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The Intercooler with Spraying Water for Air Compressors

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THE INTERCOOLER WITH SPRAYING WATER FOR AIR COMPRESSORS

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ABSTRACT

A spraying water device to cool gas can be used in the intercooler of air compressors instead of the heat exchanger. It is more effective for heat transfer because the gas is in direct contact with the cooling water sprayed on to the gas. This paper gives the cooling form, the separating water method from gas, and the calculating formula for heat transfer. Through experiments under the normal pressure, the calculated result of the formula is satisfactory and the separating process, using a group of streamline baffles to block water, has a low pressure drop and a better separating effect, water content is 0.1 % after separation. The content does not influnce the next compression.

SYMBOLS

F	resistance
C	resistance coefficient
R	density
L	average diameter of drops
V	velocity
t	time
a	acceleration
m	drop mass
R_e	Reynolds number
Z	length
v	viscous-force
B	distance between the baffles

N safe coefficient; number of the baffle holes

Q heat transfer; volume flow

D diameter; water vapour content in air

x velocity coefficient

e shrinkage coefficient

H altitude of water

N_u Nusselt number

Y mass ratio of gas / water

C_p constant-pressure specific heat of gas

E thermal conductivity of air

S cross section area

T temperature

r latent heat of water

W mass flow

i specific enthalpy

SUBSCRIPTS

g gas

w water

n vertical direction of curve

b saturation point

a average

INTRODUCTION

The intercooler system with heat exchangers is commonly adopted for air compressors, but its heat transfer is not more effective than cooling water is in direct contact with the gas. Therefore, the heat exchanger in a intercooler may be replaced by this device in which the gas is directly cooled by cooling water sprayed on to the gas by spray heads. It can obtain good results because the heat resistance decreases and the heat transfer area increases. The main questions to be solved in the new method are, how to separate the gas from the cooling water for putting the gas into next sylinders to be compressed and how to increase the heat transfer effect.

SEPARATING WATER FROM GAS

Separating water from gas has different methods, but in this separating process, 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 are adopted as shown in Fig. 1. When airflow with drops passes the baffles, drops can run into the baffles as a result of acceleration, then flow down along the baffles. In order to prevent water from passing the baffles, several water grooves must be made on the baffle and the water grooves can be of various types, shown in Fig. 2. Because the model of the baffles is a streamline curve, the separating process has a low pressure drop.

According to the two phase flow theory, the basic formulas of drop movement between the baffles are

$$F = C \cdot \frac{\pi}{4} L^2 \cdot \frac{1}{2} R_g \cdot V_n^2$$

$$\frac{dV_n}{dt} = a_n - \frac{F}{m}$$

$$C = \frac{24}{R_e}$$

boundary condition: if $t = 0$, then $V_n = 0$; $Z_n = 0$
therefore count out

$$Z_n = \frac{a_n \cdot R_w \cdot L^2}{18 \cdot R_g \cdot v}\left[t + \frac{R_w \cdot L^2}{18 \cdot R_g \cdot v}\left(1 - e^{\frac{-18 \cdot R_g \cdot v}{R_w \cdot L^2} \cdot t}\right)\right]$$

$$t = \frac{Z}{V}$$

Using this formula, a certain curve of the baffle can be chosen and the distance, Z_n, between the baffles can be decided depending on the separating time and the smallest diameter of the drops to be separated. But it is necessary to add a safety coefficient to prevent small drops from passing through the baffles.

$$B = N \cdot Z_n$$

A series of experiments under the normal pressure has been done to prove the separating effect of this method. In the experiments, the airflow to be separated is conditioned to more than 95 % relative moisture and contains a great number of small drops, using spray heads to spray water on to the airflow. Then the airflow passes through the baffles. It is determined that the water content in the airflow after separation reaches below 0.1 %, or below a gram water in a kilogram gas, the pressure drop of the separating process is about $4 \sim 10$ mmH_2O when the scope of separating speed is $4.5 \sim 6.5$ M/S, and the separating length is only 200 mm. Using the experiment result, the actual pressure drop can be counted under different pressures in the intercooler and a suitable separating speed can be chosen.

According to the reseach in the inner cooling compressors with spraying water into cylinders, the following compression is not affected by the gas which has been separated and this situation has an extra benifit of saving energy. The kind of separating method can be used in the first step of separating oil from gas in the rotary compressor with oil injection.

HEAT TRANSFER

In order to increase the heat transfer effect, a spraying-showering cooling form is chosen in the intercooler, shown in Fig. 3. The gas of high temperature comes into intercooler from the bottom inlet, firstly flow through several showering plate channels to be cooled by showering water which comes from the above showering plate to the bottom showering plate. It then goes into the spraying water room to be cooled by spray-water which is sprayed by spray heads. Finally the gas is separated by the streamline baffles. The cooling water, comes from the spray heads, falls down the first showering plate, then falls to another by gravity action. Finally it goes out from the bottom water outlet by the pressure difference. The flow of the outlet water can be controled by an automatic controlling instrument.

The number and the diameter of the showering plate holes can be designed by the following formula

$$Q = N \cdot \frac{\pi}{4} D^2 \cdot \dot{x} \cdot e \sqrt{2gH}$$

but a certain water altitude on the plate must be guaranteed to prevent the gas from passing through the plate holes thus decreasing the heat transfer effect.

