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HEAT AND MASS TRANSFER CALCULATION OF THE INTERCOOLER WITH SPRAYING WATER FOR AIR COMPRESSOR

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ABSTRACT

The way of heat transfer with exchanger coil between cooling water and discharge gas is now in common use in the intercooler of air compressors. But the intercooler with spraying water is more effective than that for heat transfer because the discharge gas is in direct contact with cooling water. This paper analyses the process in the intercooler with spraying water and deduces the calculation formulas of main designing parameters depending on heat and mass transfer, two-phase flow and energy equations. In the formulas, each parameter shows evidently its effect to the efficiency of heat transfer.

NOMENCLATURE

Q	heat transter
C_p	constant-pressure specific heat of gas
T	temperature
R	latent heat per unit mass of water
D	containing water vapour in unit mass of dry gas
t	time
F	total surface area of drops
α	heat transfer coefficient
σ	moisture transfer coefficient
X_0	length of spraying water passage
L	average diameter of drops
Y	containing water in per unit mass of gas
Nu	Nusselt number
Re	Reynolds number
A	efficiency of heat transfer
M	mass
N	number of drops
Z	density
S	cross section area of passage
V	velocity, volume
H	specific enthalpy
W	mass flow
R_o	thermal conductivity of gas

C	calculating constant
B	atomizating efficiency

SUBSCRIPTS

g	gas
w	water
b	saturation point on drop surface
a	mean value
o	oil

INTRODUCTION

Intercoolers with exchanger coil is commonly adopted for air compressor, but its heat transfer is not more effective than the intercooler, in which cooling water is in direct contact with discharge gas. Therefore, it is necessary to research heat and mass transfer of the intercooler with spraying water, and discover the relationships among quantity of spraying water, water temperature, air flow velocity, average diameter of drops, relative velocity between water drops and gas, structure and dimension of the device and so on. Depending on the foundation relationships, the excellent design of the intercooler with spraying water can be found.

BASIC STRUCTURE

There are three basic processes to be completed if the discharge gas is in direct contact with cooling water to be cooled. The first is the circulating system of cooling water. Cooling water is got in the intercooler by a pump and sprays discharge gas to be cooled. The cooling water which has cooled discharge gas enters a cooling tower through a pipe by the intercooler pressure, then the cooling water enters the pump entrance after being cooled. The second is separating process. The discharge gas which has been cooled must be separated from cooling water to get into next sylinders to be compressed. There are different separating methods, but in this separation, three aspects must be guaranteed, steady flow to avoid whirlpools carrying small water drops, low separating resistance, and small volume, so that the streamline baffles can be adopted. The detailed design refers to (4). The third is heat transfer process. This process can be simplified to heat and mass transfer between water drops and gas. Through determined coefficients of the calculation formulas which we deduce, we can obtain the main parameter relationship to design the intercooler.

INFERENCE OF CALCULATING FORMULA

We take a infinitesmal volume in the intercooler with spraying water for study and give out the heat and mass transfer formula

$$dQ=[C_p(T-T_b)+R(D-D_b)]\cdot\sigma\cdot dF\cdot dt \quad (1)$$

$$dV=S\cdot V_g\cdot dt$$

where $\sigma=\frac{\alpha}{C_p}$ $dt=\frac{dX}{V_g}$

In order to obtain the relation between heat transfer area and water atomization, let us suppose the average diameter of dtops is L, the number of drops is N, the containing water is dM_w and the gas mass is dM_g in the dV, then the ratio between water mass and gas mass is

$$Y=\frac{dM_w}{dM_g} \tag{2}$$

where $dM_w=\frac{\pi}{6}L^3 \cdot Z_w \cdot N$

$$dM_g=Z_g \cdot S \cdot V_g \cdot dt$$

The surface area of drops in dV

$$dF=N \cdot \pi \cdot L^2$$

$$=\frac{6 \cdot Z_g \cdot Y \cdot S \cdot dX}{L \cdot Z_w} \tag{3}$$

Substituting (3) into (1), we obtain

$$dQ=\frac{6 \cdot \alpha \cdot S \cdot Y \cdot Z_g}{C_p \cdot L \cdot Z_w}[C_p(T-T_b)+R(D-D_b)] \cdot dX \cdot dt \tag{4}$$

Because the process of the heat and mass transfer between water and gas is isobaric in the intercooler, the quantity of heat, which is obsorbed by the gas in the dV, is the enthalpy increase of gas, or the energy equation

$$-dQ=dH \cdot dM_g$$

$$=W_g(C_p \cdot dT+R \cdot dD) \cdot dt \tag{5}$$

Put (4) and (5) together, we obtain

$$dX=V_g \cdot dt=\frac{-C_p \cdot L^2 \cdot Z_w \cdot W_g}{6 \cdot Y \cdot S \cdot \alpha \cdot Z_g} \cdot \frac{C_p \cdot dT+R \cdot dD}{C_p(T-T_b)+R(D-D_b)} \tag{6}$$

where $\alpha=\frac{R_0}{L} \cdot Nu$ $W_g=S \cdot V_g \cdot Z$

If the T_b and the D_b are mean values, or the mean value of the specific enthalpy of water, we integrate (6)

$$X_o=\frac{C_p \cdot L^2 \cdot V_g \cdot Z_w}{6 \cdot Nu \cdot Y \cdot R_o} \cdot Ln\frac{H_{g1}-H_{wa}}{H_{g2}-H_{wa}} \tag{7}$$

