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A study on performance improvement of corrugated type total heat exchanger considering the structure of flow passage on surface †

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Abstract

Three types of flow passage structure of a total heat exchanger (perforated type, slit type, and embossed and perforated type) are studied to enhance the heat exchange performance of a heat recovery ventilation system (total heat exchanger). The perforated type has four punched rows of 6mm holes in the flow passage channel, and the slit type has six processed rows of 40mm length. The embossed and perforated type has holes of about 1mm diameter and protrusions of about 0.2mm height on all surfaces. The heat exchange efficiency of the modified total heat exchanger was compared to that of a general total heat exchanger with a smooth surface. The Korean Standard (KS) heat recovery ventilator test condition was applied for tests. In the case of cooling operation based on a typical Reynolds number of 140 (typical air flow rate of 100 m^3/hr), the perforated type, slit type, and embossed and perforated type showed temperature efficiency improvement of 1.2%, 2.5%, and 5.0%; latent efficiency improvement of 18.0%, 32.3%, and 24.5%; and enthalpy efficiency improvement of 7.9%, 11.5%, and 11.2%, respectively. The corresponding improvements of heating operation were 3.0%, 3.4%, and 4.0%; 5.0%, 6.6%, and 18.7%; 3.2%, 4.3%, and 7.7%, respectively. On the other hand, the air pressure drop throughout the modified flow passage of the total heat exchanger increased by up to 1.7% at the typical Reynolds number of 140, from the air pressure drop of the regular total heat exchanger.

Keywords: Heat recovery ventilation system (total heat exchanger); Enhancement of heat and moisture transfer; Temperature efficiency; Latent efficiency; Enthalpy efficiency

1. Introduction

As the demand for refreshing indoor atmosphere and healthier environment increases, there have been many studies related to ventilation systems. To maintain a comfortable indoor atmosphere, it must be ventilated with the outside air, and this ventilation causes the energy loss of cooled or heated indoor air. One of the methods which can reduce such energy loss and, at the same time, improve indoor air quality (IAQ) using the ventilator is to apply the heat recovery ventilation system [1-5].

Among the heat recovery ventilation systems, especially in high temperature and high humidity regions, a ventilation system which simultaneously processes both sensible heat and latent heat is needed; currently, membrane filter type total heat exchangers (a total heat exchanger or enthalpy exchanger with hydrophilic membrane cores) are used. A total heat exchanger uses a thin membrane material film which allows heat transfer and partial moisture transpiration between two fluids. Total heat exchangers found in the current market, like the one shown in Fig. 1, generally have direct cross flows without a mixture of hot and cold air, and each flow passage is a corrugated type (front view in Fig. 1). The surface of the corrugated shape is a smooth flow passage due to the production simplicity and the special characteristics of paper. (Top view in Fig. 1)

Zhang and Jiang [6] evaluated the performance of a

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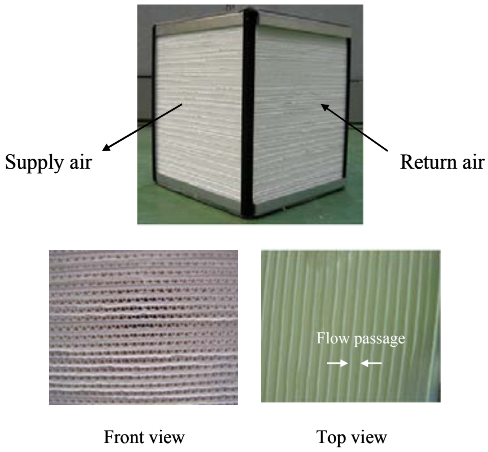

Fig. 1. Schematic view and flow passage for general total heat exchanger.

