THE EFFECTIVENESS OF AIR-TO-AIR HEAT EXCHANGERS WITH FLAT FINNED TUBES

A. I. Dzyakau, V. G. Kiselev
Belarussian National Technical University
Nezavisimosti ave., 65, 220013, Minsk, Belarus
Tel/Fax : 231 30 59, E-mail: shadow_gl@mail.ru

Abstract

Heat recovery heat exchangers are of growing importance in heating, ventilating, air conditioning systems, and dryers. This paper is concerned with the recovery of heat from exhaust air streams for preheating of other air streams. The method and relations for benefit calculations have been obtained. It has been shown that this method makes possible to provide benefit calculations for different types of heat exchangers. There is optimum number of modules for heat recovery heat exchangers to provide maximum benefit.

KEYWORDS
Heat recovery**,** heat pipe heat exchangers, economic efficiency.

INTRODUCTION

Air-to-air heat exchangers using an evaporating and condensing process are widely spread for heat recovery in heating, ventilating, air conditioning systems, and dryers, etc. The most prolific in the field of heat recovery systems is a heat exchanger which employs separate heat pipes with outer finned surface. This type of the heat exchanger can provide high heat transfer efficiency typical for a counterflow scheme of motion both heated and cold airflow. However, the cost of the heat pipe exchangers is too high because each pipe of the exchanger should be filled in working liquid. To reduce the expenses, the heat exchanger having closed internal volume for evaporating and condensing process can be used. In this case the effectiveness of such type of the exchanger with equal heat transfer surface will be reduced. This means that in the heat exchanger with closed internal volume for evaporating and condensing process the value of the heat flux transferred is defined by temperature drop typical for a parallel flow both cold and heated air. The cost reduction of the heat exchange equipment can be achieved by increase of a specific efficiency of heat transfer of the heat exchangers with finned surface and minimal production cost. From this point of view, aluminum flat finned tubes heat exchangers are considered to be the most perspective for use in the heat recovery systems.

CALCULATION OF THE ECONOMIC EFFICIENCY

The analysis of economic efficiency of the heat recovery systems for the ventilation systems has been performed [1]. However, this analysis failed to provide the recommendation on the optimum parameters for heat exchange equipment. This paper reveals the methods for the calculation of the cost of the heat recovery efficiency in the ventilation systems and the dependence on the production cost for the heat exchange equipment has been defined.

The economic efficiency of the heat recovery exchanger is given by

$$S = Z_{hp} - Z_b ,$$

where, $\triangle Z = (Z_{hp} - Z_b)$ is the cost difference for both cases of applying heat recovery or without heat recovery respectively ($/year). The proposed cost difference for the energy recovery system with heat recovery is calculated in the usual manner:

$$\triangle Z = \triangle U_т - \triangle U_e - \triangle к \cdot E_n - \triangle A_i ,$$

where $\triangle U_т$ – heat energy cost savings ($/year); $\triangle U_e$ – extra electric energy costs ($/year); $\triangle к$ – capital cost due to the heat recovery equipment used in the system ($); E_n – normative effectiveness ratio of capital investments (1/year); $\triangle A_i$ – extra costs for renovation, operating and major repair, and servicing ($/year).

The heat energy cost savings can be defined as

$$\triangle U_T = \triangle Q_T \cdot c_T ,$$

where $\triangle Q_T$ – heat energy cost savings (Gcal/year); c_T – heat energy cost ($/Gcal).

To make the calculation for the heat energy cost savings, the following equation is used

$$\triangle Q_T = \eta(T_u - \overline{T}_{am}) \cdot \tau_{hr} \cdot n_d /24 \qquad (1)$$

where η – the heat recovery effectiveness; T_u – standard exhaust air flow temperature; τ_{hr} – duration of the heat recovery operation per year; $\overline{T}_{am}$ – average outside air temperature for the heat recovery operation; n_d – duration of the heat recovery operation per day.

