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Applications of wickless heat pipe heat exchangers in HVAC systems

Ehsan Firouzfar*, Mohammad Soltanieh[1], Hosien Noei[2]

* Chemical Engineering Department, Islamic Azad University, Quchan branch, IRAN

1, Chemical Engineering Department, Sharif University of Technology, Tehran, IRAN

2, Chemical Engineering Department, Ferdowsi University, Mashhad, IRAN

Abstract

Heat pipes are two-phase heat transfer devices with high effective thermal conductivity. Due to the high heat transport capacity , heat exchanger with heat pipes have become much smaller than traditional heat exchangers in handling high heat fluxes. With the working fluid in a heat pipe, heat can be absorbed on the evaporator region and transported to the condenser region where the vapour condenses releasing the heat to the cooling media. Heat pipe technology has found increasing applications in enhancing the thermal performance of heat exchangers in microelectronics , energy saving in HVAC systems and other industrial sectors. Wickless heat pipe (Thermosyphon) heat exchangers are still a new application in an air conditioning (HVAC) system. The purpose of adding a thermosyphon heat exchanger in a HVAC system is to provide control over the relative humidity (RH) and energy saving. In order to incorporate a thermosyphon heat exchanger in a HVAC system, several changes have to be made to the existing system. This includes the size of the blower, overall size of the unit and the cooling load of the system. Development activity in thermosyphon technology in HVAC systems in Asia in recent years is surveyed.

Key words **:** thermosyphon ,sensible heat ratio(SHR), HVAC systems ,relative humidity(RH), energy saving .

خلاصــه:

لوله های گرمایی وسایل انتقال حرارت دو فاز با ضریب هدایت موثر بالا می باشند. با توجه به ظرفیت انتقال حرارت بالا مبدل حرارتی با لوله گرمایی از مبدلهای حرارتی مرسوم با همان فلاکس حرارتی بالا کوچکتر می باشند. گرما در قسمت تبخیرکننده توسط سیال عامل جذب شده و سیال عامل از مایع به بخار تبدیل و سپس گرما در قسمت چگالنده به منبع سرد منتقل می شود. تکنولژی لوله گرمایی کاربردهای زیادی در افزایش بازده مبدلهای حرارتی در میکروالکترونیک و سیستم های تهویه مطبوع و دیگر موارد صنعتی نموده است. کاربرد مبدلهای حرارتی لوله گرمایی بدون فتیله (ترموسیفون) در سیستم های تهویه مطبوع جدید می باشد. هدف از اضافه نمودن مبدل حرارتی ترموسیفون در سیستم تهویه مطبوع کنترل رطوبت نسبی هوای خروجی و صرفه جویی انرژی می باشد. با قرار دادن یک مبدل حرارتی ترموسیفون در سیستم تهویه مطبوع تغییرات زیادی در سیستم ایجاد می گردد. این تغییرات شامل ظرفیت فن و اندازه کلی واحد تهویه و بار سرمایش سیستم می باشد. در این مقاله پیشرفتهای اخیر در تکنولژی ترموسیفون در سیستم های تهویه مطبوع در آسیا مرور می گردد.

Introduction

As a highly-effective heat transfer element, heat pipes have gradually recognized, and are playing a more and more important role in almost all industrial fields. A heat pipe is an evaporation-condensation device for transferring heat in which the latent heat of vaporization is exploited to transport heat over long distances with a corresponding small temperature difference. The heat transport is realized by means of evaporating a liquid in the heat inlet region (called the evaporator) and subsequently condensing the vapour in a heat rejection region (called the condenser). Closed circulation of the working fluid is maintained by capillary action and /or bulk forces. The heat pipe was originally invented by Gaugler of the General Motors Corporation in 1944, but did not truly garner any significant attention within the heat transfer community until the space program resurrected the concept in the early 1960's[1]. An advantage of a heat pipe over other conventional methods to transfer heat such an a finned heat sink, is that a heat pipe can have an extremely high thermal conductance in steady state operation. Hence, a heat pipe can transfer a high amount of heat over a relatively long length with a comparatively small temperature differential. Heat pipe with liquid metal working fluids can have a thermal conductance of a thousand or even tens of thousands of times greater than the best solid metallic conductors, silver or copper.

There are generally at least five physical phenomena that will limit, and in some cases catastrophically limit, a heat pipe ability to transfer heat. They are commonly known as the sonic limit, the capillary limit, the viscous limit , the entrainment limit and the boilling limit[2] .

