

Experimental study of heat transfer from the gas-vapor mixture to the surface in rectangular channel with the water vapor condensation

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Abstract. The laboratory setup was developed for studying the water vapor condensation process from the gas mixture on a vertical flat heat exchange surface in rectangular channel 10×2 cm. The experiments were carried out with normal pressure of steam-air mixture. The results allowed to determine the heat transfer coefficient from steam-gas mixture to the heat transfer surface. The dependences of the heat transfer coefficient on the initial moisture content and the mixture flow rate in the heat exchanger channel were obtained.

1. Introduction

The important task in sphere of energy saving is the flue gas heat recovery for energy and industrial enterprises [1]. The natural gas combustion products contain large amount of water vapor. Using the latent heat of water vapor condensation is called the deep flue gas heat recovery. Designing the surface-type heat exchangers to realize this task involves calculating the heat transfer surface area, which depends on the heat transfer coefficient. A known difficulty is the calculation of the heat transfer coefficient from the flue gases to the heat exchange surface where the water vapor condensation process takes place [2].

Existing methods are limited by the heat medium parameters and structural characteristics of the heat recovery units. Using the calculation method for designing of a new heat exchange unit requires a thorough analysis. Known techniques are based on experimental data on water vapor condensation on the surface of the tube bundle with smooth and finned tubes [1–4]. Criterial equations were obtained for certain ranges of speed and moisture values. Application of the tube bundle is caused by using water as the heated medium.

However, in some cases it is more appropriate to use another medium for heating. For example, the air is used as a heated medium during winter. That significantly increases the heat recovery depth and allows to condense the maximal moisture amount [5, 6]. Such heat exchangers are usually plate-type. The mathematical model of designed condensing plate-type heat exchanger for air heating contains a calculation of the heat transfer coefficient from the flue gases to the air flow, which strongly depends on the heat transfer on the air side as it has lower value. To test the mathematical model adequacy it is necessary to check the calculated heat transfer coefficient by experiment with vapor condensation. Due to lack of experimental data on the condensing surface heat exchangers the task was to carry out series of experiments on the water vapor condensation on a vertical heat exchange surface with the



upward and downward gas-vapor mixture movement in a laboratory setting with close to practical speed and moisture values.

2. Experimental part

The experiment's goal is to determine the heat transfer coefficient from the gas-vapor mixture to a vertical heat exchange surfaces with water vapor condensation. The experimental setup is shown in Figure 1.

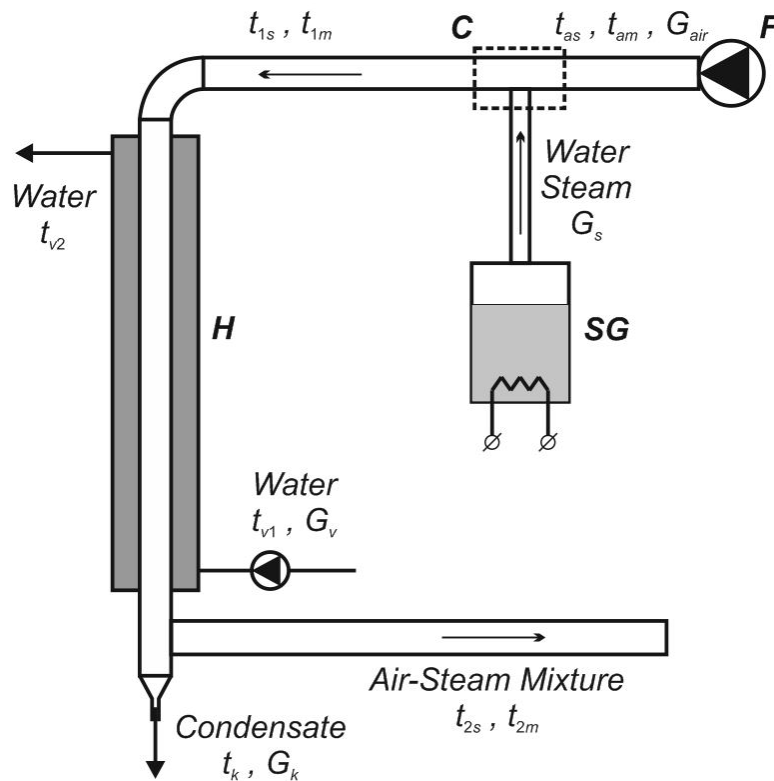


Figure 1. The experimental setup.

As a gas-vapor mixture the steam-air mixture was used. The air stream is fed by fan F to the mixing chamber C where it is humidified by the steam from the electric steam generator SG . The resulting moisture content in mixture is calculated using the initial air moisture and amount of water evaporated in the steam generator. In addition, the moisture content in mixture flow is controlled by the testimony of dry and wet thermometers ($t_{1s}, t_{1m}, t_{2s}, t_{2m}$). The steam-air mixture is fed into a vertical heat exchanger H with the gas passage in form of rectangular cross section 10×2 cm which is surrounded by a cooling water channel. The water is used as a heated medium because the heat transfer coefficient from the wall to water is significantly higher than from the steam-air mixture to the wall. That allows to determine the last one with greater accuracy.