When the heat recovery is used in the drying devices and ventilation systems, the heat of the exhaust air stream is directed to heat the supplied air. To make use of the Eq. (1), we have to define the average ambient air temperature of the duration of the heat recovery operation. The data on average duration of τ_T , various meanings of the air temperature T_{am} [2] for different climatic zones have been used to define $\overline{T}_{am}$ and τ_{hr} . Several modes can be realized to provide low potential heat recovery in the ventilation systems. The realization depends on the exhaust air temperature T_u and demanded data on the supply air temperature. One of the modes can be realized if the supply air temperature demanded T_{in} is less than that of the exhaust air temperature T_u . In this instance the heat recovery will be realized at all the ambient air temperatures from T_{min} to T_{in} .

To find the time of the heat recovery operation τ_{hr} the following equation can be used

$$\tau_{hr} = \left(\sum_{T_{min}}^{T_{in}} \tau_T \right). \qquad (2)$$

If the ambient air temperature is less than

$$T_{am} = \frac{T_{in} - \eta \cdot T_u}{1-\eta}, \qquad (3)$$

the supplementary air heat should be used to provide the demanded supplied air temperature.

The supplementary air heat needs not to be used if the meaning of the ambient air temperature exceeds the value calculated (3). In this case, the ambient air temperature for the heat recovery operation can be calculated as

$$\overline{T}_{am} = \left(\sum_{T_{min}}^{T_{in}} \tau_T \cdot T \right) / \tau_{hr} . \qquad (4)$$

If the supply air temperature T_{in} is higher than that of the exhaust air temperature T_u , another mode can be realized. In this case, the heat recovery will occur at all the ambient air temperatures from T_{min} up to T_u . To make the calculation for the duration of the heat recovery operation τ_h the equation similar (2) can be used

$$\tau_{hr} = \sum_{T_{min}}^{T_u} \tau_T .$$

For the second mode, the supplementary air heat has to be used if the ambient air temperature T_{am} is less than that of the required supply air flow T_{in} . The average ambient air temperature for the duration of the heat recovery for this mode is defined as

$$\overline{T}_{am} = \left(\sum_{T_{min}}^{T_u} \tau_T \cdot T \right) / \tau_{hr} . \tag{5}$$

The heat exchange surface temperature will be equal to zero if the ambient air temperature falls to up T_{fr} . Therefore, the condensate of the damp exhaust air flow is exposed to freezing. Frosting of the finned heat exchange surface will result in filling the finned space with ice deposition and blocking up the air circulation. This factor will result in the termination of the energy saving system operation. In this situation all the heat recovery systems for ventilated emissions are equipped with the frosting protection systems.

There are various ways of the heat exchange surface protection from frosting: exhaust air recirculation, supplementary heat of the supply air in front of the heat recovery device, etc. Basically, all the ways of protection are aimed to provide the heat recovery systems with the outdoor supply air temperature having the temperature equal or exceeding T_{fr} . In this case, the effectiveness of the heat recovery will be reduced when the frosting protection system has been functioned.

When the frosting protection system is employed, the value of the average outside air for duration of the heat recovery operation, is given by the Eqs. (4) or (5). However, in this case, while summing up the product $\tau \cdot T$, the value of the current temperature is accepted equal T_{fr} if the ambient air temperature is less than T_{fr} .

The operation of the heat recovery system is always connected with an auxiliary energy consumption for overcoming the pressure drop when heat and cold air flows are passing through the heat exchanger. The value of the auxiliary energy consumption is given by:

$$\Delta U_{el} = (V_h \cdot \Delta P_h / \eta_h + V_c \cdot \Delta P_c / \eta_c)\ \tau_f \cdot c_{el} ,$$

where V_h , V_c – hot and cold air flow; ΔP_h , ΔP_c – pressure drop for hot and cold air flow; η_h , η_c – coefficient of efficiency of electric motors of fans for hot and cold air flow; τ_f – duration of fan operation per year; c_{el} – one kW·h electric energy cost.

The aforementioned equation will enable us to define the relation of the economic efficiency due to the heat recovery and capital cost for installation of the heat exchange equipment. When selecting a heat exchange equipment, the manufacturing cost is important. Hence, the presented equations allow to realize a method for selection of an effective heat exchanger design to be used for the heat recovery and its manufacturing technique:

- drawing up a range of the heat recovery devices;
- calculation of the capital cost for the heat recovery equipment installed;
- calculation of the heat recovery economic efficiency for a heat exchanger.

