Experimental Study of Heat Transfer and Flow Characteristics for a New Type of Air Heater

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Abstract: A new type air heater was developed, and an experimental set-up was built to analyze its characteristics. Within the Reynolds number from 2000 to 15000, the integrated characteristics in air heater channels with and without holed baffles have been studied experimentally. The experimental results show that the average *Nu* number increases greatly but the friction factor increases only slightly with the *Re* number. The Webb performance evaluation criterion has been adopted for analysis purposes. It is found that the integrated characteristics of heat transfer and flow friction increase with the hole's diameter at the same hole density (which is equal to the ratio of the hole's total area to the baffle's area), and the heat transfer rate increases with the hole density at the same hole diameter. The *C* type baffle has the best performance at the same heat transfer surface area and fan power consumption; its heat transfer rate improves about 44 to 69 percent.

Key words: holed baffle, integrated characteristics, heat transfer, air flow

1 INTRODUCTION

The heat transfer enhancement technique has been widely used in the fields of air conditioning, refrigeration systems, petroleum and chemical industries, energy, electronic devices, aviation and so on. Augmentation techniques usually employ baffles attached to the heated surfaces in the rectangular channel so as to provide an additional surface area for heat transfer and to improve the mixing process. In recent years, many researchers about augmentation techniques employ baffles focus on two aspects: 1) change the baffle size and position[1~9].2) holed baffles, which allow a part of fluid to pass through the holes and hence the hot zone and form drag are reduced. At the same time, the mixing behind baffles can be increased. The studies have also shown that the holed baffle enhance the heat transfer rate with lower pressure loss penalty. Berner et al[1] experimentally investigated the main features of the flow over baffles and the influence about flow over baffles of different heights. Patankar et al[2] studied the heat transfer enhancement characteristics in a rectangular channel with staggered baffles, Habib et al[4] and Yilmaz et al[7] showed the increase in the pressure loss is much higher than the increase in the heat transfer coefficient, and confirms the results of Kelkar and Patankar and Webb and Ramadhyani[5~6]. Lopez et al[8] reported the heat transfer and flow characteristics in a channel with baffles by the numerical calculation method. Rajendra Karwa et al[9] demonstrated the flow and heat transfer performance in a channel with holed baffle, and present the friction factor have a clear reduction at the same heat transfer compared with the normal baffle. Dutta et al [10~12] studied experimentally the heat transfer characteristics in a rectangular channel with inclined perforated baffles.

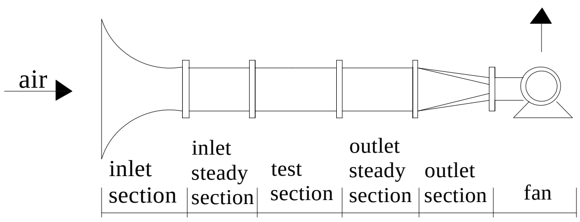
On the basis of the previous works, in this paper, the air flow and heat transfer behavior of a new type air heater, which is constructed by a rectangular duct with some staggered low holed density baffles, was studied and analyzed systematically.

2 EXPERIMENTAL APPARATUS

A schematic view of the experimental system is shown in Fig.1. The experimental apparatus mainly includes several sections: inlet section, inlet steady section, test section, outlet steady section and outlet section. The test section is a rectangular wind tunnel, and it is made of two 10mm aluminum plates(up and base position) and two 15mm adiabatic plates(both sides). The electric heating films are laid on the outside surface of the top and bottom aluminum plates. The electric voltage and current across the heater is kept constant. In this experiment, air flow-rate can be changed by adjusting the manual valve. The main measurement parameters include inlet and outlet bulk air temperature, plate temperature distribution, pressure drop through the heater, air flow rate and the voltage and current.

The thermocouples are mounted on the outer surface of the up and bottom wall of the test section(Fig.2), The temperature readings from thermocouples are all recorded after reaching steady state by using a computer-controlled data acquisition system. Air flow rate is measured by the rotor flow-meter.

Fig. 1 Schematic diagram of the experiment



is controlled at the range of 283~323K.

