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Operation Analysis on Refrigeration System Combined with Heat Pipe

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ABSTRACT

Sometimes, the traditional refrigeration system should operate even in cold seasons to control the temperature in data centers, control units of power stations. There are problems about operation economy and operating stability. The combination of refrigeration systems with heat pipes could provide a solution to weaken the problems. In this paper, a refrigeration system combining the separate heat-pipe cycle with the coupling of the evaporator is introduced, in which the models of both the refrigeration cycle and heat pipe cycle runs alternately. The evaporator is shared, while the condenser of each other works independently. Then, controllable operation is realized, and the system can not only meet the cooling requirement, but also decrease the energy-consumption in the data center. Using the simulation software DeST, the system is applied to the data center in cold regions with high latitude. The results show the higher latitude the region has, the greater the energy-saving advantage it gets to be.
Keywords: refrigeration, air conditioning, heat pipe, energy saving

1. INTRODUCTION

At present, the data center processing large data gets to play an important role in all the fields. However, the data center, same as the telecommunication base station and the controlling unit in power station, has a strict demand on temperature controlling, and the energy consumption from the air-conditioning system is alarming. In some cases, air-conditioning energy consumption could account for over 50% of the total energy consumption. In order to reduce energy consumption, reducing costs and building green data center is the main task of the modern information construction in all walks of life.

In order to develop economical and reliable air conditioning system, the application of heat pipe on refrigeration has been practiced deeply by many enterprises, scholars and etc. T.S. Jadhav and M.M. Lele b(2015) investigated the HPHX for heat recovery in air conditioning system, and showed the maximum energy saving potential revealed for hot and dry, warm and humid and composite Indian climatic zones. Zongwei Han, et al(2016), numerically analyzed the operating characteristics of the heat pipe for integrated evaporative cooling for computer room air conditioning system, and the integrated system had better energy efficiency, i.e. 31% reduction in energy consumption due to the adoption of evaporative condenser and the separate type heat pipe technology. Their integrated system with heat pipe and the refrigeration system were coupled just on the evaporator, the condenser of each other works independently, the evaporator bear the total evaporation load still, each condenser only need to ensure the condensation load of their own system based on their different operation principles about compression system and heat pipe system. Application of heat pipe on refrigeration could extend with other structures, Behrooz M. Ziapour(2010) analyzed the heat pipe/ejector refrigeration cycle, its COP increased with increasing the evaporator temperature and decreasing condenser temperature, which can reach about 0.30 at Te=10 ℃, Tc =30 ℃ and Tg=100℃.

Heat pipe is a kind of heat transfer component with high conductivity, in the case outdoor temperature is lower than indoor temperature, it can serve as refrigeration unit. In the northern, such as Qiqihar, Moscow and Vladivostok, et al, the average temperature is very low all the year. In the months of 11, 12, 1, 2, 3, the average temperature is below 0℃. However, the temperature set indoor is maintained as 27℃. The temperature difference between indoor and outdoor is quite large.

Moreover, the combined refrigeration system could increase the reliability operating in cold climate since it needn't to work under extremely low temperature environment. And, the main energy consumption components in the heat pipe cycle is just from fans and pumps, the energy consumption is greatly reduced.

In this paper, we combine the advantages of both the heat pipe and the local weather, designing a kind of combined air conditioner with heat pipe unit and vapor compression refrigeration. With this technology, the energy-consumption could be reduced obviously.

2. PRINCIPLE AND PARAMETERS OF THE SYSTEM

2.1 Structure of the combined System

The refrigeration system which is combined with heat pipe could take advantage of saving energy under low temperature environment. But the cooling capacity of the heat pipe would vary with outdoor temperature, the cooling supply just from heat pipe can't meet the requirement of air conditioning over the year.