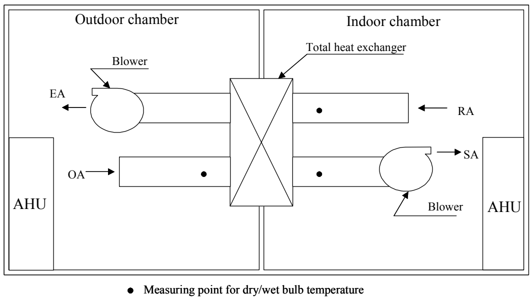

Fig. 2. Schematic view for facility of 2-chamber type.

membrane type total heat exchanger by introducing a mathematical model of heat and moisture transfer. Zhang and Niu [7] proposed a formula related to the calculation of the effectiveness of a total heat exchanger from the NTU (number of transfer unit) for heat and mass transfer. Zhang [8], using the real boundary condition between the surface and flow of a total heat exchanger, indicated the characteristics of heat transfer and mass transfer as a Nusselt number and a Sherwood number, respectively. Bai et al. [9] experimentally evaluated the heat transfer characteristics of a total heat exchanger at various operating conditions. Since most studies evaluated existing total heat exchangers, a detailed study on the performance increase of a total heat exchanger is necessary.

In the case of a metal heat exchanger, the corrugated shape of the flow passage distributes the flow evenly and acts as a fin, which increases the heat transfer area and improves the overall heat transfer. However, in the case of the total heat exchanger, the corrugated shape of the flow passage does not act as a fin due to the low thermal conductivity of the paper material.

The heat transfer enhancement method of common compact heat exchangers can be applied to the total heat exchanger. The well known method of breaking the boundary layer and creating turbulent intensity through the flow passage gives good heat transfer even in a total heat exchanger. Since the air flow rate through the total heat exchanger is relatively low, the effect of heat transfer enhancement in this range is expected to be greater in the total heat exchanger. Compact type heat exchangers use a variety of methods to improve heat transfer performance, one of these methods being the application of flow passage structures such as the louvered fin type, perforated fin type, slit fin type, wavy fin type and offset strip fin type [10]. Louvered type or offset strip type is difficult to apply because of their complicated shapes to total heat exchanger made of paper material. Rather, a simple flow passage structure shall be selected.

The above well known method of heat transfer enhancement for a compact heat exchanger is applied for a relatively high Reynolds number. When the heat transfer enhancement technology for metal materials is applied to the total heat exchanger, the degree of heat transfer enhancement in the range of small Reynolds numbers of a typical operation range of a total heat exchanger must be confirmed. This study focuses on this confirmation. The result from this study contributes to the heat transfer enhancement of a total heat exchanger with both sensible heat transfer and latent heat transfer.

2. Test apparatus

2.1 Apparatus and method of the test

To evaluate the performance of a total heat exchanger, the present study used a standard calorimeter. The performance tests were conducted in according to the Korean Standard KS B 6879 [11]. The calorimeter has two rooms. One simulates the indoor air conditions and the other the outdoor air conditions, required. Fig. 2 indicates the block diagram of the 2-room method, and the size of each chamber was 3.5 (W) x 3.0 (D) x 3.2 (H) m. The AHU is an air-conditioning unit that controls the temperature and humidity conditions in the chambers. The total heat exchanger was installed between indoor and outdoor chambers, and other spaces were isolated by using a polyurethane insulating panel of 0.1m in thickness.

The total heat exchanger was connected to blowers and wind tunnels, which were installed in the indoor chamber (SA side) and outdoor chamber (EA side). When flow is generated between these chambers with different temperature conditions, outside air (OA) will flow indoor through the total heat exchanger, and simultaneously, the room air (RA) for ventilation will be exhausted outdoor (EA) through the total heat exchanger. Meanwhile, the outside air and the room air process heat and moisture transfer through the total heat exchanger. Air-sampling sensors were placed at three different spots to measure the dry bulb and wet bulb temperatures of air. The air flow rate through the total heat exchanger was measured by a differential pressure meter installed at the nozzle on the wind tunnel. When both the indoor and outdoor chambers stabilized (it usually took two more hours), data such as dry bulb temperature, wet bulb temperature, air flow rate, etc., were measured for ten minutes. This procedure was repeated three times. Once the test results fell within an acceptable degree of less than 0.6% of each other, the average of the measured data was used as the performance result of the total heat exchanger.

2.2 The test elements and conditions

This study designated three types of modification in the flow passage structure of a total heat exchanger: first, the perforated type structure with holes processed on the surface flow passage of corrugated shapes; second, the slit type structure with slits processed; and third, the embossed and perforated type structure with both embossing works and holes processed.