THE OPTIMUM NUMBER OF THE HEAT EXCHANGER MODULES

As an example, we shall define an optimum design of the heat recovery exchanger made of a number of separate modules. The module consists of two similar heat exchangers (evaporator and condenser). The heat exchangers are connected by means of pipelines to form a tight system for two-phase heat-carrier. The heat recovery system consists of several modules located consistently in the direction of movement of supply and exhaust air. A number of the heat exchangers which design differs with the number of the modules used, will be analyzed. The calculation of the thermal efficiency for a module consisting from the heat exchangers with the face area for 0,72 m^2 air flow has shown that the thermal efficiency will be 0.18, the air pressure of both supply and exhaust air respectively 40 Pa and 43 Pa at the air flow of 5000 m^3/h.

The dependence of the thermal efficiency of the recovery system on the number of the modules had been defined for analysis (Fig. 1). For this purpose, the relation stated in [3] was used:

$$\eta = \frac{n \cdot \eta_o}{1 + (n-1) \cdot \eta_o},$$

where η_o – the module efficiency; η – the recovery system efficiency; n – number of modules.

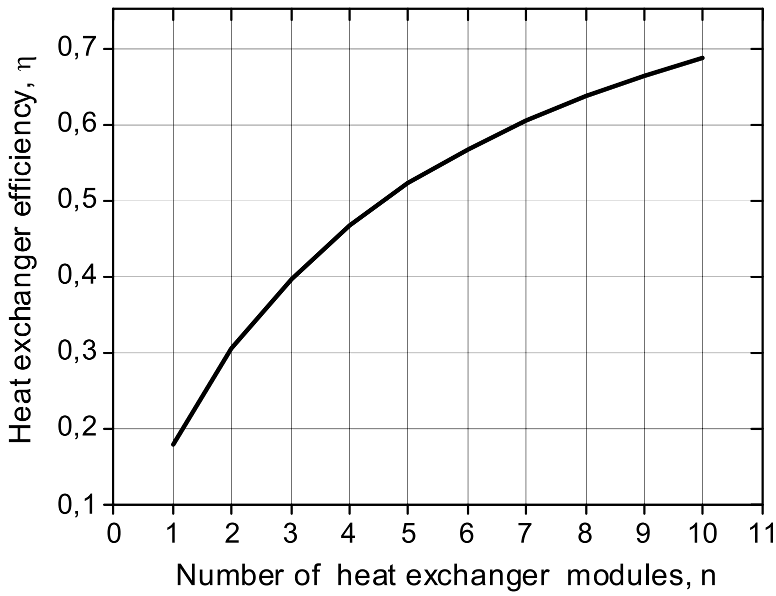

Fig.1. Dependence of the heat exchanger efficiency η on the number of modules n

The calculation of the manufacturing cost for this module, its cost and capital cost for its installation in the recovery system was performed. The estimated value of the capital cost for the installation of a single module was \$395. Sufficient degree of the calculation accuracy will enable us to accept that the capital cost of applying the heat recovery system will be proportional to the number of the modules used. However, the capital cost of the installation of the heat recovery system is one of the components of the capital cost related to the rest. Another component is the cost of the automatics and the frosting protection system for the heat exchange surface. The cost of this component will be \$305.

The calculation of the economic efficiency for the heat recovery system consisting from 2 up to 9 modules has been performed. Thus, it was supposed that kW·h cost of electric energy would \$ 0.02, Gcal cost of heat energy – \$14; efficiency of electric motors of fans – 75 %. Minsk was found to be the climatic zone for the energy recovery operation. The value of the heat recovery efficiency was defined from the relation (Fig. 1), and pressure losses at the moment of air flow movement were increased proportionally to the number of modules.

Relations (Fig. 2) of economic efficiency of the number of the heat exchange modules employed in the energy recovery system has a maximum. This corresponds to the optimum number of the heat exchange modules providing the maximal economic efficiency. In this instance, the greatest rate of the economic efficiency (\$330) will be achieved when using 3 or 4 heat exchange modules in the energy recovery system.

