A review of heat recovery technology for passive ventilation applications

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Abstract. Regenerative heat exchangers are widely used in life support systems, gas turbines, boilers and other high-temperature industrial installations. These heat exchangers are used for cooling and heating gases, humidification and dehumidification of gases, heat recovery from high-potential heat carriers. Today, the increase in energy consumption and the increase in energy prices require a large-scale energy-saving policy in the creation of modern engineering structures – residential, commercial and industrial facilities alike. When designing and creating life support systems to save energy, it is advisable to use secondary energy resources, such as, for example, the heat of the air removed from the room. The energy intensity of conventional ventilation systems is on average 50–80% of the total energy intensity of the engineering systems of the facility where they are operated. The use of rotating regenerative heat exchangers in ventilation and air conditioning systems makes it possible to return up to 85% of heat to the system at a relatively low capital investment. In this regard, when improving such systems, considerable attention should be paid to the calculation, optimization and increase in the efficiency of heat exchangers. Thus, this work is about increasing the efficiency of rotating regenerative heat exchangers in ventilation and air conditioning systems.

1. Introduction

Regenerative heat exchangers are characterized by the fact that the nozzle, which has a large heat transfer surface, alternately accumulates and releases heat. Regenerative heat exchangers used to recover the heat (and sometimes cold) of the removed air are of the following types – stationary switchable, with a rotating nozzle and with rotating air distribution chambers [1-3]. Stationary heat exchangers are made in the form of nozzles from metal shavings, gravel, crushed stone, which alternately switch from the heat absorption mode to the heat release mode [4-6]. The disadvantages of these devices are their large dimensions and the difficulty of ensuring the necessary tightness of the switchable air valves. As a result, stationary heat exchangers are not widely used, including in the technology of air conditioning and ventilation systems. Rotating regenerative heat exchangers (RHEs) are much more often used.

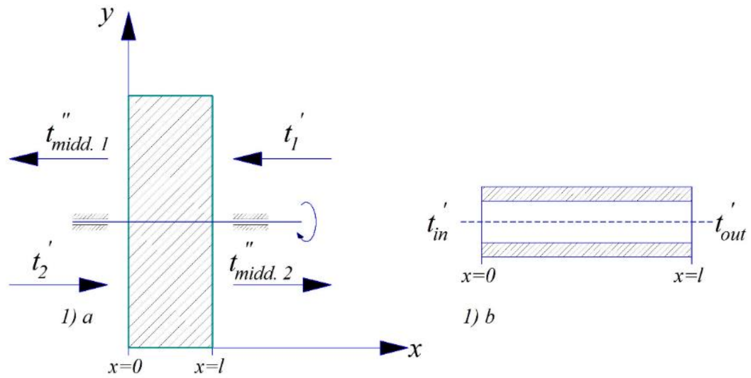

Fig. 1. *a*. Rotating regenerative heat exchanger nozzle; *b*. Section of the RHE nozzle channel

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Today, air conditioning and ventilation (AC and V) systems typically use several types of air-to-air heat exchangers: rotating regenerative heat exchangers, plate recuperators, recuperators with intermediate coolant and heat pipes.
The RHE nozzle is shown in coordinate axes, indicating the direction of movement of the coolants (Figure 1a). Let's consider the flow of air through a single channel of the nozzle (Figure 1b). The heat transfer process in the channel during rotation of the nozzle is generally non-stationary. The channel surface temperature varies along the length of the nozzle and over time [7-10].

2. Experiment

The purpose of the experiment was to study thermal processes in the nozzle of a rotating regenerative heat exchanger, obtain data allowing to evaluate thermal efficiency and identify the parameters that influence it, as well as obtain values of average heat transfer coefficients.
The stand is mounted on the basis of a block-exhaust unit AeroMaster XP04 (company Remak (Czech Republic)), which includes sections of exhaust and supply line fans, a section of a rotating regenerative heat exchanger and an air filter section (filtration class G3). The unit is connected to the air duct network using transitions. The experimental stand includes: a section of a rotating regenerative heat exchanger XPXR04 (1) with a VLT 2800 frequency controller (Danfoss); fan sections for exhaust (2) and supply (3) lines HRAP 04/D with frequency regulators VLT 2800; air filter section HRNO 04/K (4) on the supply line; electric heater SV-315/9.6 (Arktika company) (5) with TRN-D power regulator (Remak company); metering diaphragms for the supply (6) and exhaust (7) lines IRIS 315. The stand is designed for testing with a maximum air flow of the supply tract of 1800, and of the exhaust tract – 2700.
To conduct an experimental study, a stand was developed, the schematic diagram of which is shown in Fig. 2.