Fig. 3(a) shows the perforated type with four rows of 6mm diameter holes processed parallel to the direction of flow. Fig. 3(b) shows the slit type with six rows of slits of 40mm in length. Fig. 3(c) shows the embossed and perforated type with approx. 1.0mm diameter holes and approx. 0.2mm height protrusions all over the field of flow passage. The Fig. 3(d) shows an element of the total heat exchanger made by stacking each type of flow passage on layers. The total heat exchangers have direct cross flows without the mixture of hot and cold air. Although these heat transfer enhancement methods using structural modifications are used in general compact heat exchangers, they have never been used or evaluated in total heat exchangers made of paper material. An existing total heat exchanger shown in Fig. 1 as well as each type of

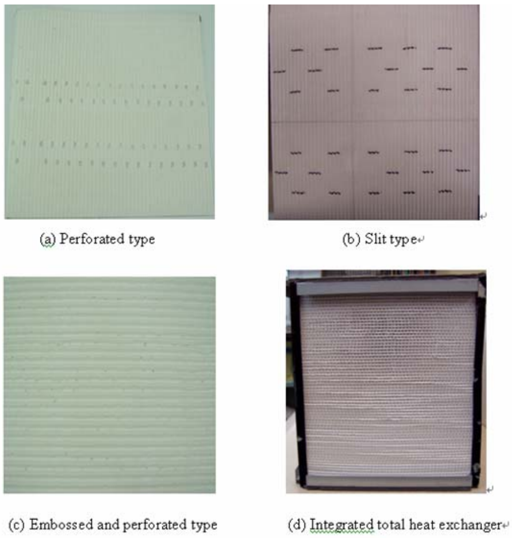

Fig. 3. Schematic view and flow passage for modified total heat exchangers.

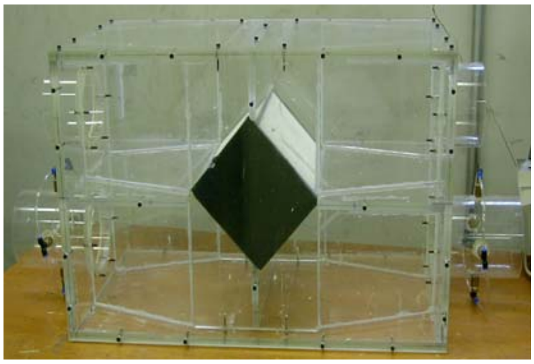

Fig. 4. Schematic view an element installed in acrylic chamber.

the modified total heat exchangers was installed in the acryl cases, as shown in Fig. 4, to evaluate the heat exchange performance. The size of the heat exchanger was 220 (W)×220 (D)×245 (H)mm, and the typical air flow rate was 100CMH (m^3/hr) (corresponding Reynolds number of about 140). All other specifications such as size of total heat exchanger, pitch and height of the corrugated shape, etc., except the surface structure, were the same, and Table 1 shows specifications of each type of the modified total heat exchangers.

The test condition of KS B6879 [11] was selected for the evaluation of ventilation performance. In the case of cooling operation, the dry bulb temperature and wet bulb temperature were at 27℃ and 19.5℃ for indoor (corresponds to absolute humidity: 0.011161 kg/$kg_{dry\ air}$), and 35℃ and 24℃ (corre-

Table 1. Specifications of each type of total heat exchanger.

Spec.	General type	Per-forated type	Slit type	Embossed and perfo-rated type
Width×length×height [mm]	220×220×245	←	←	←
Corrugated number, pitch/one plate	52ea, 4mm	←	←	←
Number of plate (one side flow) [ea]	65	←	←	←
Flow passage	Corrugated structure	←	←	←
Surface condition	Smooth	Four rows of 6mm diameter holes	Six row of slit of 40mm in length	Approx. 1.0mm diameter holes and approx. 0.2mm height protrusions

sponds to absolute humidity:0.014318 kg/kg$_{dry\ air}$) for outdoor, respectively. In the case of heating, the dry bulb temperature and wet bulb temperature were at 20℃ and 15℃ for indoor (corresponds to absolute humidity:0.008620 kg/kg$_{dry\ air}$), and 7℃ and 6℃ (corresponds to absolute humidity:0.005409 kg/kg$_{dry\ air}$) for outdoor, respectively. Since the incoming air to the total heat exchanger in the cooling operation has much more water vapor than that in heating operation, moisture transfer enhancement will greatly affect the efficiency of the total heat exchanger in cooling operation.