It is shown (Fig. 2) that the increase of the heat recovery efficiency due to the increase the number of the heat exchange modules is inexpedient. This will result in the decrease of the_economic efficiency for the energy recovery system. If 9 heat exchange modules have been used, negative economic efficiency will take place.

It is supposed that the economic efficiency may be increased due to the improvement of the characteristics for a heat exchange module. For this purpose it is necessary to intensify both external and internal heat exchange in the flat tubes. The intensification of the internal heat exchange process is illustrated by estimated relations of the economic efficiency of the heat recovery system with the number of the heat exchange modules (Fig. 2) for various values of the heat efficiency for a heat exchange module.

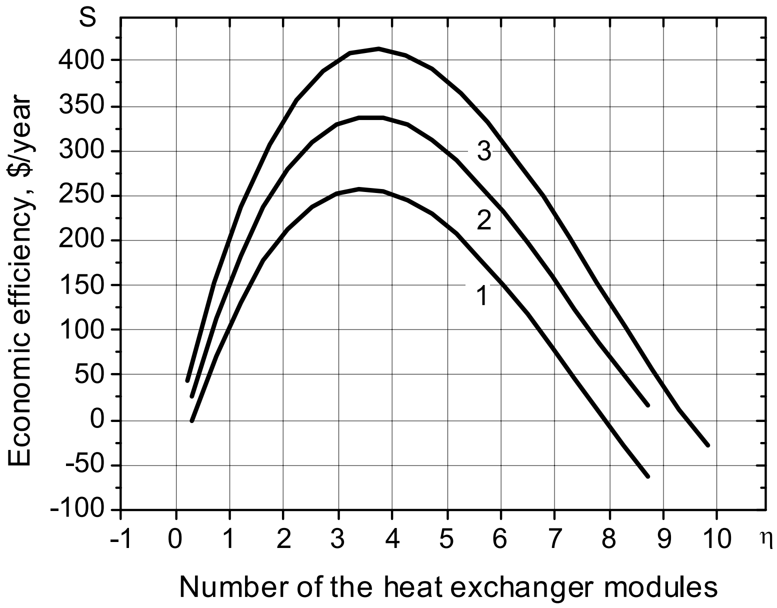

Fig. 2. Dependence of the economic efficiency on the number of the heat exchanger modules used: 1 – heat exchanger module efficiency 0.16, 2 – heat exchanger module efficiency 0.18; 3 – heat exchanger module efficiency 0.20

Figs. 1, 2 show that the increase in the heat efficiency for the heat exchange module from 0.16 to 0.20, the optimum number of the modules, providing maximum economic efficiency, will not be varied practically. The value of the economic efficiency will be increased essentially.

The economic efficiency will be equal to zero at the increase of the number of the heat exchange modules in despite the growth of the heat efficiency for the heat recovery system. Thus, when selecting a heat exchange equipment, it is necessary to use the equipment providing not the maximum heat recovery efficiency but the maximum economical efficiency.

CONCLUSIONS

The results of the analysis for the effect of the heat exchange design on the economic heat recovery efficiency enable us to draw the following conclusions:

- method considered for the calculation of the economic efficiency allows to estimate quantitatively the heat exchange equipment design and technology costs for manufacturing, a parity of capital costs and energy costs, heat efficiency of the exchange equipment;
- it was found that there is the optimum number of the modules for the heat recovery system to provide the maximum economic efficiency.

References

1. Besant R., Simonson C. Air-to-air energy recovery // *ASHRAE Journal*. 2000. No. 5. Pp. 128-136.
2. *Building Climatology: Inquiry Textbook*, Stroizdat, Moscow, USSR, 1990 (*Stroitelnaia Klimatologia: Spravochnoe Posobie k SNiP 2.01.01 – 82*). *In Russian.*
3. Vasiliev L.L., Kiselev V.G., Matveev Yu.N., Molodkin F.F. *Heat Pipes Heat Exchangers – Utilizators*, Nauka I Technika, Minsk, Belarus, 1987. 199 p. (*Teploobmenniki-Utilizatori na Teplovih Trubah*). *In Russian.*