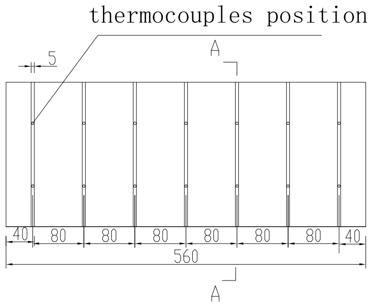


Fig. 2

Schematic diagram of the thermocouple

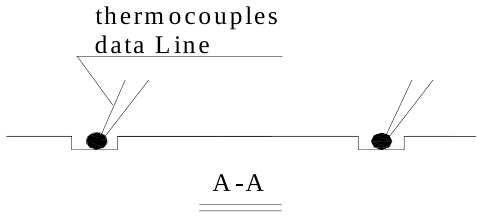


Fig. 3 Holes arrangement in the baffles

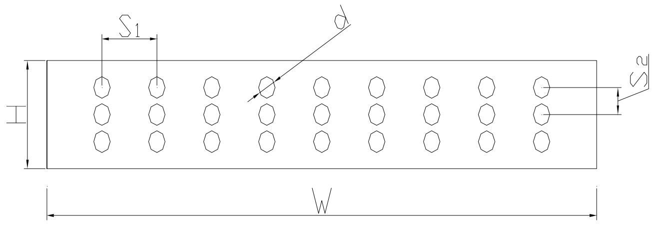


Table 1 The holed baffle geometric parameters

Baffle type	Hole row	Hole diameter d(mm)	Horizontal distance s_1(mm)	Vertical distance s_2(mm)	Hole number n	Hole density (%)
A	-	-	-	-	-	-
B	2	4	20	10	18	3.77
C	3	6	40	7.5	12	5.65
D	3	4	20	7.5	27	5.65

Table 1 shows the holed baffles geometric parameters in this study. Three kinds of holed baffles(B,C and D type) and the normal baffles(A type, without any hole) are designed to study the characteristic of air heater. The holes in the baffle are arranged parallel shown in the Fig.3. All readings are noted under steady-state condition, which is assumed to have been obtained when the temperature doesn't deviate over a 5-min periods, and the air temperature

3 .DATA REDUCTION

The flow Reynolds number is defined as:

$$\mathrm{Re} = \frac{\rho \cdot u \cdot d_e}{\mu} \quad (1)$$

Where ρ is the fluid density, μ is the fluid viscosity, and u is the wind average velocity and d_e is the channel hydraulic diameter. $d_e = \frac{2W \cdot H}{W + H}$.

W is the channel width, H is the channel height.

The friction factor is calculated from the pressure drop across the flow channel using Darcy friction factor equation.

$$f = \frac{\Delta p \cdot d_e \cdot 2}{L \cdot \rho \cdot u^2}. \quad (2)$$

Where Δp is the pressure drop across the channel (the heated test section) and L is the length of the heated test section.

Due to the good insulation of the channel, it is found by measurement that the heat losses to the surrounding is less than 5% of the whole heating. So, it is logically to suppose that the heat released by electric heating films is carried out completely by air through heat conduction and heat convection modes. The heat flux q is calculated as $q = Q/2A$, and $Q = I \bullet U$

Where A represents the surface area of the top and bottom walls, and I and U are the current and voltage applied across the heater respectively.

The average heat transfer coefficient is evaluated from the following equation:

$$\alpha = \frac{q}{T_w - T_f} \quad (3)$$

Where T_w is the average wall average temperature, T_f is the bulk temperature of air.

The average Nusselt number of the channel Nu is defined as :

$$Nu = \frac{\alpha d_e}{\lambda} \quad (4)$$

Where λ is the thermal conductivity of air.

4 RESULTS AND DISCUSSION

For confirm the experiment system, experimentation on the baffled duct is preceded by data collection on smooth duct, and the friction factor and the Nusselt number are determined for the smooth channel and compared with the literature values. The average Nusselt number for the smooth surface(without baffle) is compared with the correlation for a smooth rectangular duct given Yilmaz [7]:

$$Nu = 0.0919 \cdot \mathrm{Re}^{0.706} \cdot \mathrm{Pr}^{0.333} \quad (5)$$

The friction factor results are compared with the correlation for a smooth rectangular duct given by Blasius:

$$f = 0.316 \cdot \mathrm{Re}^{-0.25} \quad (6)$$

The standard deviation between the experimental results for the present smooth channel and correlations in the literature has been found to be under the limits of ±10%. These results ensure the accuracy of the data collected with the present experimental setup.

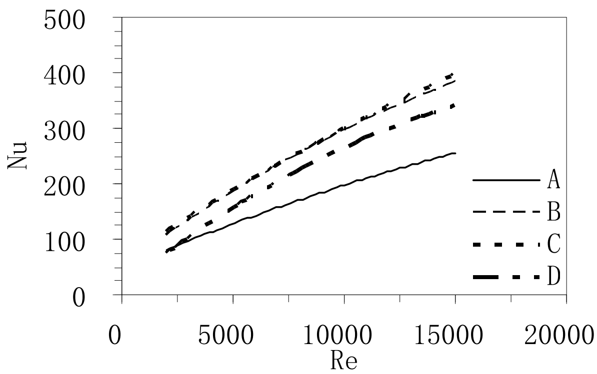


Fig. 4 Average Nusselt number vs. Reynolds number

Fig. 4 shows the variation of the average Nusselt number with Reynolds number for different holed density. It is found that in most cases the baffle with holes will improve the heat transfer coefficient efficiently, and the Nusselt number for all values of the holed density increases with Reynolds number.With the increase of *Re*, the *Nu* almost increases linearly. In this study, the heat transfer coefficients of holed baffles are all higher than the normal baffles, the difference about the behaviour of the normal and holed baffles can be attributed to the different flow structures, when flow over the baffles, the holed baffle allows a part of the fluid pass through the holes and hence the hot zone and form drag are reduced. At the same time, the mixing behind baffles can be increased, and the laminar boundary layer thickness will become thin. All those lead to heat transfer enhancement. For C and D baffles, which have same hole density, the heat transfer effect of C is better than that of D. For B and D baffles, which have the same hole diameter, the heat transfer effect of B(hole density is small) is much better than D. These can contribute to the virtual surface of the heat transfer of B# more than that of D#. Over the range of the Reynolds number studied, the heat transfer performance of C# is the best one, and its Nusselt number is 1.41~1.58 times than that for normal baffle channel. When the Reynolds number is equal to 10000, at least its Nusselt number can increase 50 percent.