2.3 Data reduction

The heat exchange efficiencies indicating the performance of the total heat exchangers are the temperature efficiency from the measured dry bulb temperature, latent efficiency from the absolute humidity, and enthalpy efficiency from enthalpy. Eq. (1) defines these efficiencies.

$$\varepsilon = \frac{x_{OA} - x_{SA}}{x_{OA} - x_{RA}} \qquad (1)$$

where, ε indicates temperature, latent and enthalpy efficiencies, and the corresponding measured values of x are dry bulb temperature, absolute humidity, and enthalpy of the air. The subscripts SA, OA, and RA in formula (1) indicate supplied air, outside air, and ventilation air, respectively.

The effective ventilation volumes of the total heat exchangers were measured according to KS B 6879 [11], and the leak rate was measured by using the CO_2 measurement method. The CO_2 concentration was analyzed by gas chromatography. Eq. (2) indicates the leak rate R, and formula (3) indicates the effective ventilation volume Q_E considering the leak rate.

$$R = \frac{B_{SA} - B_{OA}}{B_{RA} - B_{OA}} \qquad (2)$$

$$Q_E = Q_S \times (1 - R) \qquad (3)$$

The leak rates of the modified total heat exchanger and the general total heat exchanger with a smooth surface were about 10%.

The calorimeter that was used satisfied the KS B 6879 [11] with respect to the accuracies of measurement devices. An uncertainty analysis was carried out by the method of Kline and McClintock [12]. For the typical Reynolds number of 140, the uncertainties of the temperature efficiency, latent efficiency and enthalpy efficiency were 1%, 2.5% and 3.4% for the cooling operation, and 0.5%, 0.7% and 1.4% for the heating operation, respectively. The error of the Reynolds number was estimated to be 0.6%.

3. Discussion

Fig. 5 shows the temperature efficiency of the modified total heat exchangers and the general total heat exchanger with respect to a Reynolds number, under KS cooling operation. The Reynolds number varied from 105 to 280 (corresponding to 75-200CMH based on air flow rate). Temperature efficiency decreases as the Reynolds number increases, showing a tendency similar to the general air-to–air heat exchanger. The temperature efficiency of the modified total heat exchanger is slightly higher than that of the general total heat exchanger with a smooth surface in the entire range of Reynolds numbers. For a typical Reynolds number of 140, which corresponds to the typical air flow rate of the total heat exchanger tested, the temperature efficiencies of the perforated type, slit type, and embossed and perforated type increase by 1.2%, 2.5% and 5.0% respectively, from that of the general heat exchanger.

Fig. 6 shows the result of latent efficiency under KS cooling operation. The latent efficiency of the modified total heat exchanger is much higher than that of general heat exchangers with a smooth surface in the entire range of Reynolds numbers. For a typical Reynolds number of 140, the latent efficiencies of the perforated type, slit type, and embossed and perforated type increase by 18.0%, 32.2% and 24.5% respectively, from that of the general heat exchanger. Since moisture transfer enhancement greatly affects the performance of a total heat exchanger in cooling operation (humid condition), these significant increases of latent efficiency accelerate the energy performance in a total heat exchanger. The slit type heat exchanger shows the largest latent efficiency. Although we were able to obtain a large increment in latent efficiency, additional study would be necessary to propose the optimum flow passage structure considering the arrangement and size of the slit. The modified flow passage structure gave a larger increase in latent efficiency than in temperature efficiency, compared to the general heat exchanger. Since the temperature efficiency even in the general total heat exchanger is high (about 95%) already, there is not much room for further increase of efficiency. However, the typical latent efficiency in cooling operation for the total heat exchanger is quite low. In view of this, the modified total heat exchanger has a larger probability for increase of moisture transfer than for increase of temperature transfer.