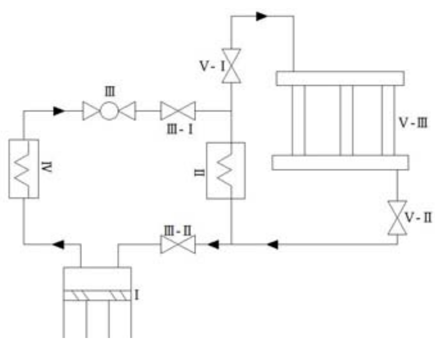


Figure 1 Diagram of refrigeration system combining the separate heat-pipe cycle with one evaporator

In this paper, a kind of air-conditioning combined with heat pipe is introduced in view of air conditioner system in cold regions. On the premise of raising the efficiency and improving the cooling capacity of the system, the system has two operation principles-- the efficiency-priority, and cooling capacity-priority. In other words, if the heat pipe cycle can meet the cooling requirement, the system would apply the efficiency-priority principle, in which the heat pipe cycle is turned on by regulating the three-way valve. In the Contrast, the refrigeration capacity priority would be chosen when the cooling supply of heat pipe is inadequate, which means the power input frequency of compressor would be regulated according to the cooling requirement from users.

In Fig.1, Ⅰ is the compressor ,Ⅱ is the evaporator, Ⅲ is the throttle valve, and Ⅳ is condenser. What's more, Ⅴ symbolizes the cycle of heat pipe. Ⅴ-Ⅰ is the heat pipe loop pneumatic valve, Ⅴ-Ⅱ is the heat pipe fluid loop road valve, and Ⅴ-Ⅲ is the separated heat pipe. Ⅲ-Ⅰ is the fluid road valve of the air-conditioning system, and Ⅲ-Ⅱ is the pneumatic valve of the system.

The pneumatic valve and fluid road valve of the air-conditioning system are on the both ends of the evaporator Ⅱ; Meanwhile, the evaporator Ⅱ and the heat pipe cycle are of parallel structures. The heat pipe line consists of the heat pipe loop pneumatic valve Ⅴ-Ⅰ, the heat pipe fluid loop road valve Ⅴ-Ⅱ, and the separated heat pipe Ⅴ-Ⅲ.

Then, the heat pipe line as well as the evaporator constitutes the heat pipe cycle. The modes of the system are illustrated as followed:

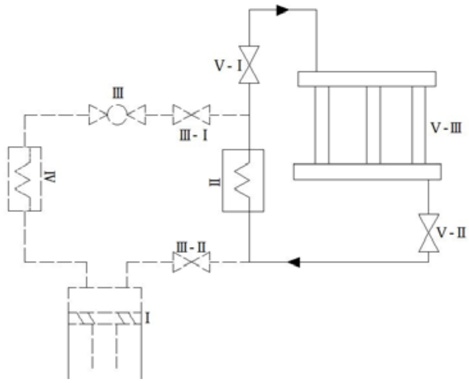


Fig.2 the system under heat-pipe mode

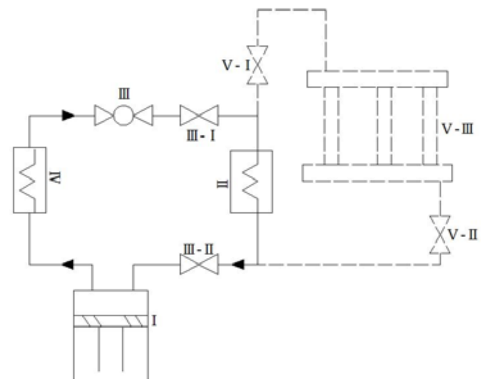


Fig.3 the system under refrigeration mode

(1) Suppose the outdoor temperature is lower than the set-point t0, the first transition temperature, the temperature difference between the closed environment and the outdoor is large, in Figure 2, both of the heat pipe loop pneumatic valve Ⅴ-Ⅰ, and the heat pipe fluid loop road valve Ⅴ-Ⅱ are opened, meanwhile, the fluid road valve, as well as the pneumatic valve of the air-conditioning system must be closed. So, the heat pipe line as well as the evaporator constitutes a closed cycle. Refrigerant would absorb heat and evaporate in the evaporator Ⅱ, then reject heat and condense in the separated heat pipe Ⅴ-Ⅲ. The cooling quantity is provided by the evaporator Ⅱ.

(2) When the outdoor temperature is higher than the set-point t1, the temperature difference between the closed environment and outdoor is small, in Figure 3, both of the heat pipe loop pneumatic valve Ⅴ-Ⅰ, and the heat pipe fluid loop road valve Ⅴ-Ⅱ are closed. At the same time, the fluid road valve, and the pneumatic valve of the air-conditioning system are open. Then Evaporator Ⅱ is access to the traditional refrigeration cycle, and provides the user with the adequate cooling quantity. Here, the traditional refrigeration cycle can be either the Steam compression system or the absorption refrigeration system.