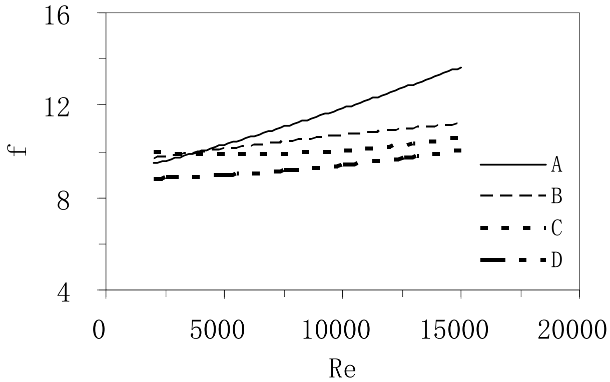


Fig. 5 Friction factor vs. Reynolds number

The curve of friction factor of with and without holed baffle against Reynolds number are showed in Fig. 5. Over the range of the Reynolds number studied, the holed baffle can reduce the pressure drop of channel effectively related to the normal baffles. The reason about reduction of pressure can be attributed to that: one is a part of fluid across the hole directly, the other is that the effect surface of baffle become small. At the same time, when Reynolds number is more than 4000, the friction factor for B is higher than that for C, and that for C is greater than that for D again, greater the hole density, greater the friction factor. That is to say, the values of friction factor decreases with the increasing of hole density. For C and D, which hole density is equal, the friction factor of C is less than that of D. This is because that when fluid flow across hole, the local resistance of the big hole diameter may be smaller than that of the small hole diameter. For B and D, the friction factor of B is more than D, this indicates that the distributary effect of holes become weak when hole density is small, and lead to much greater pressure drop ultimately.

5 HEAT TRANSFER PERFORMANCE EVALUATION

In order to understand the augmentation integrated characteristic for holed baffles, the Webb performance evaluation criterion[13] is adopted to compare the integrated characteristic of holed baffles under the same surface area and friction factor condition. The results of evaluation are showed in Fig. 6, and the calculation equation is defined as:

$$\eta = (Nu / Nu_0 /(f / f_0)^{1/3} \qquad (7)$$

Where Nu_0 and f_0 are the Nusselt number and friction factor for normal baffle respectively.

The values of η increases with increasing Reynolds number. The tendency of the curves about different baffles is very alike.

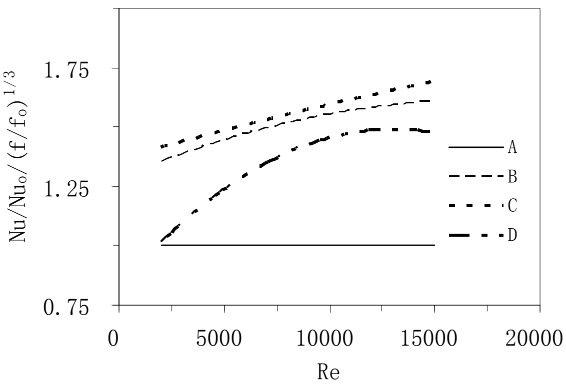


Fig. 6 Performance analysis curves

Under the same heat transfer surface area and friction factor condition, the heat transfer rate is increased 30%~54% than that for normal baffle. At the range of Reynolds number, the number C baffle has the optimum performance, and its heat transfer rate can improve about 44%~69% compared to the results for the normal baffles.

6 CONCLUSIONS

Heat transfer enhancement and friction characteristics in a rectangular channel with and without holed baffle have been studied experimentally. The curves of average Nusselt number and friction factor against Reynolds number are acquired. Webb performance evaluation criteria are adopted, main findings are as follows:

1) The holed baffle can enhance the heat transfer, For C baffle, its Nusselt number is 1.41~1.58 times that for normal baffle. The Nusselt number can average improve 49 percent, when the Reynolds number is more than 10000, the Nusselt number can enhance 50 percent compared with normal baffle at least.

2) When the Reynolds number exceed 4000, pressure drop increases with increasing the hole density, greater hole density,higher the pressure drop.

3) Based on the Webb criteria, at the range of Reynolds number, C# baffle give the best performance, and its heat transfer rate is 1.44~1.69 times than that for the normal baffles.

In future work, the heat transfer augmentation mechanism for holed baffle is very worth to study deeply. Representational holed baffle structure need to be presented.

ACKNOWLEDGEMENTS

The project is supported by the natural science fund of Henan Province （0411054200） by SRF for ROCS, SEM.

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