Fig. 7 shows the result of the enthalpy efficiency considering the temperature and latent efficiencies together under KS cooling operation. For the typical Reynolds number of 140, the enthalpy efficiencies of the perforated type, slit type, and embossed and perforated type increase by 7.9%, 11.5% and 11.2%, respectively, from the that of the general total heat exchanger. The large increase in latent efficiency results in a large increase in enthalpy efficiency.

Figs. 8, 9 and 10 show the temperature efficiency, latent efficiency, and enthalpy efficiency with respect to Reynolds numbers under KS heating operation. As in the cooling operation, the efficiencies of the modified total heat exchangers are higher than those of the general total heat exchanger in the whole range of Reynolds numbers. For a typical Reynolds number of 140, the perforated type, slit type, and embossed and perforated type show increases in temperature efficiency of 3.0%, 3.4% and 4.0%, increases in latent efficiency of 5.0%, 6.6%, and 18.7%, and increases in enthalpy efficiency of 3.2%, 4.3%, and 7.7%, respectively, from that of the general total heat exchanger. Though the efficiencies of the modified total heat ex-

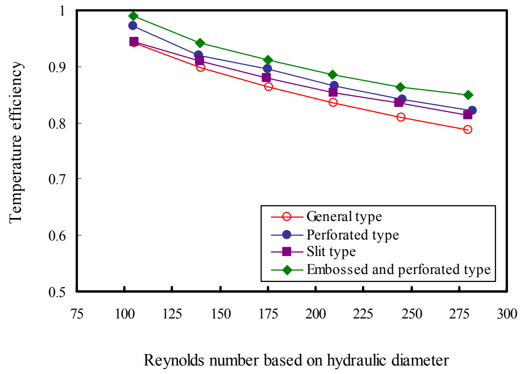

Fig. 5. Temperature efficiency for the modified total heat exchangers and the general total heat exchanger with respect to Reynolds number (cooling operation).

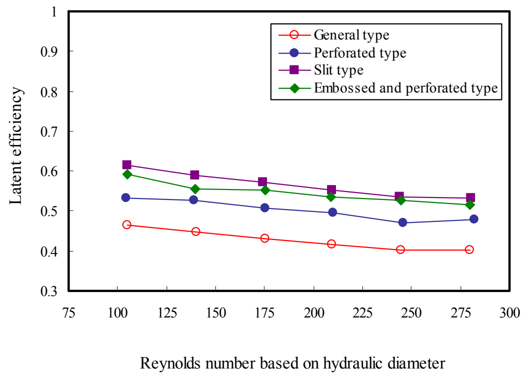

Fig. 6. Latent efficiency for the modified total heat exchangers and the general total heat exchanger with respect to Reynolds number (cooling operation).

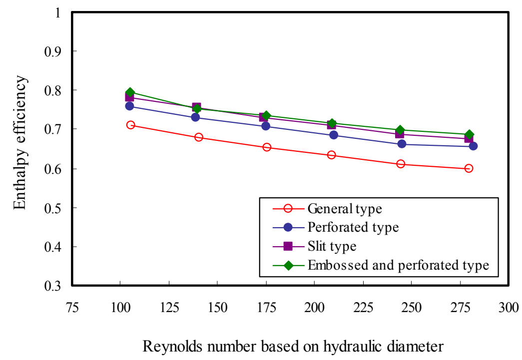

Fig. 7. Enthalpy efficiency for the modified total heat exchangers and the general total heat exchanger with respect to Reynolds number (cooling operation).

changers in heating operation are still high compared to that of the general total heat exchanger, the increases of the efficiencies are slightly less than those in cooling operation.

Since the flow resistance in a modified flow passage may increase, it is necessary to evaluate the pressure drop of air through the total heat exchanger.

Fig. 11 and Fig 12 show the pressure drop of the total heat exchanger for the variation of Reynolds number under KS cooling and heating operations. The pressure drop is defined as the pressure difference of the air through the tested total heat exchanger. The pressure drop of the modified total heat exchanger is similar to that of the general total heat exchanger in the entire range of Reynolds numbers, in case of cooling operation. In the case of heating operation, the pressure drop of the modified total heat exchanger slightly increases as the Reynolds number increases. The increase of pressure drop is about 1.7% in the typical operation range (Reynolds number of 140), which is much less than the increment of efficiency of the modified total heat exchanger.