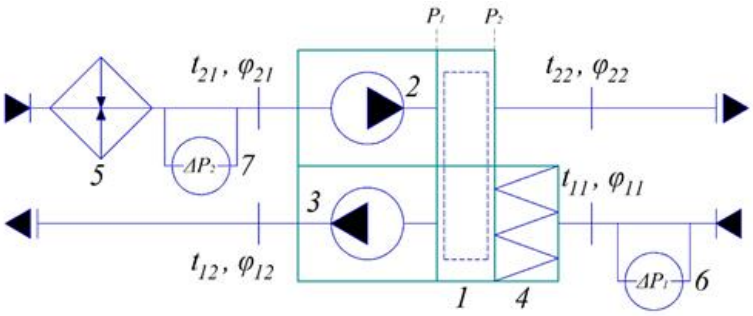

Fig. 2. Scheme of the experimental stand

The air taken from the volume of the room by the fan (2) is removed, preheated using a duct electric heater (5) to a set temperature and supplied to the regenerative heat exchanger (1). After the heat exchanger, the removed air, already at a lower temperature (due to heat exchange), is released into the environment. The supply air taken from the street by the fan (3), passing through the air intake grille and then the filter section (4) is supplied to the heat exchanger (1). The heated supply air is discharged into the free volume of the room. Heater power control is stepwise, using a 5-step transformer TRN-D.
The heat exchange nozzle is mounted on a shaft, which, with the help of bearings, rests on the dividing partition. The nozzle is driven into rotation by a belt drive using an asynchronous motor with a short-circuited armature with a clutch (maximum motor power 0.09 kW).
The heat exchange nozzle RRE XPXR04 is a cylinder with a diameter of 770 *mm* and a depth of 200 *mm*, formed by alternating smooth and corrugated tapes with a thickness of 0.09 *mm*, while channels are formed with a cross-section in the form of an isosceles triangle 1.9 *mm* high with a pitch of 3.5 *mm*. The main geometric characteristics of the section of the rotating regenerative heat exchanger XPXR04 are given below in Table 1. The entire nozzle (except for the bearings and shaft) is made of aluminum, the type of nozzle is regular.
Experimental data have been obtained to evaluate the thermal efficiency of the rotating regenerative heat exchanger under study. The efficiency of the RRE nozzle depends on the water equivalents W_1 of cold W_2 and hot air flows, expressed through the ratio $\frac{W_1}{W_2}$, the number of transfer units, and the rotation speed of the nozzle. The experimental data were presented as a dependence of thermal efficiency E on n, $\frac{W_1}{W_2}$.
The thermal efficiency value was determined using the following formula

$$E = \frac{W_1 \cdot (t_{12} - t_{11})}{W_{min} \cdot (t_{21} - t_{11})} = \frac{W_2 \cdot (t_{21} - t_{22})}{W_{min} \cdot (t_{21} - t_{11})}. \quad (1)$$

Table 1. Main geometric characteristics of the rotating regenerative heat exchanger section

№	Characteristic	Meaning
1	Nozzle diameter	0.77 m
2	Nozzle depth	0.2 m
3	Frontal cross-sectional area of the nozzle	0.46543 m^2
4	The “live” cross-sectional area of the nozzle	0.41656 m^2
5	Relative live section	0.895
6	Heat transfer area	217.24 m^2
7	Nozzle volume	0.09309 m^3
8	Compactness index	2333.67 $\frac{m^2}{m^3}$
9	Nozzle weight	24.5 kg
10	Plate thickness	0.09 mm
11	Wave height	1.9 mm
12	Wave step	3.5 mm
13	Calculated equivalent diameter	1.534 mm

3. Results

The influence of the rotation speed of the nozzle on the thermal efficiency of the rotating regenerative heat exchanger under study was experimentally established. As the rotation speed of the nozzle increases, the thermal efficiency of the RHE asymptotically increases and when a certain value is reached, the efficiency remains practically unchanged. It should be noted that an increase in rotation frequency leads to an increase in air flow, which negatively affects the thermal efficiency of the heat exchanger, leads to wear of rubbing parts, and an increase in the engine's electrical power consumption.