Main results

There are three important criteria which relate to human comfort : temperature, humidity and air motion. Comfort conditions for humans require a temperature of between 22 and 25, and relative humidity between 40% and 60% [3] . Air leaving the cooling coils of an air conditioner is usually near dew point i.e. saturated, and its relative humidity can exceed 95% . Thus a reheating coil is placed after the cooling coil to reheat the air and reduce the relative humidity, while keeping the temperature within the comfort range. The application of heat pipes for heat recovery in cold climates is widely recognised. With advancement of heat pipes with a low air pressure drop, made possible by loop configurations, heat recovery applications can be extended to milder climates and still pay for themselves. A new possibility is 'cooling' recovery in summertime, which is now economical enough to be considered. The application of heat pipes to increase the dehumidification capacity of a conventional air conditioner is one of the most attractive applications. By using dehumidifier heat pipes, one can decrease the relative humidity in the conditioned space (typically by 10%) resulting in noticeably improved indoor air quality and reduce power demand. Heat pipe also promise to improve greatly indoor air quality, and at the same time help conserve energy[4] .

Any study of an air conditioning system in a building should be focused mainly on indoor air quality , thermal comfort, energy saving and environmental protection[5]. A design method by using computational fluid dynamic simulation of the dehumidification process with heat pipe heat exchangers was presented by Song et al[6]. They reported that modeling is able to predict the thermal performance and optimize the design of the heat pipe fin stack.

Wasim Saman[7] examined the possible use of a heat pipe heat exchanger for indirect evaporative cooling as well as heat recovery for fresh air preheating. Thermal performance of a heat exchanger consisting of 48 thermosyphons arranged in six rows was evaluated. The tests were carried out in a test rig where the temperature and humidity of both air streams could be controlled and monitored before and after the heat exchanger. Evaporative cooling was achieved by sparying the condenser sections of the thermosyphons. The parameters considered include the wetting arrangement of the condenser section, flow ratio of the two streams, initial temperature of the primary stream and the inclination angle of the thermosyphons. His results showed that indirect evaporative cooling using this arrangement reduces the fresh air temperature by several degrees below the temperature drop using dry air alone. Hospitals, supermarkets and laboratories are often good heat pipe applications. Yau and Tucker [8] mentioned that for many years, heat pipe heat exchangers (HPHEs) with two-phase closed thermosyphons, as show in Fig.1, have been widely applied as dehumidification enhancement and energy savings device in HVAC systems.

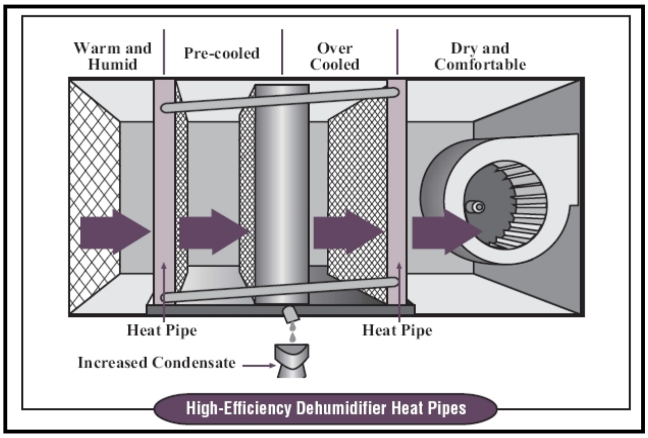

Fig.1.A typical heat pipe heat exchanger (HPHE) applied in HVAC systems.

Literature review indicated that research work related to energy recovery using HPHE carried out in sub-tropical climates are hardly found . Niu et al. [9] studied a HVAC system combining chilled ceiling with desiccant cooling for maintaining the indoor air humidity within a comfort zone and to reduce the risk of water condensation on chilled panels. The results reveal that chilled ceiling combined with desiccant cooling might conserve up to 44% of primary energy use compared to a conventional constant volume all-air system.Yat H. Yau [10] studied an 8-row thermosyphon-based heat pipe heat exchanger for tropical building HVAC systems experimentally. This research was an investigation into how the sensible heat ratio (SHR) of the 8-row heat pipe heat exchanger was influenced by each of three key parameters of the inlet air state, namely, dry-bulb temperature, relative humidity and air velocity . On the basis of his study , it is recommended that tropical HVAC systems should be installed with heat pipe exchangers for dehumidification enhancement. The heat pipe heat exchanger evaporator section functions as a pre-cooler for the AC system and the condenser section as a reheating coil as shown in Fig. 2.