Fig. 13 and Fig. 14 show the result of enthalpy efficiency for the variation of pressure drop of the total heat exchanger under KS cooling and heating operations. Here, the increase of pressure drop for a total heat exchanger represents the increase of the Reynolds number (air flow increase) for each total heat exchanger. Since the pressure drop of the modified total heat exchanger is not much different from that of the general total heat exchanger, the increase of enthalpy efficiency shows the same tendency, as shown in Fig. 7 and Fig. 10. In the case of cooling operation, the tested total heat exchangers of the modified flow passage show an increase of enthalpy efficiency from the general total heat exchanger. The slit type and the embossed and perforated type show the largest enthalpy efficiency. In the case of heating operation, the enthalpy efficiency of embossed and perforated type is the largest, and the slit type and perforated types show nearly the same efficiency.

The above results show that the modified total heat exchanger increases the exchange efficiency at a modest expense of an additional pressure drop. In the modified flow passage structures applied in the study, the exchange efficiency increased in the following order: the perforated type, slit type, and embossed and perforated type. It is believed the modified total heat exchanger is effective for improving the performance of the total heat exchangers currently in use.

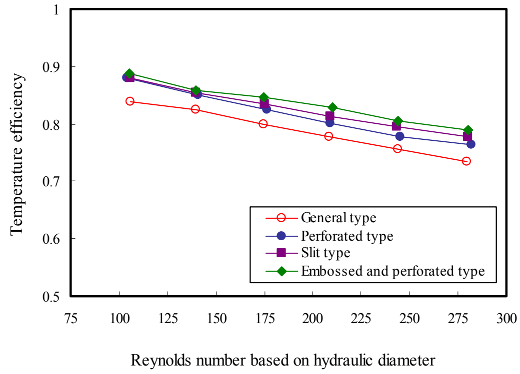

Fig. 8. Temperature efficiency for the modified total heat exchangers and the general total heat exchanger with respect to Reynolds number (heating operation).

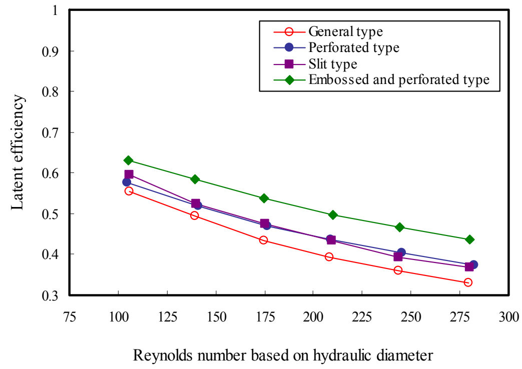

Fig. 9. Latent efficiency for the modified total heat exchangers and the general total heat exchanger with respect to Reynolds number (heating operation).

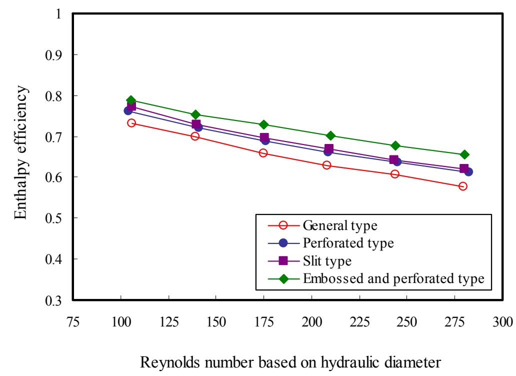

Fig. 10. Enthalpy efficiency for the modified total heat exchangers and the general total heat exchanger with respect to Reynolds number (heating operation).