The formula will become the limit, 0/0, when the process is iso-enthalpy because of $H_{g1}=H_{g2}=H_{wa}$. In order to infer the formula of the iso-enthalpy process, the condition of the iso-enthalpy is in use and the infering process is same as above. The only difference is that the heat transfer of the heat transfer equation is the quantity of heat obsorbed by the dry gas, or not containing water steam gas. The heat transfer equation and energy equation become

$$dQ=\alpha(T-T_b) \cdot dF \cdot dt$$

$$-dQ=W_g \cdot C_p \cdot dT \cdot dt$$

According to the infering process as above

$$X_o=\frac{C_p \cdot L^2 \cdot V_g \cdot Z_w}{6 \cdot Nu \cdot Y \cdot R_o} \cdot Ln\frac{T_{g1}-T_b}{T_{g2}-T_b} \tag{8}$$

Because the pressure in the intercooler is more than 2 at., the vapour content in gas, D, is nearly constant, so that the calculating formula can be simplified

$$X_o=\frac{C_p \cdot L^2 \cdot V_g \cdot Z_w}{6 \cdot Nu \cdot Y \cdot R_o} \cdot Ln\frac{T_1-T_{b1}}{T_2-T_{b2}} \tag{9}$$

In this formula, T_1 is inlet temperature of gas, T_2 is outlet temperature of gas and T_b is water temperature. When the heat transfer between water and gas is identical current, T_{b1} is inlet temperature of water and T_{b2} is outlet temperature of water. When the heat transfer is adverse current, T_{b1} is outlet temperature and T_{b2} is inlet temperature.

Contrasting (7) and (8) with (9), it is well known that $(H_{g1}-H_{wa})/(H_{g2}-H_{wa})$, $(T_{g1}-T_b)/(T_{g2}-T_b)$ and $(T_1-T_{b1})/(T_2-T_{b2})$ are similarly efficiency of heat transfer, which is decided by designing, so that the ratio is called designing parameter. (7), (8) and (9) are merged in a general fermula

$$X_o=\frac{C_p \cdot L^2 \cdot V_g \cdot Z_w}{6 \cdot Nu \cdot Y \cdot R_o} \cdot LnA \tag{10}$$

This is the calculating formula of heat transfer in the intercooler with spraying water, which shows the relation among the efficiency of heat transfer A, the length of spraying water passage X_o, the velocity of gas V_g, the average diameter of drops L, and the containing water in per unit mass of gas Y. Depending on the implication of the parameters in the formula, the formula can become

$$X_o=\frac{C \cdot V_g \cdot B}{N_u} \cdot Ln \cdot A \tag{11}$$

where $C=\frac{C_p \cdot Z_w}{6 \cdot R_o}$ $\quad B=\frac{L^2}{Y}$

The C is calculating constant and the B is atomizating parameter. The Nu can be obtained by

$$Nu=2+0.386(Pr \cdot Re)^{0.5}$$

In order to obtain the length of spraying water passage X_o, the experimental data of the spraying room of air conditioning was measured in Second Cotton Mill, Beijing, China. See [2].

	V_g; $\frac{m}{s}$	T_{w1}	T_{w2}	H_{wa}	H_{g1}	H_{g2}	X_o	(X_o)
Js: China	6.00	18.1	20.8	13.3	17.7	15.0	1.84	1.88
Luwa: Swiss	5.99	14.9	18.9	11.1	17.5	13.2	1.80	1.80
Luwa: Swiss	6.56	14.6	18.8	11.0	18.9	14.6	1.90	1.95

The experimental data was measured in a round pipe with spraying oil for cooling discharge gas of air compressor. See [3]. $T_{g1}=120℃$; $W_g=12Kg/min$; $P=2.6Kg/cm^2$.

W_o;l/min	T_{o1}	X=0.4	X=0.7	X=1.0	X=1.4	X=2.1	X=2.8
21.39	60	82.7	79.3	77.1	76.8	75.2	73.7
19.76	60	85.0	81.1	78.5	78.1	76.7	75.0
17.82	60	87.4	83.1	79.4	79.7	78.2	76.7
15.98	60	89.0	85.0	81.3	80.8	79.5	78.1
21.54	65	85.4	82.1	79.7	79.9	78.5	77.2
19.98	65	87.1	83.7	80.9	80.9	79.8	78.3
18.33	65	89.4	85.6	82.1	82.2	81.1	79.7
16.53	65	90.9	87.7	83.7	83.7	82.6	81.2

The calculating results is satisfactory with experiments by the above formula. The length of spraying water passage in the intercooler ought to be 1.5m according to the above data.

CONCLUSION

The formula (11) is suitable for designing the intercooler with spraying water. In which the relation among the main parameters can be found. X_o is the length of spraying water passage, V_g is the gas velocity, C is the calculating constant, B is the atomizating parameter, Nu is the Nusselt number and A is the efficiency of heat transfer. C and Nu can be obtained by calculating. X_o and V_g are the designing parameters of the intercooler. X_o ought to be 1.5m and V_g ough to be 6~12m/s. Ln A is requiring parameter for the intercooler, which is 2.3~4.6, B is dependent on water distribution in the gas passage of the intercooler, which ough to be more by designing way in spraying water.

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