Figure 3 shows the dependences of the thermal efficiency of the studied RHE on the rotation speed of the nozzle at various air flow rates, expressed by W_1 and W_2. From the analysis of the data obtained, it can be seen that the rotation speed of the nozzle can be considered optimal in the range from 9 to 13 $\frac{turn}{min}$.

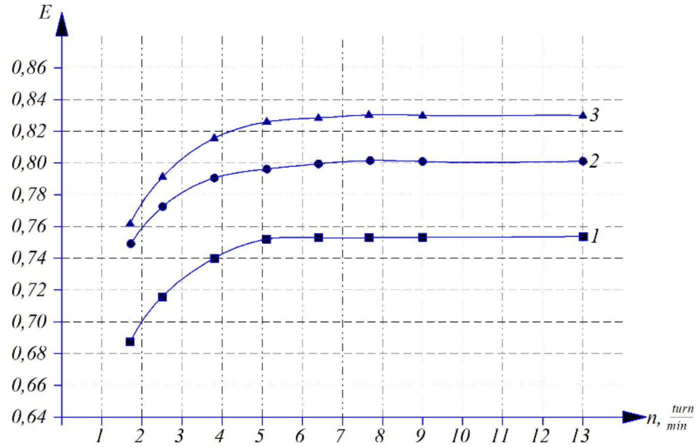

Fig. 3. Dependence of the thermal efficiency of the RRE on the speed of rotation of the nozzle at

$$1.\ W_1 = 0{,}503\ \frac{kW}{K}, W_2 = 0{,}515\ \frac{kW}{K}, \frac{W_1}{W_2} = 0{,}97.$$
$$2.\ W_1 = 0{,}503\ \frac{kW}{K}, W_2 = 0{,}567\ \frac{kW}{K}, \frac{W_1}{W_2} = 0{,}89.$$
$$3.\ W_1 = 0{,}503\ \frac{kW}{K}, W_2 = 0{,}611\ \frac{kW}{K}, \frac{W_1}{W_2} = 0{,}82.$$

Figure 4 shows the dependence of the thermal efficiency of RRE on the ratio of air flow rates, expressed through the ratios $\frac{W_1}{W_2}$. The dots show experimental data, the line shows the approximating curve. With increasing $\frac{W_1}{W_2}$, the thermal efficiency of the RRE decreases.

An experiment was conducted to determine the average sensible heat transfer coefficients from the flow of hot air to the nozzle. The average temperatures of the air flows at the entrance to the nozzle were maintained constant over time. The average temperatures of the air flows at the outlet of the nozzle were determined after the installation reached a steady state of operation. The flow rate of the cold air flow was maintained constant, and the values of the flow rates of the hot air flow varied from $1400\ \frac{m^3}{h}$ to $2600\ \frac{m^3}{h}$. Nozzle rotation speed $n = 13\ \frac{turn}{min}$. Experimental data for which the difference in heat balances did not exceed 10% were accepted for processing. The arithmetic mean value was taken as the calculated amount of heat. The discrepancy between the average amount of heat and that calculated from the hot and cold air flow was ±5%.

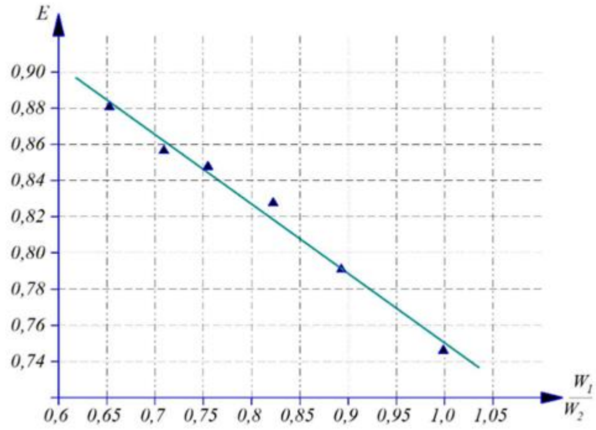

Fig. 4. Dependence of the thermal efficiency of RHE on the ratio

An assessment of changes in the moisture content of air flows in the RHE made it possible to establish that the heat exchange process occurred without condensation of moist air on the surface of the nozzle.
The results of the study to determine the heat transfer coefficients made it possible to obtain the values of the Nusselt numbers at various Reynolds numbers. The results of processing experimental data are presented in logarithmic coordinates in Figure 5.

