EFFECT OF LOW-PRESSURE ON THE REFRIGERATING CAPACITY OF DIRECT EXPANSION EVAPORATOR

Guodan. Liu[1†] , Bin. Liang[1], Angui. Li[2], Songtao. Hu[1], and Gang. Wang[1]

[1]*Institute of Environmental & Municipal Engineering, Qingdao Technological University, Qingdao, China*
[2]*School of Environmental & Municipal Engineering, Xi'an University of Architecture and Technology, Xi'an, China*

ABSTRACT

Convective heat transfer coefficient on the air side of direct expansion evaporator under low air pressure is studied by theory and experiment respectively. Results show the convective heat transfer coefficient will diminish along with the density of air under low-pressure. The lower absolute humidity of air under lower pressure will reduce the difference of water vapor pressure between the air supply and air return. And the quantity of latent heat transfer between the evaporator and the air will decrease accordingly. Meanwhile, the process of heat transfer on the refrigerant side will change under low air pressure, which will make the refrigerating capacity become even smaller.

KEYWORDS

Direct expansion evaporator, Lower pressure, Refrigerating capacity, Convective heat transfer coefficient, Sensible heat, Latent heat

0 INTRODUCTIONS

The characteristic performances of air-conditioning equipment are commonly educed on sea level pressure, and it is usually pointed out that the equipment should be used under a limited height in product instructions. However, sometimes the atmospheric pressure of working condition is different from the normal pressure. For example, the working atmospheric pressures in alpine cable cars, high-latitude air-conditioning trains, planes and spaceships are lower than the natural atmospheric pressure. In these cases, it is necessary to study the effect of atmospheric pressure on the performances of air-conditioning equipments.

The refrigerating capacity of air-conditioning namely is the heat exchange capacity between the evaporator and humid air, including sensible heat and latent heat. The effect of atmospheric pressure on the refrigerating capability mainly consists of the effect on coefficient of heat transfer, coefficient of mass transfer between the evaporator and the humid air.

1 EFFECT OF LOW-PRESSURE ON SENSIBLE HEAT TRANSFER

The process of heat transfer on the air side of evaporator takes on the characters of force convection of liquid flowing across fin-tube bundles, and existing formulas solve the problem root in the Grimson formula [1]:

[†] Corresponding Author: *Tel: +86 (532) 8507 1260*
E-mail address: h-lab@163.com

$$Nu = c\,\mathrm{Re}^m\,\mathrm{Pr}^{1/3} \qquad (1)$$

Constant c and m is related to the evaporator's structure and the material of tube and fin, but not the circumstance pressure. So for the same heat exchanger, the values of c and m under normal pressure and low-pressure should be equal, and the mathematical relationships under normal pressure and low-pressure are:

Under normal pressure： $$Nu_0 = c\,\mathrm{Re}_0{}^m\,\mathrm{Pr}_0{}^{1/3} \qquad (2)$$

Under low-pressure： $$Nu_H = c\,\mathrm{Re}_H{}^m\,\mathrm{Pr}_H{}^{1/3} \qquad (3)$$

Suffix 0 means the parameter under normal pressure, and suffix H means the parameter under low-pressure. In the common range of pressure (absolute pressure 0.1×10^5 ～ 10×10^5Pa),the Pr number, dynamic viscosity of air μ and constant-pressure specific heat can be regarded as constant [2][3].Therefore,

$$\frac{Nu_0}{Nu_H} = \frac{c\,\mathrm{Re}_0{}^m}{c\,\mathrm{Re}_H{}^m} \qquad (4)$$

Develop the criterion numbers in equation 4:

$$\frac{h_0}{h_H} = \left(\frac{\mathrm{Re}_0}{\mathrm{Re}_H}\right)^m = \left(\frac{\frac{u_0\rho_0 l}{\mu_0}}{\frac{u_H\rho_H l}{\mu_H}}\right)^m = \left(\frac{\rho_0}{\rho_H}\right)^m = \left(\frac{P_0}{P_H}\right)^m \qquad (5)$$

It can be seen from equation 5 that the coefficient of heat transfer will decline with the atmospheric pressure, as well as the heat transfer capacity.

