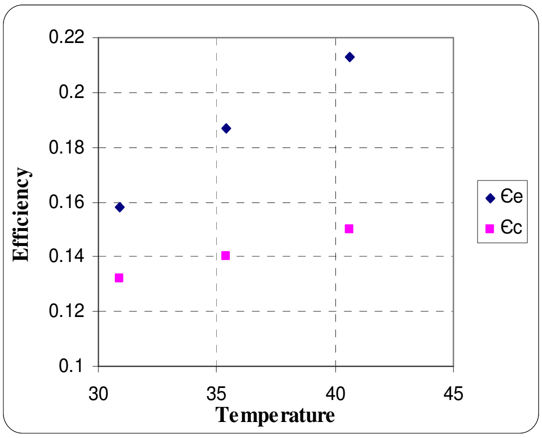

Figure 5. Effect of temperature on efficiency of HPHE

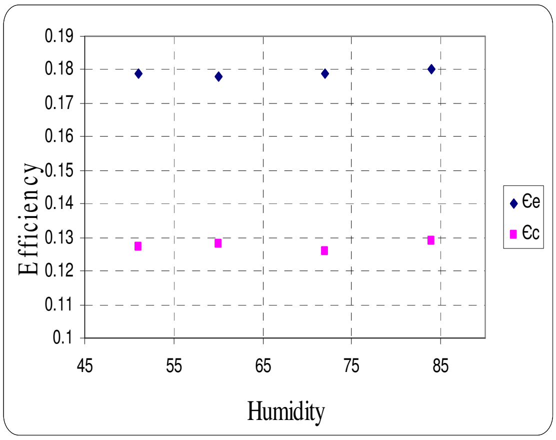

Figure 6. Effect of humidity on efficiency of HPHE

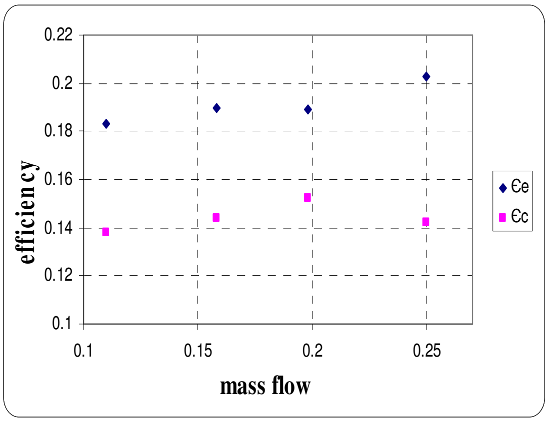

Figure 7. Effect of mass flow on efficiency of HPHE

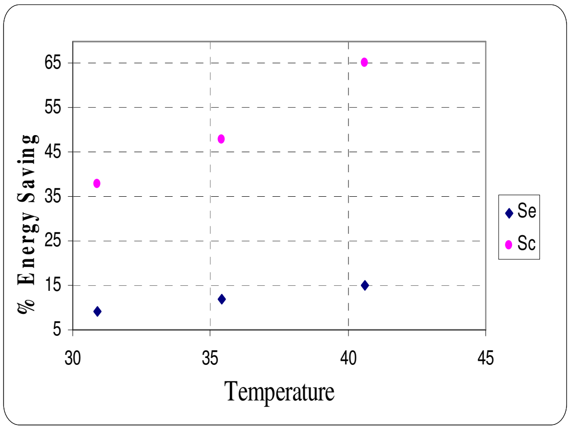

Figure 8. Effect of temperature on energy saving

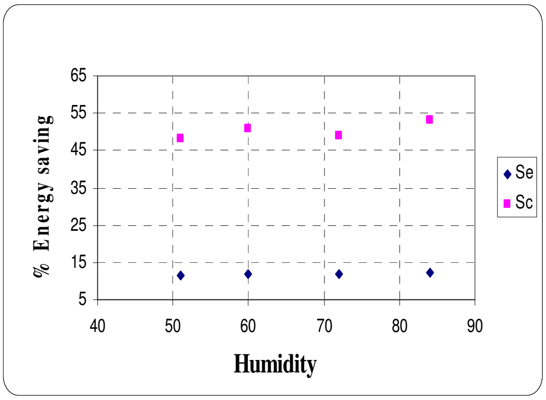

Figure 9. Effect of humidity on energy saving

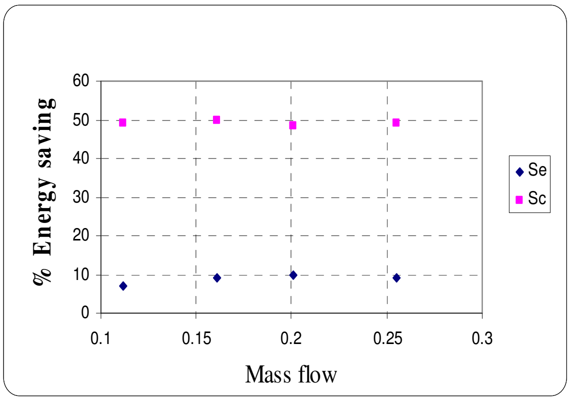

Figure 10. Effect of mass flow on energy saving

7. CONCLUSION

Nowadays energy saving has been paid more attention in the industry because of energy price rising. Air conditioning that wastes a lot of energy is very important process in many industries, so we should consider reduction of this much of energy waste. For this reason, we designed a Heat Pipe Heat Exchanger to be used in a cooling system and all experiments were run once without and repeated with HPHE for comparison. In air condition systems, mass flow, temperature and humidity of input air are important and affect the performance of the system.

From these experiments the following conclusions are achieved:

1. The efficiency on both sides of HPHE increases with increasing input air temperature. If HPHE operates in dry condition (without condensation of the evaporator section) the humidity of input air, doesn't have any effect on the HPHE efficiency.
2. The HPHE efficiency and energy saving on both sides of the HPHE are constant with changes of the input mass flow rate and humidity.
3. Energy saving on both sides of HPHE is a function of input temperature.
4. By using HPHE in air conditioning systems, we can achieve 10-15% of energy saving in the evaporator section of the HPHE for pre-cooling, and up to 40-65% energy saving in the condenser section for preheating.

References

1. .c.Balni, translated by M.R.Emam”Fundamental of Air condition”,1987.
2. A.. Farshidian far,A. Fanudi” Modern Airconditionig”2004
3. Sonntag-Borgnakke-Vanwylen ”Fundamental,s of thermodynamics” Fifth edition
4. Faghri, A., “Heat Pipe Science and Technology”, Taylor & Francis, USA, 1995.
5. Sun, J.Y., Shyu, R.J., “Waste Heat Recovery Using Heat Pipe Heat Exchanger for Industrial Practices”, Proceeding of the 5th International Heat Pipe Symposium, Melbourne, Australia, 1996.
6. Kumar S., “Gas production engineering”, Vol.4, 2nd Ed. Gulf publishing co., 1987
7. M.khoshnoodi, SH.Noie”Fundamental and Application of Heat transfer”1993
8. Xiao Ping WU, Johnson, P., and Akbarzadeh, A. “A Study of Heat Pipe Heat Exchanger Effectiveness in an Air Conditioning Application” Proceeding of the 5th internationalHeatPipeSymposium,Melbourne,-1996