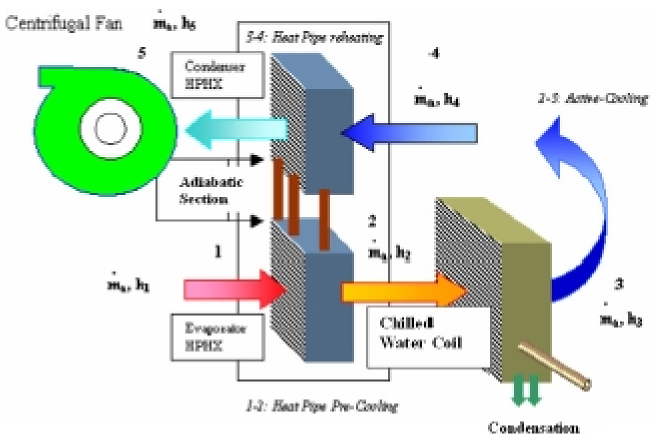

Fig.2. Simple schematic diagram for HVAC model running with a heat pipe heat exchanger[10].

By doing this the cooling capacity for the original system is re-distributed so that latent cooling capability of the conventional cooling coil is enhanced.

In hot and humid tropical climates, the moisture removal capability of the chilled water coil in the HVAC systems can be enhanced if the supply air is pre-cooled before reaching the chilled water coil. For instance, a typical HVAC system at average ambient condition of 32^0C and 58% relative humidity (RH) with total cooling load at 58.5 kw can save 14.4 kw if heat pipe heat exchanger is added into the HVAC system as shown in Fig. 3.

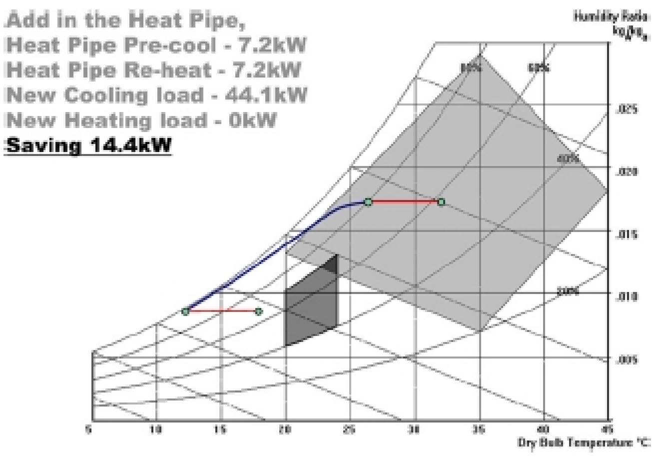

Fig.3. Simple psychrometric processes for a typical HVAC system with an added heat pipe heat exchanger at average ambient conditions of 32^0C and 58% RH.

In similar research, S.H. Noie et al. [11] investigated the effect of input air properties on the efficiency of an air conditioning system with wickless heat pipe heat exchanger at pilot scale. Mass flow, temperature and

humidity were main design parameters of that air conditioning system. Their experiments showed that by using heat pipe heat exchanger in an air conditioning system, they can save around 10-15% of energy in the evaporator and 40-65% in the condenser of the heat pipe heat exchanger.
The latent heat is a considerable factor in calculating the performance of the HPHE in humid conditions. An inaccurate result will be gained if only sensible heat is taken into account by using the Number of Transfer Units (e -NTU) method, which is quit often used for HPHE calculations.An analysis of the evaporator and condenser sections of the thermosyphon HPHE , modelling both warm and cold gas streams as moist air, has been conducted, and the modelled results compared with experimental data by X.P. WU et al.[12]. It was observed that inclusion of latent heat in HPHE modelling can significantly improve accuracy. A new kind of heat pipe dehumidifier is designed and tested by Zhao et.al. [13]. The energy-saving ratio with the heat pipe dehumidifier ranges from 11.81% to 30.34% compared with the normal dehumidifier ,according to the performance testing. The dehumification capacity and the surface cooler power increases, but the energy saving ratio is reduced with the increase of air relative humidity, dry bulb temperature and air quantity.
For calculation of the relative humidity, the data needed are the dry bulb temperature and wet bulb temperature . By measuring the dry bulb and wet bulb temperatures, the enthalpy and relative humidity of the air were determined using a psychometric chart.
Process 1-2 in fig [2] is the heat pipe pre-cooling and can be represented by :

$$\dot{Q}_{\mathrm{hpc}} = \dot{m}_{\mathrm{a}}(h_1 - h_2) \quad (1)$$

Process 2-3 is the air conditioner active cooling and can be represented by :

$$\dot{Q}_{\mathrm{ac}} = \dot{m}_{\mathrm{a}}(h_2 - h_3) \quad (2)$$

The total cooling load for the system is :

$$\dot{Q}_{\mathrm{hac}} = \dot{m}_{\mathrm{a}}\left[(h_1 - h_2) + (h_2 - h_3)\right] = \dot{m}_{\mathrm{a}}(h_1 - h_3) \quad (3)$$