2 EFFECT OF LOW-PRESSURE ON LATENT HEAT TRANSFER

As the differential equations of heat transfer and mass transfer are similar and so are their boundary conditions, they have the same solutions of non-dimension style. Thus, the process of heat transfer and mass transfer can be analogy. The mathematical relationships of heat transfer can be approximately used in mass transfer problems [1].

$$Sh = c\,\mathrm{Re}^m\,Sc^{1/3} \qquad (6)$$

The mathematical relationships under normal pressure and low pressure are respectively as follows:

Under normal pressure : $$Sh_0 = c\,\mathrm{Re}_0{}^m\,Sc_0{}^{1/3} \qquad (7)$$

Under low-pressure : $$Sh_0 = c\,\mathrm{Re}_0{}^m\,Sc_0{}^{1/3} \qquad (8)$$

So, $$\frac{Sh_0}{Sh_H} = \frac{\mathrm{Re}_0{}^m\,Sc_0{}^{1/3}}{\mathrm{Re}_H{}^m\,Sc_H{}^{1/3}} \qquad (9)$$

Develop the criterion numbers in equation 9:

$$\frac{\frac{\alpha_{D_0} l}{D_0}}{\frac{\alpha_{D_H} l}{D_H}} = \left(\frac{\frac{u\rho_0 l}{\mu}}{\frac{u\rho_H l}{\mu}}\right)^m \left(\frac{\frac{\gamma_0}{D_0}}{\frac{\gamma_H}{D_H}}\right)^{1/3} \qquad （10）$$

Within common pressure range (absolute pressure is 0.1×10^5～10×10^5Pa）, air dynamical viscidity can be considered constant and not related to air pressure[2]. And to certain fan, air pressure cannot influence its volume current velocity [4]. In addition, as an ideal gas, binary gas admixture is true of the formula [5]:

$$D = D_0 \frac{p_0}{p_H} \left(\frac{T_H}{T_0}\right)^{3/2} \qquad （11）$$

Then,

$$\frac{\alpha_{D_0}}{\alpha_{D_H}} = \left(\frac{\rho_0}{\rho_H}\right)^{m-\frac{1}{3}} \left(\frac{D_0}{D_H}\right)^{2/3} = \left(\frac{P_0}{P_H}\right)^{m-\frac{1}{3}} \left(\frac{P_H}{P_0}\right)^{2/3} = \left(\frac{P_H}{P_0}\right)^{1-m} \qquad （12）$$

Form equation 12, we can see that mass transfer coefficient increases with atmospheric pressure drop. But mass transfer also relates to vapor partial pressure. Subsequently, vapor partial pressure variation with atmospheric pressure is discussed in detail.

In the common range of pressure, the proportions of each component of the air change little [5]. According to the definition equation of the moisture content:

$$d = 622 \frac{P_v}{P - P_v} \qquad g / Kg_{\text{dry air}} \qquad （13）$$

So,

$$P_v = \frac{pd}{622 + d} \qquad \text{Pa} \qquad （14）$$

When moisture content changes in limited range, the vapor partial pressure P_v is approximately in direct proportion to environment pressure. So at the same indoor air temperature, the partial vapor pressure of the humid air will decrease with the atmospheric pressure drop.

On the other hand, the saturated vapor pressure in the boundary layer on the surface of the coil is determined only by the saturation temperature. So the vapor partial pressure difference between the moisture air and the surface of the coil pipes is:

$$\Delta p = \frac{pd}{622 + d} - p_s \qquad （15）$$

Next we will study the integrated effect of vapor pressure difference and mass transfer coefficient on the quantity of mass transfer.