3. Results

During the experiments all the parameters of the steam-air mixture at the heat exchanger outlet (dry and wet bulb temperature) and condensate amount were measured. The cooling water parameters at exchanger inlet and outlet allow to calculate the heat balance. The overall heat transfer coefficient k is calculated by the heat transfer equation. The heat transfer coefficient α_1 from the gas-vapor mixture to the heat transfer surface is calculated from equation (1).

$$k = \frac{1}{\frac{1}{\alpha_1} + \frac{\delta}{\lambda} + \frac{1}{\alpha_2}}. \quad (1)$$

Where α_2 – the heat transfer coefficient from the wall to water; δ/λ – the wall thermal resistance.

The first experiment was carried out without adding steam to the air flow. The founded heat transfer coefficient from the air to the wall was in good agreement with the calculations based on known criterial equation. When the vapor is added to the air stream the heat transfer coefficient increases by several times. The experiments allowed to obtain the heat transfer coefficient values with a margin error 7-10%. Some experimental results are given in the table 1 for mixture flow rate in the channel value about 1.8 m/s. The initial moisture content of the steam-air mixture was varied from 0.01 to 0.2 kilograms per kilogram of dry gas (kg/kg.d.g.).

Table 1. The experimental results for mixture flow rate about 1.8 m/s.

Parameter	Value		
Initial moisture content of the steam-air mixture, kg/kg.d.g	0.01	0.1	0.21
Inlet temperature of mixture, °C	26	59	69
Outlet temperature of mixture, °C	17	42	49
Final moisture content of the steam-air mixture, kg/kg.d.g	0.01	0.06	0.05
Condensate flow, g/s	0	0.19	0.37
The overall heat transfer coefficient k , W/(m ² ·K)	11	44	100
The heat transfer coefficient from the wall to water α_2 , W/(m ² ·K)	135	204	236
The heat transfer coefficient from the steam-air mixture to wall α_1 , W/(m ² ·K)	12	58	174

Next, the effect of flow rate on the heat transfer coefficient value was studied. The flow rate was varied from 1.8 to 3.7 m/s. The results are shown in Figure 2.

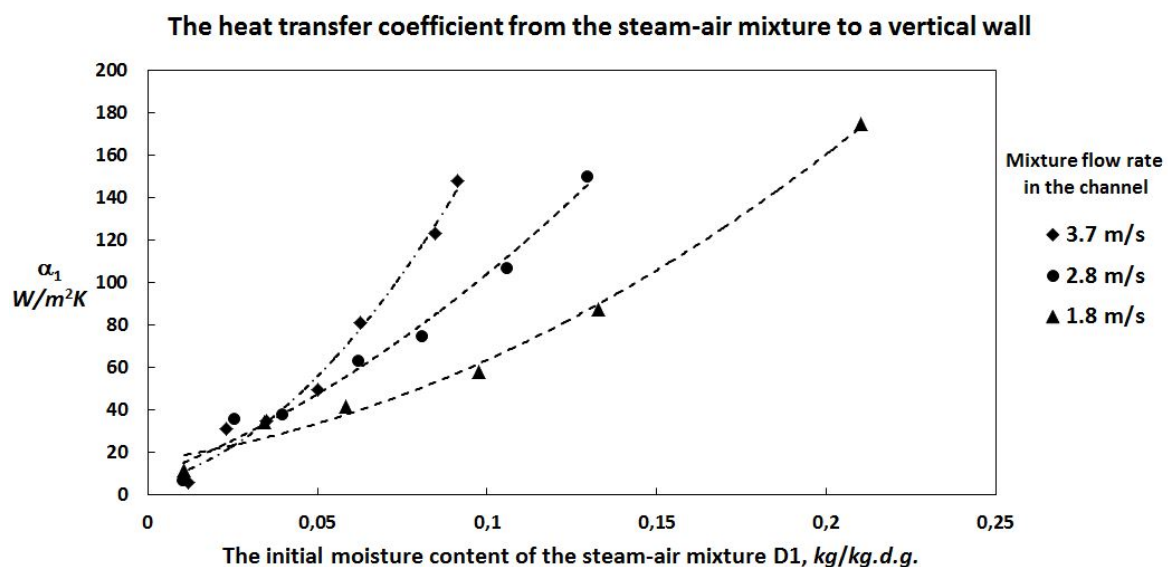


Figure 2. The dependence of heat transfer coefficient on the initial mixture moisture content at different flow rates.

4. Conclusion

The experimental data indicate that the heat transfer coefficient k is in the range from 25 to 100 $W/(m^2 \cdot K)$ and substantially less dependent on the flow rate than from initial moisture content. The water vapor condensation process from the air-steam mixture increases the heat transfer coefficient from mixture to the heat transfer surface by 1.5÷10 times. This means that the decline in the convective component of the heat transfer coefficient α_1 is compensated by mass transfer during the water vapor condensation. For getting numerical equation it is necessary to continue the experiments and analyze the results.

5. References

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Acknowledgments

The study was realized in “National research Tomsk polytechnic university” in framework of federal target program “Research and development in prior directions of scientific-technological complex development in Russia in 2014-2020 year”, unique identifier of R&D project RFMEFI58114X0001.