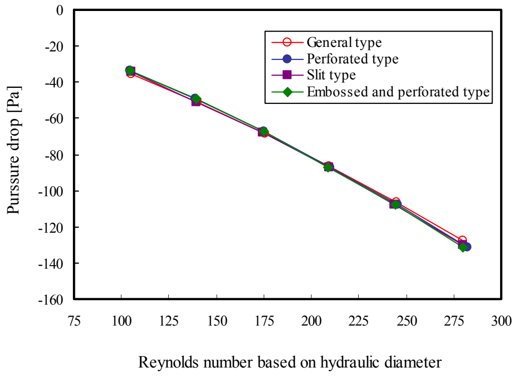

Fig. 11. Pressure drop of total heat exchanger for the variation of Reynolds number (cooling operation).

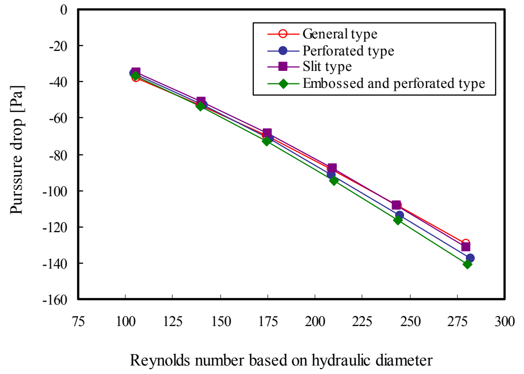

Fig. 12. Pressure drop of total heat exchanger for the variation of Reynolds number (heating operation).

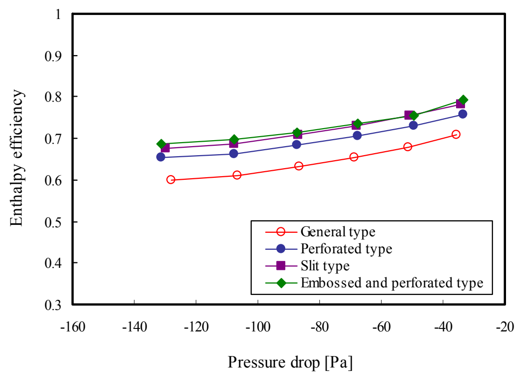

Fig. 13. Enthalpy efficiency for the variation of pressure drop (cooling operation).

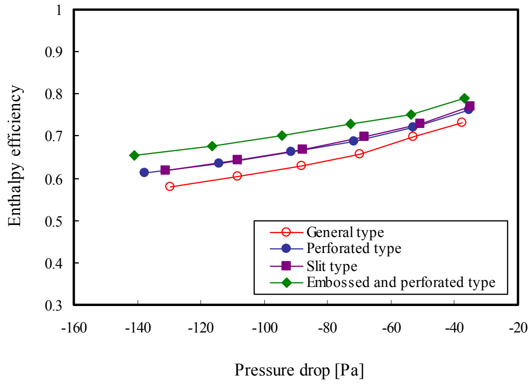

Fig. 14. Enthalpy efficiency for the variation of pressure drop (heating operation).

4. Conclusions

An experimental study was performed to increase the exchange efficiency of total heat exchangers. The present study utilized heat transfer enhancement technology, which was applied in a compact type heat exchanger, and evaluated the degree of enhancement of heat and moisture transfers in the range of low Reynolds numbers. The exchange efficiencies of the modified total heat exchangers were compared with that of the general total heat exchanger having smooth surface. The conclusions are as follows:

(1) The heat exchange efficiencies of the perforated type, slit type, and embossed and perforated type total heat exchangers were greater than that of the general total heat exchanger with a smooth surface. Especially, for a typical Reynolds number of 140 (air flow rate of 100CMH) under KS cooling operation, it was shown that the increases in the temperature efficiency were 1.2%, 2.5%, and 5.0%; the increases in latent efficiency were 18.0%, 32.0% and 24.5%; and the increases in enthalpy efficiency were 7.9%, 11.5%, and 11.2%, respectively. The corresponding enhancement of heating operation were 3.0%, 3.4%, and 4.0%; 5.0%, 6.6%, and 18.7%; 3.2%, 4.3%, and 7.7%, respectively.

(2) The modified total heat exchangers showed a slight increase of pressure drop compared to the pressure drop of a general total heat exchanger.

(3) The modified flow passage structure applied in this study was reviewed from a manufacturing point of view, and it is judged to be applicable to the existing general total heat exchanger.

Acknowledgements

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