The formula of the quantity of mass diffuse is[5]:

$$m_w = \frac{\alpha_D}{R_w T} (p_v - p_s) \qquad （16）$$

So the quantity of mass diffuse under normal pressure and low-pressure is:

Under normal pressure $$m_{w_0} = \frac{\alpha_{D_0}}{R_w T}(p_{v_0} - p_{s_0}) \qquad (17)$$

Under low-pressure $$m_{w_H} = \frac{\alpha_{D_H}}{R_w T}(p_{v_H} - p_{s_H}) \qquad (18)$$

Under the same indoor air temperature, surface temperature of coil pipes and moisture content, the ratio of quantity of mass transfer in normal pressure and low pressure is:

$$\frac{m_{w_0}}{m_{w_H}} = \frac{\frac{\alpha_{D_0}}{R_w T}\left(\frac{P_0 d}{622+d} - p_{s_0}\right)}{\frac{\alpha_{D_H}}{R_w T}\left(\frac{P_H d}{622+d} - p_{s_H}\right)} = \frac{\alpha_{D_0}}{\alpha_{D_H}} * \frac{p_0 d - p_{s_0}(622+d)}{p_H d - p_{s_H}(622+d)} = \left(\frac{p_H}{p_0}\right)^{1-m} * \frac{p_0 d - p_{s_0}(622+d)}{p_H d - p_{s_H}(622+d)} \qquad (19)$$

Thus it can be seen that the dehumidification capacity is related to the saturated vapor partial pressure on the surface of coil pipes, which is determined by the evaporating temperature of air-conditioning handling units, and the atmospheric pressure. The quantity of mass transfer related to atmospheric pressure can be calculated by equation 19.

3 EXPERIMENTAL RESEARCHES

Experiment plan

The evaporator is installed in the high-altitude environment simulation cabin. The state points of air supply and air return can be obtained by testing the temperature and relative humidity. The air volume can be gotten by testing the velocity of air supply. In the experiment process, atmospheric pressure of the altitude environment simulation cabin is set at 101.4,89.8,79.5,70.1,61.6,54.0kpa(which are the atmospheric pressure at the altitude of 0,1000,2000,3000,4000,5000m) respectively, above parameters are tested under each pressure in order to get the quantity of heat and mass transfer of the evaporator.

Experiment results

1） Effect of low-pressure on sensible heat transfer

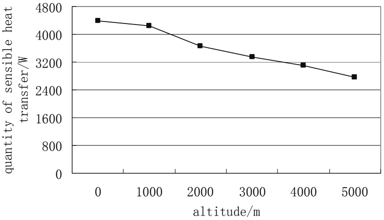

Figure1. Quantity of sensible heat transfer under atmosphere pressures

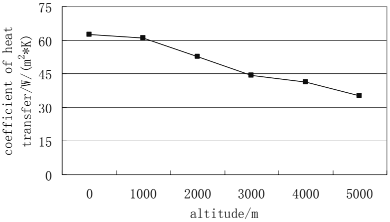

Figure2. Coefficient of heat transfer different under different atmosphere pressures

From figure1 and 2, it can be seen that the quantity of sensible heat transfer and coefficient of heat transfer decline with the drop of the atmospheric pressure. This is in concordance with the theory analysis above mentioned.

2） Effect of low-pressure on latent heat transfer

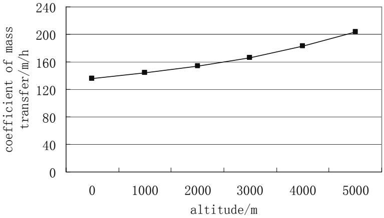

Figure3. Coefficient of mass transfer under different atmosphere pressure

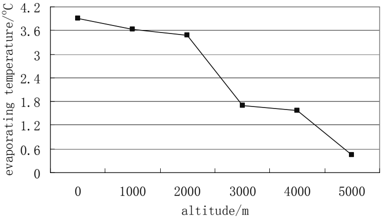

Figure4. Evaporating temperature under different atmosphere pressure

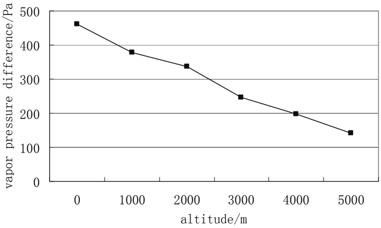

Figure5. Vapor pressure differences under atmosphere pressure

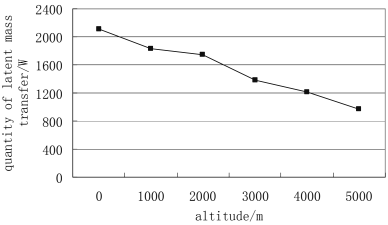

Figure6. Quantity of latent heat transfer different under different atmosphere pressure

