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Experimental investigation of heat exchange process under intensive moisture condition

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SUMMARY

The processes associated with condensation of steam out of steam/air mixture are well known in technology. In practice it is necessary to prepare air for the air conditioning systems at temperatures up to 70 °C and moisture content to 0.1 kg/kg. Intensive moisture release from the air leads to a formation of film of liquid on the heat exchange surface which results in an increase of thermal resistance to heat transfer. When calculating heat exchangers, it is imperative to assume a thickness of this film.

Experimental investigation has been conducted to determine a film thickness at an installations that comprised rows of ribbed pipes washed, in series, with steam/gas flow. The flow was cooled with water prepared for a delivery to the experimental unit.

The parameters of the study were as follows: heat flow density related to the outer surface area: from 985 to 1,520 W/m^2 , mass velocity: 4.5 kg/m^{2}s; flow temperature: from 49.0 to 70 °C, air moisture contents: from 0.08 to 0.1 kg/kg.

The obtained experimental values of film thickness (0.3...1.0)10^{-3} m may be recommended for use when making calculations of air preparation equipment. Suggested are methods that contribute to a reduction of film thickness on heat exchange surface .

INTRODUCTION

The processes associated with condensation of steam out of steam/air (steam/gas) mixture are widely used in air (gas) drying techniques .

When designing a number of condensation devices, in particular, mechanical air dryers and air conditioners, thermal resistance of the water film formed on the heat exchange surface was not taken into account [1, 2].

In practice, it is necessary to prepare air having considerable moisture content up to 0.1 kg/kg. Under these conditions a liquid film is formed on the heat exchange surface thereby increasing total thermal resistance to heat transfer.

The objective of this study deals with experimental determination of the thickness and, respectively, thermal resistance of the film condensed on the heat exchange surface under conditions of intensive mass transfer.

EXPERIMENTAL STUDY

The experimental installation has been designed as a closed circulating loop of steam/air flow wherein an operating section (air cooler) and zones of air preparation (heater and humidifier) were incorporated.

The working section of the experimental installation was a ribbed pipe heat exchanger. It was made as a steel sheet casing 0.42 m long, 0.165 m wide and 0.2 m high. The casisng had ports for letting steam/air flow in and out, and its inner surface was divided into twelve equal parts wherein ribbed pipes were centrally located.

The particulars of ribs on the pipes were:

- rib diameter - 0.032 m
- space between ribs - 0.008 m
- pipe diameter - 0.012 m
- rib thickness - 0.0045 m
- ribbing coefficient - 10

The schematic disgram of the installation is shown in Fig.1.

In the course of the study, the full heat modelling method under stable heat and mass transfer mode was used.

The study was made with steam/air mixture within the heat flow range characterized by: outer surface of ribbed pipe q_0 = 985 ...1,520 W/m^2; mass velocity of flow w_ρ = 4.5 kg/(m^{2}s), flow temperature t_f= 49.0...70 °C, moisture content d = 0.08...0.1 kg/kg.

During experiments air was prepared with the aid of a heater and steam generator. Cooling water was supplied to the heat exchange pipes of the working section through a head tank. To adjust temperature of the water flow, the heater was installed in the water supply line.

Temperature conditions of the cooled and cooling flows was adjusted so as to change the air preparation process vector in the course of the experiments. During the experiments a reduced heat removal coefficient has been determined as a ratio of heat flow density to the measured difference between average values of flow temperature and heat exchange surface that may be represented as follows:

$$\alpha_j = \frac{1}{\dfrac{1}{\alpha_c \xi} + \dfrac{\delta_f}{\lambda_f}}$$

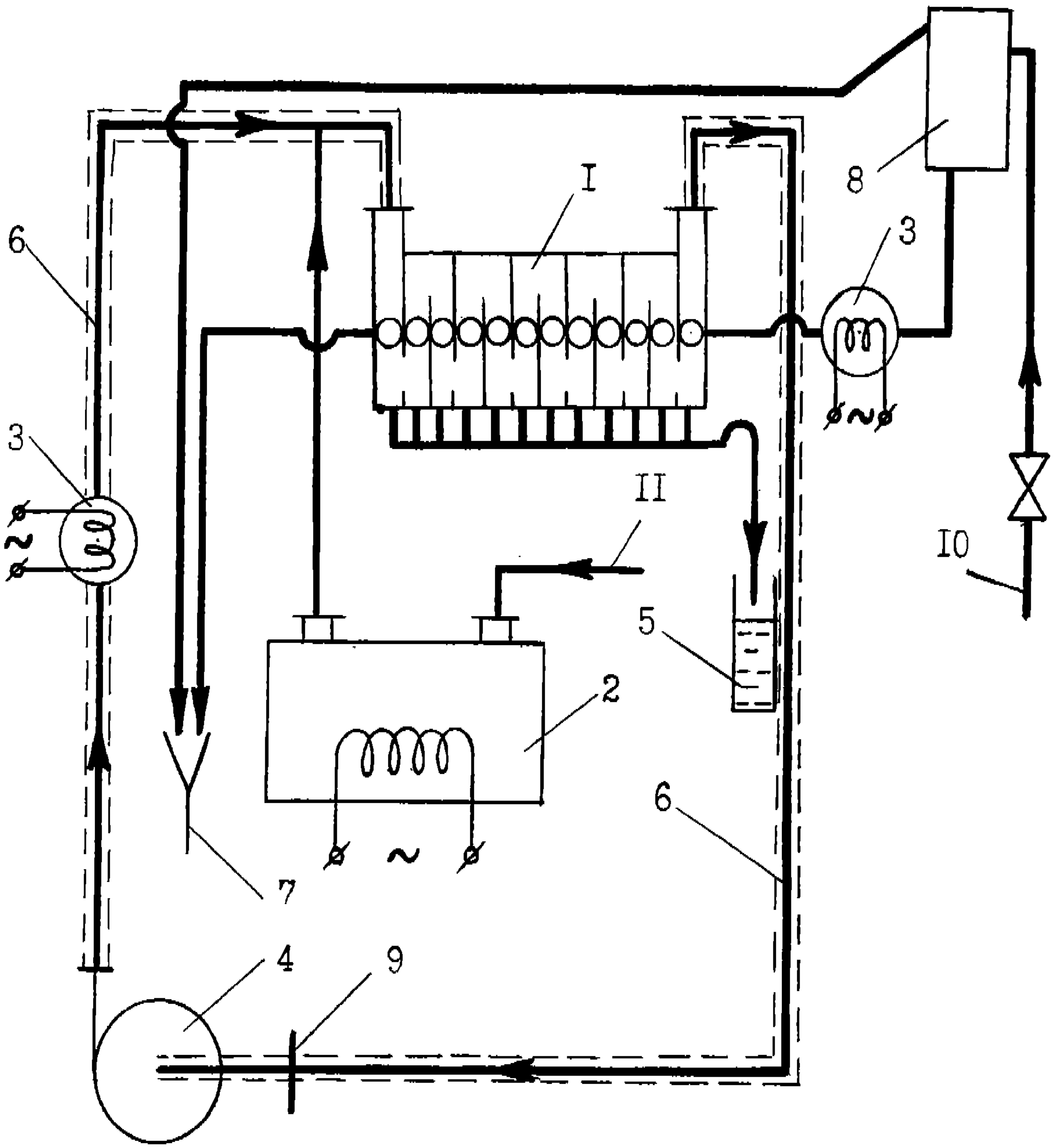

Fig. 1. Schematic Diagram of Experimental Installation
1 - experimental unit; 2- steam generator; 3 - mass metter and flow heater; 4 - fan; 5 - measuring vessel; 6 - air duct; 7 - water outlet; 8 - head tank; 9 - damper; 10 - water duct; 11 - water fresh.

where,

α_c - convective heat removal coefficient determined experimentally under the dry mode, W/(m^{2}K);

δ_f - water condensate film thickness, m;

λ_f - water film heat conductivity coefficient, W/(mK);

ξ - coefficient of moisture formation that characterizes a ratio of the total heat flow to dry flow.

$$\xi = \frac{Q_c + Q_m}{Q_c}$$

where,

Q_c - heat transferred at convective heat flow, W;
Q_m - heat transferred with condensed water mass flow, W.

The value of moisture formation coefficient has been determined, in the experiments, based on the expression used in engineering practice:

$$\xi = \frac{i_1 - i_2}{C'_p(t_1 - t_2)}$$

where,

i_1, i_2 - the enthalpies of steam/gas flow at inlet and outlet of the experimental section, kJ/kg,
t_1, t_2 - temperatures of steam/gas flow at inlet and outlet of the experimental section, ^{0}C,
C'_p - isobario heat capacity of steam/gas flow at its average temperature, kJ/(kg.K).

The calculated value of the film thickness (δ_f) was determined from the equation (1).

In the course of the experiments the experimental section operating modes ware monitored by the amount of the introduced water condensate.

Fig. 2 shows calculated and experimental values of the reduced heat removal coefficient (α_j) depending on moisture formation coefficient (ξ).

CONCLUSION

The experimental values of the average condensate film thicknesses have comprised, within the range of investigated parameters, (0.3...1.0)10^{-3} m and may be assumed when calculating air preparation equipment.

