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A study of secondary heat recovery efficiency of a heat pipe heat exchanger air conditioning system

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ABSTRACT

A heat pipe air conditioning (AC) system which used heat pipe heat exchanger (HPHE) to realize secondary heat recovery was proposed. With the meteorological parameter of Hefei city (31°53′N and 117°15′E) as the reference, we analyzed the consuming energy between secondary heat recovery HPHE AC system and the common heat recovery HPHE AC system theoretically. The analysis of experimental data revealed that the average heat recovery efficiency of the HPHE AC system in winter is 21.08%, while 39.2% in summer. The results show that the secondary heat recovery HPHE AC system has a certain energy-saving advantage.

1. Introduction

Heat pipe which has the advantages of the superior heat superconducting ability, steady property, small-sized and controllable structure has been widely used in central AC system; therefore, the optimization of heat pipe performance and the development of new type heat pipe has interested researchers. The gravity heat pipe has proven quite good experimental effect in researches in the reinforcement in heat and visualization of heat transfer [1–3]. The researches of the loop heat pipe prioritize the transient characteristics and development of new type capillary wick, the optimization of the capillary structure, additionally, the high-ranking loop heat pipe, the loop heat pipe of hybrid evaporator, the cryogenic loop heat pipe and other new type of loop heat pipe technology [4–9]. Based on the bronze – ultrapure water heat pipe, the dual channel flat loop heat pipe has been studied, suggesting that under different power supplies the total thermal resistance of such heat pipe is over 20% lower than the single channel loop heat pipe [10]. Loop heat pipe was applied to a photovoltaic-solar loop heat pipe/heat pump composite heating system, setting up the experimental platform and studying the performance of such system [11–13]. The heat pipe compound cooling system suitable for the highly densed electronic integrated system, such as machine room and base stations has been put forward, in which vapor compression refrigeration, vapor compression composite refrigeration/heat pipe and heat pipe cooling partition work mode have been employed with the simulation results that energy saving ratio of such system has increased 40% more than conventional vapor compression refrigeration technology [14]· The application of heat pipe technology in AC system is mainly based on the analysis of the influence of the thermal efficiency upon heat recovery system through studying heat pipe type and compound mode. The HPHE was used in AC system of waste heat recovery unit, and the relationship between fresh air temperature, return air mass flow rate and the system heat recovery efficiency has been experimented [15]. Sodium-stainless steel (STS) HPHE heat transfer performance and temperature range have been studied by numerical simulation, of which the error between the simulation results and the experimental data remains within 5%, steadying in the range of the normal operation, and when the error reaches 11%, the lowest temperature is lower than permissible operating temperature range of the heat pipe [16]. The performance and the energy conserving potential of the HPHE AC system was analyzed through the collected statistical data of the different Indian climatic zones [17]. The field investigation of the supply and demand relations between the existing AC system and the architecture suggests installation of HPHE in AC system and simulation of the specification and quantity of the HPHE that the system will require showing that HPHE has obvious energy saving advantages and economic value [18,19]. HPHE conducts heat exchange via sensible heat, so it can hardly satisfy the require-

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Nomenclature

B	Atmospheric pressure, Pa
d_s	Sonic limit diameter, m
d_c	Carry limit diameter, m
d_b	Fin root diameter, m
d	Humidity ratio, g/kg
F	Frontal area, m^2
g	Gravitational acceleration, m/s^2
G	the air mass flow rate, $kg/(m^2 s)$
H	Air enthalpy, kJ/kg
L_f	Flow length ratio
L	Bundle length, m
W	Bundle width, m
M	Mass flow-rate, kg/s
T	Temperature, °C
η_w	Heat recovery efficiency of winter, %
η_s	Heat recovery efficiency of summer, %
v	Duct air speed, m/s
σ	Surface tension, N/m
p_v	Tube steam pressure, Pa
Δh	Enthalpy difference, kJ/kg
Δp	Pressure loss, mmH_2O
N	the tube row number on the flow direction
f	Friction coefficient
μ	Dynamic viscous, kg/(m s)
γ	Latent heat of vaporization, kJ/kg
Q_c	Sonic limit of heat transfer, kW
Q_{ent}	Carry limit of heat transfer, kW
P_s	Vapor pressure of saturated air, Pa
α	Fresh air ratio, %
φ	Relative humidity, %
ρ_L	Liquid density, kg/m^3
ρ_v	Vapor density, kg/m^3