From figure 6, it is clear that the quantity of mass transfer decreases with the atmospheric pressure drop. It occurs for two reasons: firstly, the vapor pressure of humidity decreases under lower pressure, which makes the vapor pressure difference between humid air and the surface of coil pipes diminished (figure 2). Secondly, the Re number becomes smaller under lower pressure, and that makes the Sh number decrease. On the other hand, the diffusion coefficient increases under lower pressure. All of these make the mass transfer coefficient increases under lower pressure. As are shown in figure 3 and 5, the mass transfer coefficient increases gently with atmospheric pressure drop, while the vapor pressure difference decreases more sharply. Under the integrated actions of them, the quantity of mass transfer decreases with the atmospheric pressure.

As is shown in figure 4, the evaporating temperature declines with the decline of atmospheric pressure. As a result, the temperature of air supply becomes lower. On the other hand, the dehumidify capability of air-conditioning handling unit declines under low-pressure, so under the same condition of air return, the moisture content of handled air increases. The enthalpy of humid air is related to temperature and moisture content. As enthalpy of processed air increases, the enthalpy difference between handled air and returned air reduces. And due to the reduction of the air density in low pressure circumstance, the mass flux of air declines. Because effects of above factors, the refrigeration capability of air-conditioning declines.

4 CONCLUSIONS

1）The mean convective heat transfer coefficient and quantity of sensible heat transfer decline reduces with the decline of atmospheric pressure.

2）The mass transfer coefficient increases gently in lower pressure, while the vapor partial pressure difference between the humid air and the surface of coil pipes decreases sharply. That makes the quantity of mass transfer and latent heat transfer decreases.

REFERENCES

1. Chen Zhongqi. 1989. Special Topic Forum of Heat Transfer. Press of high education.

2.Hu Songtao, Zhu Chun, Wang Dong, Zhang Changxing., Experimental study on preformance of electric heater under low pressure, Heating Ventilating & Air Conditioning, 2006,vol 3.:22～24

3. Liu Yedi, Zang Jianbin, Qiu Da, Wu Xuanzhong. Discussion of air-conditioning system used in Qinghai-Tibet trains. Rolling stock, 2001, 9: 13～16

4. Nie Xiongguang, Li Fuzhong.1990. Energy Conservation and denoising of fans. Science press.

5. Zhang XImin. 1993. Heat Transfer: China Press of construction and industry.

NOMENCLATURE

α	convective heat transfer coefficient	[W/m^2*K]	T	characteristic temperature	[K]
α_D	convective mass transfer coefficient	[m/h]	Δp	Vapor partial difference	[Pa]
C_A	concentration of A matter in the diffusion direction	[Kg/m^3]	R_e	Reynolds number	
c	constants in heat transfer equation		Sc	Schmidt number	
D	diffusion coefficient of water vapour in air	[m^2 /s]	Sh	Sherwood number	
d	moisture content	[g/$Kg_{\text{dry air}}$]	u	air stream velocity	[m/s]
l	characteristic length	[m]	μ	dynamic viscosity of air	[N.s/m^2]
m	constants in heat transfer equation		ν	kinematic viscosity of air	[m^2 /s]
m_w	quantity of mass transfer	[kg/h]	ρ	air density	[kg/m^3]
N_u	Nusselt number		Pr	Prandtl number	
P	atmospheric pressure	[Pa]	R_w	gas constant	
P_v	water vapur pressure of indoor air	[Pa]	P_w	saturated vapour pressure of coil pipes	[Pa]