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Efect Of Working Fluid On The Performance of Thermosyphon Heat Exchangers In Series Used In An Air Conditioning System

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Abstract. The effect of working fluid on Heat Pipe Heat Exchangers (HPHX) in series used for the purpose of energy conservation in an air conditioning system has been investigated at pilot scale in this paper. The significance of this study is comparison between Methanol and Acetone as working fluids of two HPHXs in series which make them more efficient in contrast to a single HPHX. The results show that use of Acetone in both of HPHXs has the most energy saving in comparison with other cases. However, it is observed that also by filling one HPHX with methanol and one with acetone, acceptable amount of energy is recovered.

Keywords: Air conditioning, Heat pipe heat exchanger, Working Fluid, Thermosyphon, Energy saving

1. Introduction

Because human population is increasing, energy demand and consequently its price have risen. Therefore, energy saving is one of the main subjects in industry. Air conditioning is amongst the most energy consuming systems which need more attention regarding reduction of energy consumption. Heat pipe heat exchangers (HPHX) are proposed as a solution to this problem. Using HPHX will reduce primary energy consumption, thus reducing air pollutions. HPHXs have many advantages such as high heat recovery effectiveness, high compactness, no moving parts, light weight, relative economy, no external power requirements, pressure tightness, complete separation of hot and cold fluids, and high reliability[1]. An important role of the HPHX is to recover heat from warm outdoor air and reheat the dew-point air stream and as a result save energy of reheating. Evaporator of the HPHX acts as a pre-cooler for the warm outdoor air before it reaches the refrigerant system, resulting in enhanced capability of the cooling coil. The condenser of the HPHX is reheating the outlet air stream from the cooling coil and reducing that the relative humidity below 70%. The heat pipe heat exchanger which used in this study is essentially a gravity-assisted wickless heat pipe, which is very efficient for the transport of heat with a small temperature difference via the phase change of the working fluid. It consists of a number of individual thermosyphons. Its tubes filled with a certain amount of working fluid.

The operating characteristics of vertical heat pipe heat exchanger have been investigated extensively in recent years [2-8]. One of 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[9]. Application of heat pipe and thermosyphon technology in air conditioning systems have been studied by numerous researchers. Abd El Baky et.al, in 2007 used HPHX for recovering energy in air conditioning systems. They expressed that when the temperature of inlet fresh air is about 40°C ,heat transfer in condenser and evaporator of HPHX increases about 48% also the results show that HP has the best performance when the inlet temperature is near the temperature of the HP's working fluid[10].

HPHX of thermosyphon type consist of three main sections; evaporator section that is in contact with hot medium and removes heat from it and the working fluid changes from liquid into vapor; Adiabatic section; and Condenser section which is in contact with cold medium and transfers the latent heat of the working fluid to it. One of important advantage of the thermosyphon heat exchanger is that its critical heat flux is 1.2-1.5 times greater than the heat pipe [11]. In practice, the effective thermal conductivity of thermosyphon exceeds that of copper 200–500 times [1].

Any study of air conditioning systems for buildings should mainly be focused on indoor air quality, thermal comfort, energy saving and environmental protection [12]. In contrast, normal comfort conditions for human require temperature of approximately 22 to 25°C, with relative humidity between 40 and 60% [13].

The aim of this study is to investigate the thermal performance and effectiveness of thermosyphon heat exchanger for heat recovery in air conditioning applications with two kinds of working fluids by varying the inlet humidity, mass flow rate and the difference of fresh warm and return cold air temperature through the evaporator and condenser side.

In this study, tests with two series thermosyphon or gravity-assisted wickless heat pipe heat exchanger (HPHX) were carried out at a pilot scale unit.

2. Experimental Setup

In this paper the experiments were run in a pilot shown in Fig. 1, which is consisted of ten different segments connected to each other with a duct, 50cm*60cm in cross section area. A centrifugal fan blew air into the duct with controlled mass flow rate. The velocity of air flow in was measured by an orifice.