Subscripts

c	Entrainment limit
L	Liquid state
s	Sonic limit
S	Summer
W	Winter
v	Steam
max	Maximum
con	Condensation section of heat pipe
eva	Evaporation section of heat pipe

ments of dehumidification. The pump-assisted separated heat pipe (PASHP) with working medium R134a was applied in an experiment. In this experiment when the number of sets of heat pipes increased from 0 to 4, the dew point temperature decreased from 11.7 °C to 8.2 °C and the dehumidifying capacity increased by 29.5% in the system. Therefore, when employing PASHP, the dehumidification ability was enhanced and the energy consumption was reduced in the AC system [20,21].

The current researches of HPHE mainly focus on the reduction of the energy consumption of the fresh air (FA) through heat recovery from the exhaust air (EA), rarely dealing with the reduction of the reheating energy consumption for air treatment with heat pipe technology; therefore, a new type of heat pipe heat recovery AC system has been put forward, in which the return air (RA) and supply air (SA) heat exchanger can reduce or eliminate the energy losses of the reheating system, then heat exchange will take place between EA and FA in order to reduce the air treatment energy consumption. This is the secondary heat recovery of HPHE AC system.

2. The comparisons between systems

2.1. common heat recovery HPHE AC system (sign as system A)

In the common heat recovery HPHE AC system (Fig. 1), RA and SA can obtain the goal of energy saving with heat pipe. The FA mixed with RA in cooling coil can reduce the reheating capacity in air treatment and as well the energy consumption of FA in summer. Because the SA volume is greater than that of RA, the reduction of the reheating energy consumption is limited, neither can it solve the problem of high indoor positive pressure caused by continuous SA. Thus this system can only be used in summer but not in winter; and particularly in transitional seasons increasing the amount of FA will significantly lower its energy saving efficiency.

2.2. Secondary heat recovery HPHE AC system (sign as system B)

Secondary heat recovery HPHE AC system (Fig. 2) uses the wick heat pipes to realize the heat transfer between EA and FA, contains multiple sets of horizontal wick heat pipe as the heat exchangers, and places the controller in its middle which is intended to control the temperature of point W1 by adjusting the flow of the returning condensing liquid in the heat pipe to hold sway over the total units of heat transfer. The heat exchanger can both be used during winter and summer; the high-temperature section of the wick heat pipe is the evaporation end, and the low-temperature is the condensation end. In summer, the capillary pump loop (CPL) HPHE makes use of heat pipes to realize the heat exchange between RA and SA; the heat exchanger consists of multiple sets of capillary pump circuit heat pipes, in the middle of which also there is a controller, the pipe sections of RA are evaporation end and sections of SA are condensation end. In summer, the sensible heat of the RA is utilized to heat up the low-temperature air which runs out of the cooling coil, and in winter the device is out of service.

This system has two advantages: In summer, the heat exchange between RA and SA is of the same volume, so the heat that the heat pipes draw from RA should suffice the reheating capacity that SA requires. The heat transfer between EA and FA is also of the same volume, it can maximally reduce the energy consumption in the process of handling FA. In winter the wick heat exchanger works solely, by adjusting the percentage of FA to control the energy-saving issues; During transitional seasons when the percentage of FA changes, if the device is in refrigeration mode the two heat exchangers work simultaneously, but if in heating way, only the wick heat exchanger runs. In both modes the operations proceed at the highest efficiency of heat transfer. Therefore, the system is able to run in all seasons with remarkable energy-saving effects.

3. Calculation of designing the HPHE

3.1. Requirements for designing HPHE

In accordance with the requirements of the experiment we designed two HPHEs with the following specifications: design air volume is 1000 m^3/h; working temperature range of the system is 5 °C ∼ 10 °C; the temperature of working environment ranges within 18 °C ∼ 40 °C; inside the heat pipe the working medium is liquid ammonia (boiling point is 33.42 °C; specific heat: liquid ammonia is 4.609 kJ/kg K). All the single heat pipe should undergo thermal performance test, and the proportion of the pipes whose temperature drop between the two test spots is lower than 2 °C is 100%.