Process 4-5 is the heat pipe reheat load and can be represented by :

$$\dot{Q}_{\mathrm{hpr}} = \dot{m}_{\mathrm{a}}(h_5 - h_4) \quad (4)$$

For process 1-3, sensible heat ratio (SHR) is represented by :

$$\mathrm{SHR}_{\mathrm{Active\ Cooling}} = C_{\mathrm{p}1-3}(T_1 - T_3)/(h_1 - h_3) \quad (5)$$

Where $C_{\mathrm{p1\text{-}3}}$ is the moist air specific heat and can be represented to acceptable accuracy by :

$$C_{\mathrm{p1\text{-}3}} = 1.005 + 1.84\, W_{\mathrm{Active\ Cooling}}\ \mathrm{kJ\,kg_a^{-1}\,K^{-1}} \quad (6)$$

Since the dependence on humidity ratio, W is quite weak, a mean value can be used in Eq.(6),

$$W_{\mathrm{Active\ Cooling}} = (W_1 + W_3)/2 \quad (7)$$

Similarly, for process 1-5, SHR is represented by :

$$\mathrm{SHR}_{\mathrm{NET}} = C_{\mathrm{p1\text{-}5}}(T_1 - T_5)/(h_1 - h_5) \quad (8)$$

The power supplied to the compressor and the blower was measured for calculation of the coefficient of performance , COP[14].

$$\mathrm{COP} = \frac{\text{Total cooling load (Btu/hr)}}{\text{Total electrical power input (W)}} \quad (9)$$

From Fye et al. 's experiments[14] , the COP of the system was lower when the thermosyphon was installed. This was expected because the cooling load was slightly lower. Although the cooling load was decreasing, the constant power supply to the compressor of the air conditioning unit and the blower resulted in a lower coefficient of performance.

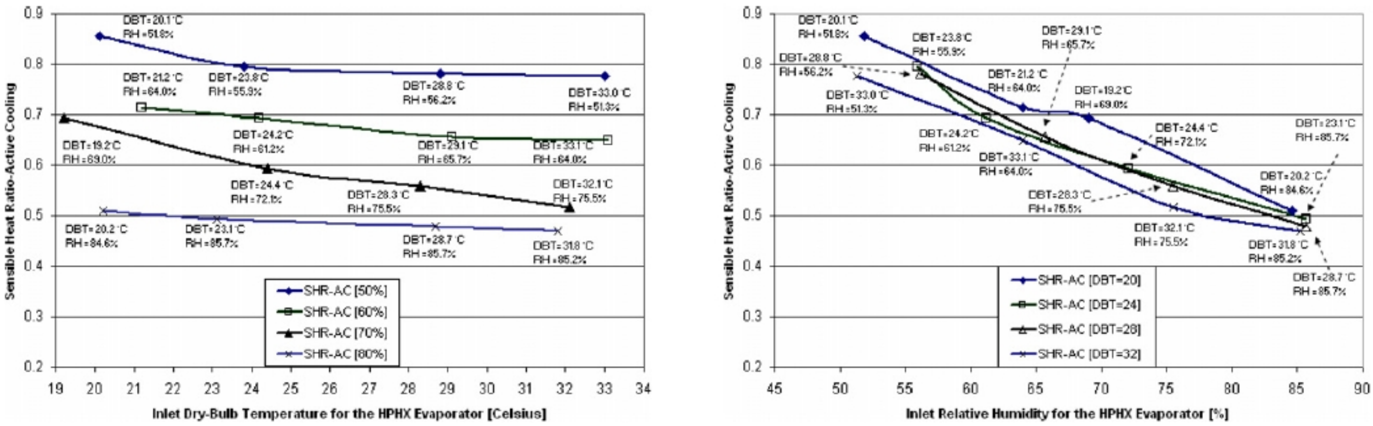

Fig 4. The influence of inlet DBT and inlet RH on sensible heat ratio for mass flux rate 2.2kg/sm²[10]

The experimental results demonstrated that, the overall SHR of the HVAC system was reduced by the heat pipe heat exchanger as inlet DBT or inlet RH increased. These results implied that the moisture removal capability for the HVAC system with heat pipe heat exchanger was increasing as inlet DBT or inlet RH increased so it is recommended that tropical HVAC systems should be installed with heat pipe heat exchangers for dehumidification enhancement.

Conclusion

A short review of wickless heat pipe applications in HVAC systems contains mainly data from some country in Asia which testifies, that heat pipes are very efficient heat transfer devices, which can be easily implemented as thermal links and heat exchangers in HVAC systems to ensure the energy saving and environmental protection.

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*Corresponding author : E - mail : Firuzfar @ yahoo.com