According to the basic equation of the heat and mass transfer, the heat transfer formula can be written down in an infinitesimal, dZ

$$dQ = \frac{6N_u \cdot Y \cdot R_g \cdot S \cdot E}{C_p \cdot R_w \cdot L^2} \left[Cp(T_g - T_b) + r(D_g - D_b) \right] dt \cdot dZ$$

The energy equation is

$$dQ = -(C_p \cdot dT_g + r \cdot dD_g) \cdot W_g \cdot dt$$

then obtain

$$dZ = \frac{-C_p \cdot R_w \cdot L \cdot V_g}{6N_u \cdot Y \cdot E} \cdot \frac{C_p \cdot dT_g + r \cdot dD_g}{C_p(T_g - T_b) + r(D_g - D_b)}$$

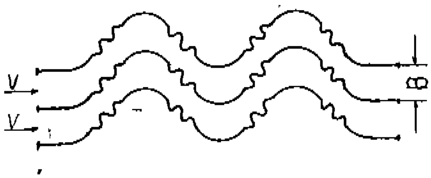
This formula can be simplified yet

$$Z = \frac{C_p \cdot R_w \cdot L^2 \cdot Vg}{6N_u \cdot Y \cdot E} \cdot \mathrm{Ln} \frac{i_1 - i_{ba}}{i_2 - i_{ba}}$$

Through testing the formula with experiments under the normal pressure, the result is satisfactory. Using this formula, the calculating process is simple and convenient. It can be executed in i - D chart of the same pressure as that in the intercooler,similar to the computation of the air conditioning engineering in the air washer.

CONCLUSION

A new intercooler of the air compressor, with spraying cooling water on to the gas to transfer heat, is put forward. In this intercooler the streamline baffles are adopted to separate water from gas and have a low pressure drop and a better separating effect through experiments. This separating method can be used in the first step of separating oil from gas in the rotary compressor with oil injection. The designing method for the baffle curve and the distance between the baffles, and the calculating formula of the heat transfer in the intercooler are deduced.



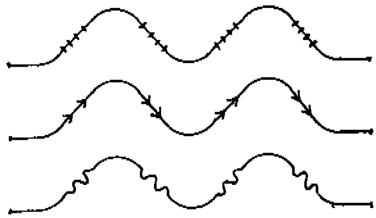


Fig. 1 Streamline baffles

Fig. 2 Different water grooves on baffle

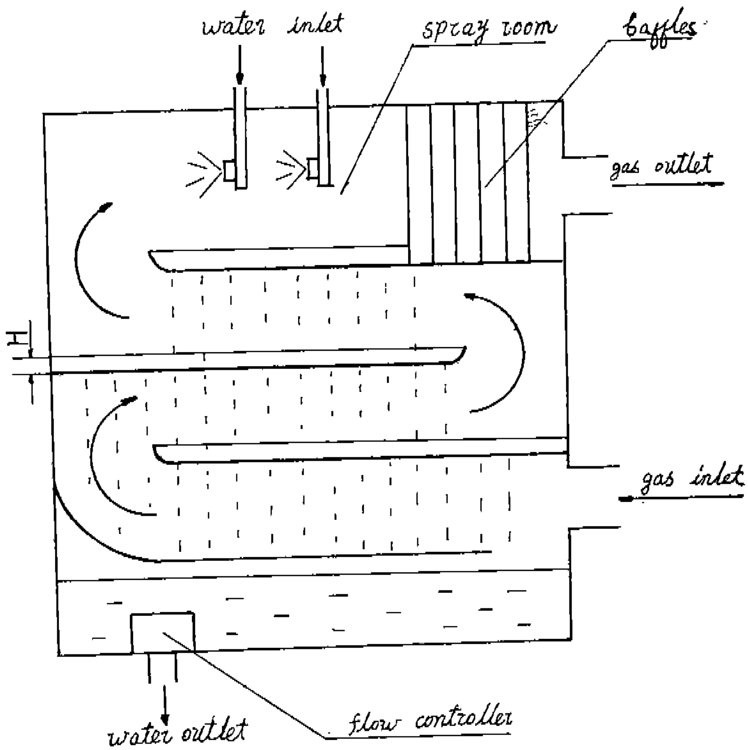


Fig. 3 The sketch map of the intercooler with spraying water

PREDICTIONS OF HEAT TRANSFER IN COMPRESSOR CYLINDERS

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ABSTRACT

Two numerical models are used to investigate the instantaneous heat transfer between the cylinder walls and gas in a reciprocating compressor. One model uses simple mass and energy balances to predict the bulk thermodynamic properties of the gas in the cylinder. Heat transfer between the cylinder walls and the gas is calculated with a widely used correlation for the heat transfer coeffiecient. The other model solves the unsteady continuity, momentum, and energy equations for the gas in the cylinder using a finite-difference technique. No heat transfer coefficient is needed in this model. Results from the finite-difference model agree quite well with the published results from experiments and similar computations for compressors and non-firing reciprocating engines. The instantaneous heat transfer predicted by the simple model is an order of magnitude less than that predicted by the finite-difference model.

INTRODUCTION

Heat transfer between the cylinder walls and the gas affects the thermal efficiency of reciprocating compressors. The significance of heat transfer has been debated [1, 2, 3], but no definitive answers have been offered for two questions. How important is heat transfer in determining compressor efficiency, and to what extent can designers control the impact of heat transfer?

Research on the effect of heat transfer has taken two basic approaches. The first combines experimental measurements with a heat balance to determine the overall heat transferred to the gas [4, 5, 6, 7]. The advantage of this approach is that it is straightforward. The main disadvantage is that it gives compressor designers little insight into the mechanisms of heat transfer, and the design changes that can improve compressor performance.

The second approach uses a numerical model based on the first law of thermodynamics [2, 8, 9]. An advantage of this approach is that parameters may easily be changed to predict the effects of design modifications. The chief disadvantages