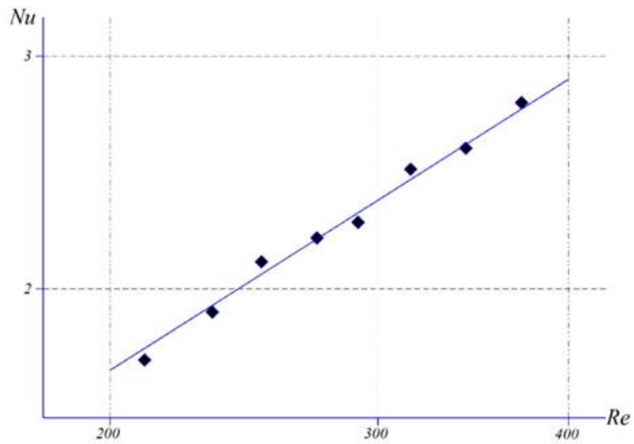

Fig. 5. Criterion dependence $Nu = f(Re)$

The heat transfer of the nozzle under study is approximated by a power function $200 \leq Re \leq 400$

$$Nu = 0{,}037 \cdot Re^{0{,}73} \quad (2)$$

The standard deviation of the points does not exceed 0.104.
The results of the criterion values were compared with the data of various authors presented in [11÷16], which showed that the values are quantitatively close to each other.
When calculating and designing a rotating regenerative heat exchanger for ventilation and air conditioning systems, the pressure drops characteristics become no less important than its heat transfer characteristics [17, 18].
An experiment was carried out to determine the pressure drop of rotating regenerative heat exchangers XPXR04. Static pressure measurements were carried out before and after the nozzle (along the direction of air movement) in the range of air flow rates from $950\ \frac{m^3}{h}$ to $2700\ \frac{m^3}{h}$ at the nozzle rotation speed $n = 13\ \frac{turn}{min}$. The results of the experimental study were summarized in the form of the dependence of the Euler criterion on the Reynolds criterion

$$Eu = f(Re)$$

$$Eu = \frac{\Delta P}{\rho \cdot U^2}, \quad (3)$$

ΔP – where is the pressure drop of the air flow, U – is the average speed of air flow in the channel, ρ – is the air density. The results of processing experimental data are presented in logarithmic coordinates in Figure 6.

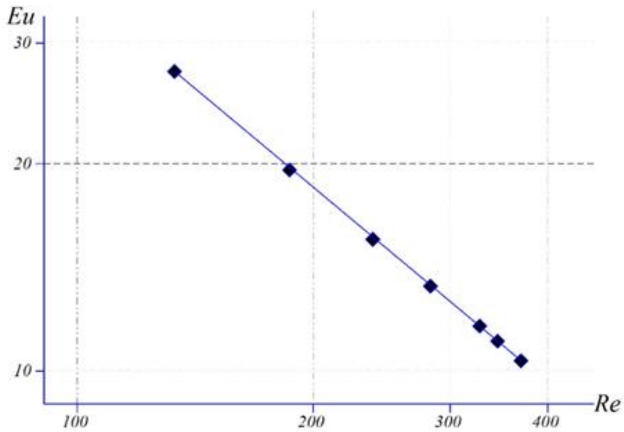

Fig. 6. Criterion dependence $Eu = f(Re)$

The results of the experimental data are $150 \leq Re \leq 400$ approximated by a power function

$$Eu = 2462{,}4 \cdot Re^{-0{,}925}. \quad (3)$$

4. Conclusion

Analyzing the presented graphs, we can conclude that the results of theoretical studies are in good agreement with experimental data. The discrepancy is 4÷8%. The fact that the calculation data is in good agreement with the experimental data confirms the acceptability of using the calculation method for the rotating regenerative heat exchanger under study in further research.

Data were obtained to evaluate the thermal efficiency and pressure loss of a rotating regenerative heat exchanger. The values of average heat transfer coefficients were obtained.

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