The air was going through a heating section consisted of five 1kW U shaped electrical heaters in order to control the input air temperature. A vaporizer of 45cm*40cm*70cm in size made of stainless steel sheets of 2

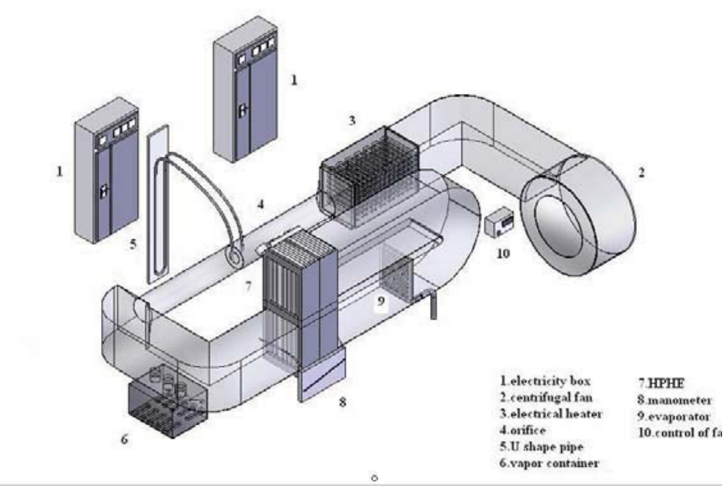

Fig. 1: Schematic of the pilot

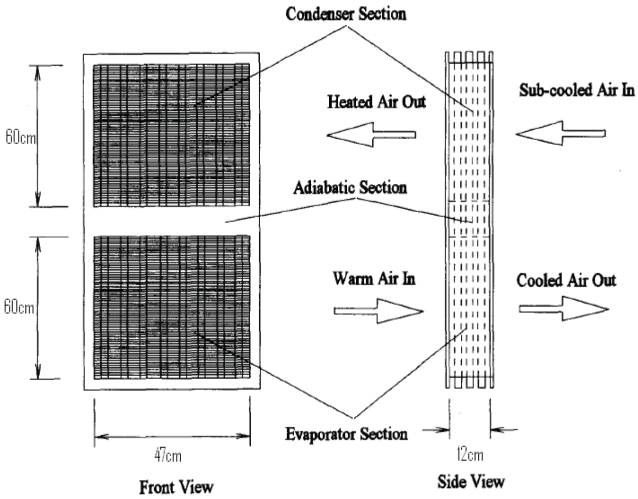

Fig. 2: Schematic of the HPHX

mm thickness was placed before the HPHXs which within it thirty 1kW electrical elements were mounted to heat water and control the humidity of the flowing air.

The HPHXs as schematically shown in Fig. 2 were built of 36 Thermosyphon tubes of 16 mm OD seamless pure copper with staggered arrangement in 3 rows. The tube bank transverse and longitudinal pitches were 37 and 32 mm, respectively. Flat aluminum fins of 0.4 mm thickness and density of 8 fins/inch (along tube length) were attached to the tube bundle. Each HPHX had a total size of 120cm*47cm*12cm. The filling ratios of the working fluid in all experiments were fixed at 60%, while acetone and methanol were used as working fluids.

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

4 Thermocouples were used throughout different sections of the system to measure the temperature and a humidity meter was placed after the vaporizer to monitor the humidity of prepared inlet air.

The performance of the HPHXs and the amount of energy saving were studied in three different cases with variable temperature and humidity of the input air into the evaporator while the mass flow rate was fixed. In the first case both of HPHXs were filled with acetone, then the first HPHX was filled with methanol and the second one with acetone (case 2) and in the third case both with methanol.

3. Theory And Calculations

With input and output flows through the HPHXs shown schematically in Fig.3, the energy saving at the evaporator and the condenser of the HPHXs are calculated, respectively, as:

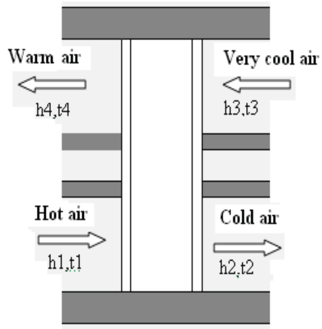

Fig. 3: Streams to and from the HPHX

$$S_e = \frac{h_1 - h_2}{h_1 - h_3} = \frac{m_{dry\,air} * C_{S,1} * (T_1 - T_2)}{\left(m_{dry\,air} * \left(C_{S,1} * T_1 - C_{S,3} * T_s\right)\right) + \left(m_{Water} * \lambda_{Water}\right)} \tag{1}$$

$$S_c = \frac{h_3 - h_4}{h_S - h_3} = \frac{m_{dry\,air} * C_{S,3} * (T_4 - T_3)}{m_{dry\,air} * C_{S,3} * (T_S - T_3)} \tag{2}$$