2.2 Model Simplification

To make the analysis more concise and clearer, so the hypothesis is raised for the mathematical model as followed:
⑴The refrigerating capacity of the vapor compression refrigeration is fixed as 1000 kW;
⑵The refrigerant flow process in the cooler is regarded as one dimensional steady flow;

2.3 Working Conditions

Table 1 Refrigeration cycle design condition

Working conditions	Indoor air		outdoor air	
	dry air temperature （℃）	Wet bulb temperature (relative humidity)	dry air temperature （℃）	Wet bulb temperature (relative humidity)
Standard	27	19.5	35	24（40%）
Operating	33	heat humidity ratio 95%	35	24 (40%)

Shown in Table 1, both the demands of temperature and humidity indoor and the working condition outdoor are assumed as the typical conditions.

For satisfying the 1000kW cooling requirement, suppose a vapor compression refrigeration system is arranged, in formal operation case, the compressors take about 315kW, the fans for indoor heat exchanging take about 54kW, the fans for outdoor heat exchanging take about 15.6kW, the pumps for cooled water take about 37kW.

2.4 The design of heat pipe

According to the design requirement, the cooling capacity is 1000kW, and the R134a is chosen as the working medium. The set temperature t_0 is 8℃, once the environment temperature is lower t_0, the heat pipe system would be switched and provide 1000kW cooling capacity continuously. The material for the tube shell and the fin is copper and aluminum alloy respectively. The heat pipes are placed in equilateral triangle, the horizontal tube center distance 0.3m. Suppose the condenser is cooled by natural convective air, the velocity of outside air is set as 2.5m/s.

Based on the assumption, the condenser of the separate type heat pipe could be designed, the logarithmic mean temperature difference is 6.16℃, the overall heat transfer coefficient is 56.03$W/(\mathrm{m}^2K)$, it demand about 2895 m^2 of the total heat transfer area based on the rib side with the condensation length 1461m.

3. ENERGY CONSUMPTION

3.1 Determination of structural parameters

The condenser of the separate heat pipe is designed under the condition that the outdoor temperature is 8℃, and the air velocity is about 2.5 m/s .In fact, its cooling capacity varies with the outdoor temperature. The relationship is shown in Fig.5. It is 1000kW when the temperature of inlet air is 8℃, the total capacity decreases gradually when the inlet air temperature increases. The higher the transition temperature t_0 is, the higher the economic cost gets to be. Besides, the higher the outsider temperature is, the smaller the cooling capacity of heat pipe will get to be. If the temperature is higher than 14℃, the cooling capacity of heat pipe is too small that can even be ignored, compared to the total cooling demand.

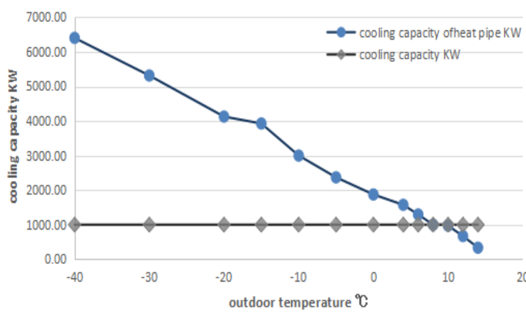


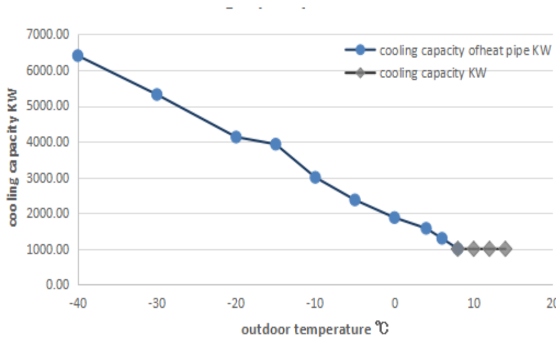
Figure 4 The cooling capacity with two modes

The cooling capacity of heat pipe is large enough to suffice the cooling demand of the air conditioner system when the temperature is at or lower than 8℃. On the contrary, when the temperature is higher than 8℃, the cooling capacity of heat pipe can no longer meet the demand of the air conditioner system. In this case, it is time to turn on the refrigeration mode. Besides, the cooling capacity of the compressor is assumed fixed to simplify the calculation. In Fig.4, there is an intersection where the temperature is about 8℃. Then if the temperature is higher than the transition temperature, the compressor works to supply the cooling demand needed for the data center.