Heat exchange intensity increases with the increase of the moisture component of heat flow

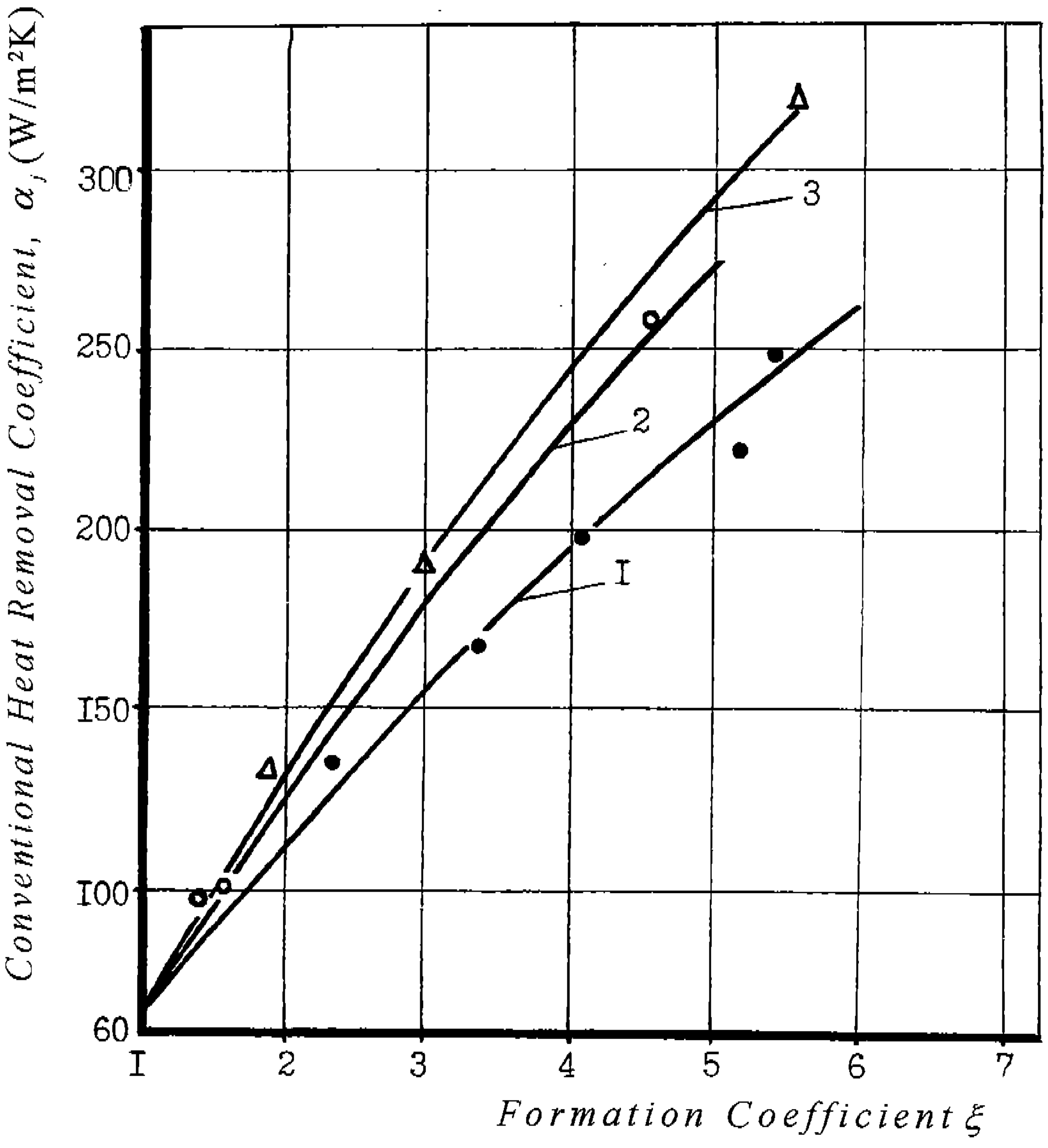

Fig. 2. Conventational Heat Coefficient Versus Moisture
Formation Coefficient ξ at Mass Velocity of Steam/Air Flow w_p = 4.5 kg/m^{2}s
1 - calculated curve at δ_f = 1x10-3m
2 - calculated curve at δ_f = 0.5x10-3m
3 - calculated curve at δ_f = 0.3x10-3m
Δ - experimental values at δ_f = 0.3x10-3m
○ - experimental values at δ_f = 0.5x10-3m
● - experimental values at δ_f = 1x10-3m

(Q_m) and the reduction of the condensate film thickness on the heat exchange surface. In so doing, the experiments prove that a reduction of film thickness under ξ = const. may be achieved due to optimal selection of cooling fluid temperature that determines an inclination of the process vector in the J - d air preparation diagram.

If the heat exchange process cannot be intensified by adjusting the cooling fluid temperature, it is necessary to envisage the devices ensuring mechanical removal of condensate film from the heat exchange surface.

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