Where S_e is the ratio of recovered energy in the evaporator section of HPHXs to the required cooling energy to point 3 condition. Whereas S_c is the ratio of transferred heat to the cool air flow as preheating at the condenser of the HPHX to the total heat needed to bring up the refreshing air to the comfort temperature (T_s) which by standards, it should be 18°C[14]. Y is the absolute humidity, λ is the latent heat and C_s is the heat capacity of the air which can be calculated by:

$$C_S = 1005 + 1884Y \quad \left(\frac{J \text{ for mixture}}{kg_{\,dry\,air}\,{}^oC}\right) \tag{3}$$

Ideally we should have h_1-h_2=h_4-h_3, however because of energy waste, always h_1-h_2>h_4-h_3 [1]. Therefore the efficiency of the HPHXs was introduced as:

$$\varepsilon = \frac{h_4 - h_3}{h_1 - h_2} \tag{4}$$

The temperature of the output air from the evaporator of the refrigerating system was controlled manually around 10^{o}C, so at point 3 in Fig.3 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 HPHX is known.

In the dehumidifying process the evaporator section of the HPHX 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.

4. Results And Discussion

As Tables 1. and 2. show, with increasing the input air temperature (T_1) in all cases, energy saving in the evaporator section (S_e) has increased. This is the result of rise in the difference between the input flow temperatures (T_1 and T_3) to the exchangers which is actually the driving force for heat transfer and exchange between warm and cold fluids. Since the recovered heat from the warm stream (h_1-h_2) has gone up, the amount of preheating load has increased so that the parameter S_c has also gained value with increment of input air temperature.

The results confirm that when the humidity of inlet air builds up, S_e declines which in fact is because the latent heat in the denominator of the S_e correlation (Eq. 1) increases. This trend is also repeated for energy saving in the condenser section (S_c).

The remarkable result of this article is that for Cases 1 and 2 the difference between average amount of all parameters (Se and Sc) is reasonable and small however, this is not the situation when Cases 2 and 3 are looked up, so it can be proposed that when we have an expensive working fluid which has well efficiency we can use two exchangers which being placed in series and fill one of them with the expensive working fluid and another with cheaper and use expensive working fluid less than before. Therefore in this paper it appeared that by using Acetone as working fluid of one heat exchanger and Methanol for the other we can have a great deal of thrift.

Accordingly, experimental investigation on the total efficiency of HPHX (ε) reveals that in Case 1 we achieved the largest efficiency among all cases and it appears that in Case 2 we didn't achieve efficiency as good as Case 1, but its value is more than Case 3 which is noticeable.

Table 1. Energy saving in the evaporator section.

S_e				
Temp	RH	Case1	Case 2	Case 3
30	66	0.12	0.13	0.05
35	66	0.14	0.16	0.09
40	66	0.15	0.17	0.1
45	66	0.16	0.17	0.11
40	50	0.23	0.19	0.11
40	60	0.2	0.16	0.1
40	70	0.17	0.13	0.1
40	80	0.12	0.1	0.08
Ave		0.16125	0.15125	0.0925

Table 2. Energy saving in the condenser section.

S_c				
Temp	RH	Case1	Case 2	Case 3
30	66	0.28	0.28	0.08
35	66	0.5	0.45	0.14
40	66	0.8	0.63	0.39
45	66	1.09	0.92	0.55
40	50	0.95	0.8	0.58
40	60	0.94	0.79	0.55
40	70	0.84	0.75	0.36
40	80	0.78	0.48	0.32
Ave		0.7725	0.6375	0.37125

Table 3. Efficiency of the HPHXs

ε				
Temp	RH	Case1	Case 2	Case 3
30	66	0.69	0.65	0.55
35	66	0.81	0.62	0.35
40	66	0.87	0.62	0.68
45	66	0.89	0.67	0.65
40	50	0.86	0.81	1.00
40	60	0.88	0.89	0.95
40	70	0.88	0.93	0.63
40	80	0.95	0.74	0.62
Ave		0.85375	0.74125	0.67875

5. 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, heat pipe heat exchangers in series has been designed to be used in an air conditioning system. Results of experiments with two working fluids used in this research, indicate that it is not necessary to load both heat exchangers with high performance fluid with low heat resistance (in this case acetone) to achieve the desired outcome. Thus reasonable heat recovery and energy saving has been observed with one heat exchanger loaded with acetone and the other with methanol in comparison to the case where both HPHXs working fluid was acetone.

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