3.2 Energy Consumption Analysis

When the separated heat pipe works, the fan coils for indoor air operates still, and pumps for chilled water from the evaporator need energy consumption, therefore, the total energy consumption in heat pipe mode is 91kW.
When the conventional refrigeration system works, the rate of work is, the energy-consumption is 421.6kW, the COP of the vapor compression refrigeration is about 2.37.

Based on the combined system described in this paper, the potential of cooling capacity is calculated as shown in Fig.5. The lower the environment temperature, the more the cooling capacity provided by the heat pipe system, and the more its COP, moreover, it is always far greater than the COP of refrigeration cycle, as shown in Fig.6.



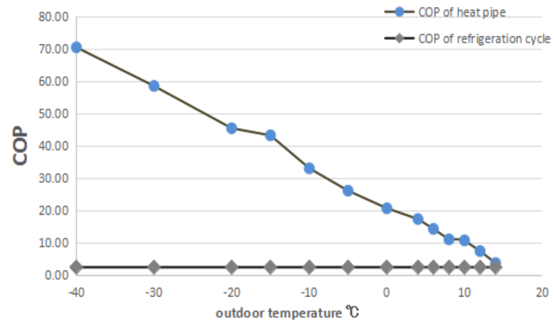


Figure 5 Potential of cooling capacity **Figure 6** Coefficient of performance

The data center and telecommunication station demand to control the temperature all the year, therefore, if the combined system is used in some cities with high latitude, the energy consumption would be saved obviously. Such as Qiqihar is a city in north of China, Fig.7 shows its annual temperature distribution from the data of DeST, there are about more than half a year when the environment temperature is lower than 10℃. It is feasible to cooling the building with heat pipe mode directly.

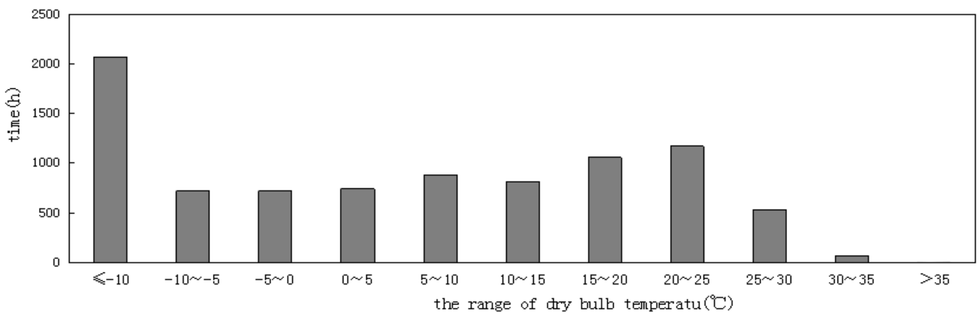


Figure 7 Annual Temperature Distribution in Qiqihar

The similar data about some cities with various latitudes are collected as in Table 2. For Seoul, the total time that the temperature is over 8℃ is about 3960h, the left hours are for heat pipe, meaning that the refrigeration model in this system can run for about half a year, the energy consumption is the sum of the two modes for the whole year.

Similarly, it can be obtained the total time about the temperature distribution in Saint Peters-burg, Qiqihar, Vladivostok, Moscow. Based on the data, the refrigeration system combined with heat pipe could operate with various performances, Table 2 shows the calculated results.

Table 2 Simulation Results of cooling performance for Different region

City	Latitude	Running hours		Energy- consumption	COP
		Heat-pipe	refrigeration		
Seoul	37.33°N	3376h	5384h	$2.557*10^6$ kWh	3.4
Qiqihar	45~48°N	4800h	3960h	$2.106*10^6$ kWh	4.16
Vladivostok	43°09’N	4901h	3859h	$2.073*10^6$kWh	4.23
Moscow	55°45′21〃N	5023h	3737h	$2.033*10^6$ kWh	4.31
Saint Peters-burg	59~60°N	5155h	3605h	$1.989*10^6$ kWh	4.40

In Table 2, Seoul, Saint Peters-burg, Qiqihar, Vladivostok, Moscow, the five cities locate at different latitudes, their climate parameters are different, the lower the yearly averaged temperature could bring the lower operation energy consumption with the combined refrigeration system. In Fig.8, the higher latitude the region has, the more the saved energy in the refrigeration system running in this region, and the COP of the system would increase gradually. Obviously, the COP of the combined refrigeration system is always greater than the COP of the traditional refrigeration system.

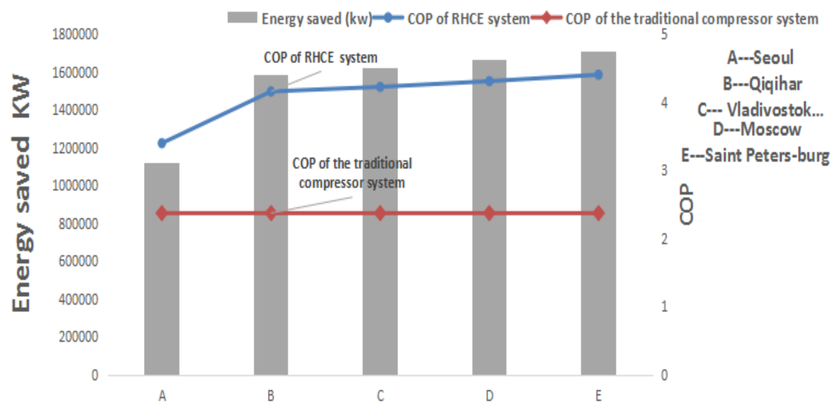


Figure 8 Operation performance in some cities with different latitudes

4. CONCLUSIONS

The combined refrigeration system could be applied in cooling for data center and telecommunication station all over the year, where the heat pipe and the traditional chiller are coupled through the same evaporator, the condensers for each other and the compressor works independently. The principles for the compression system and the heat pipe system are different, the independent condenser only need to ensure the condensation load of their own system, making the refrigeration system more stable, as well as improving safety.

The combined refrigeration could switch the vapor compression refrigeration mode and heat pipe mode alternatively in term of the environment temperature, moreover, in higher latitude cities, the combined system could operate with higher efficiency. As the discussion in this paper, the combined refrigeration system has 50% energy-saving compared to the traditional vapor compression system.

REFERENCES

Ziapour B M, Abbasy A. First and second laws analysis of the heat pipe/ejector refrigeration cycle[J]. *Energy*, 2010, 35(8):3307-3314.

Jadhav T S, Lele M M. Theoretical energy saving analysis of air conditioning system using heat pipe heat exchanger for Indian climatic zones[J]. *Engineering Science & Technology An International Journal*, 2015, 3(4):669-673.

Cao J, Li J, Zhao P, et al. Performance evaluation of controllable separate heat pipes[J]. *Applied Thermal Engineering*, 2016, 100: 518-527.

Han Z, Zhang Y, Meng X, et al. Simulation study on the operating characteristics of the heat pipe for combined evaporative cooling of computer room air-conditioning system[J]. *Energy*, 2016, 98:15-25.

Naghavi M S, Ong K S, Mehrali M, et al. A state-of-the-art review on hybrid heat pipe latent heat storage systems[J]. *Energy Conversion & Management*, 2015, 105:1178-1204.

Wang Z, Zhang X, Li Z, et al. Analysis on energy efficiency of an integrated heat pipe system in data centers[J]. *Applied Thermal Engineering*, 2015, 90:937-944.

Chaudhry H N. A study on optimising heat pipe geometrical parameters for sustainable passive cooling within the built environment[J]. Applied Thermal Engineering, 2015, 93:486-499.
Yan C, Shi W, Li X, et al. A seasonal cold storage system based on separate type heat pipe for sustainable building cooling[J]. Renewable Energy, 2016, 85:880-889.
Ling L, Zhang Q, Yu Y, et al. Study on thermal performance of micro-channel separate heat pipe for telecommunication stations: experiment and simulation[J]. International Journal of Refrigeration, 2015, 59:198-209.
Li J, Lv L. Experimental studies on a novel thin flat heat pipe heat spreader[J]. Applied Thermal Engineering, 2016, 93:139-146.