Possibilities of Heat Exchanger Use in Pigsty Ventilation Systems

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Abstract. There is a considerable increase in energy demand during autumn-winter conditions due to the necessity to keep optimal microclimatic conditions in pigsties. When heat exchangers are used in the ventilation systems on the premises of pigsties, clean and cold air (in the autumn-winter period) gets an amount of heat energy from unclean but warm air. Up to now heat exchangers have not been used widely in Latvia and therefore there is no experience about the use of heat exchangers for microclimatic stability in piggeries. The goal of the investigation is to clear out the possibilities of heat exchanger use at farms in Latvian climatic conditions.
The article deals with experimental results obtained from experiments about plate counter-flow heat exchanger models with plastic cellular boards (HE PVC) and plastic plates (WVT 120K) as heat transfer surfaces. Operational parameters which describe the energy efficiency of heat exchangers were calculated – power of recovered heat energy Φ, heat transfer coefficient, and coefficient of performance (COP) by recovered heat. The parameters were analyzed depending on outside air temperature in an interval from +6°C to -16°C.
In the weather conditions of Latvia it is important to achieve heat transfer as completely as possible, widening thus the interval of heat deficit coverage towards lower outside air temperature.

Key words: Heat exchanger, pigsty, ventilation system

INTRODUCTION

Researches into possibilities of recuperation of heat energy from polluted outflow air have been conducted in Germany and other countries of the EU (Air Heaters..., 2009; Abluftsysteme…, 2008; Healthy..., 2009).

Nowadays several companies offer appropriate recuperative outflow air heat exchangers. According to constructional details polluted outflow air heat exchangers are classified as: tubular heat exchangers-double pipe, shell and tube, coiled tube; plate heat exchangers - gasketed, spiral, plate coil, lamella; extended surface heat exchangers-tube-fin, plate-fin; fixed matrix regenerators, rotary (Kuppan, 2000). The basic flow arrangements of the air in a heat exchanger are: parallel-flow, counter-flow, and cross-flow. The choice of a particular flow arrangement is dependent upon the required exchanger effectiveness, air flow paths, packaging envelope, allowable thermal stresses, temperature levels, and other design criteria. When selecting a heat exchanger for a given duty, the following points must be considered: construction materials; operating pressure and temperature, temperature program, and temperature driving force; flow rates; flow arrangements; performance parameters - thermal effectiveness and pressure drops; fouling tendencies; types and phases of matter; maintenance, inspection, cleaning, extension, and repair possibilities; overall economy; fabrication techniques; intended applications.

To raise the level of energy efficiency of the ventilation systems of pigsties, it is practical to introduce heat exchangers. A heat exchanger is a device built for efficient heat transfer from one medium to another. When a heat exchanger is used in the ventilation system on the premises of a pigsty, clean and cold air (in the autumn-winter period) gets an amount of heat energy from unclean but warm air. Respiration of pigs and processes occurring on the surface of manure cause the generation of carbon dioxide and ammonia, which are considered harmful gases not only for people and animals but also for the equipment, as high relative humidity (occurs also during respiration of pigs) influences working conditions as well. Therefore the materials used for the construction of heat exchangers must have high resistance to corrosion and high thermal conductivity.

Heat exchangers have not been widely used in livestock breeding in Latvia, mainly because of the shortage of experience of the use of heat exchangers in our climatic conditions. Experimental plate heat exchanger HE-PVC is made of polyvinylchloride (PVC) cellular boards, which are set at a certain distance by means of wooden lathes. Through the space between the boards blows unclean warm outflow air, but through the cellular board hollows blows fresh warming up air (Ilsters et al., 2007). Plate heat exchanger is a type of heat exchanger that uses plates to transfer heat between two gases or fluids. This has a clear advantage over a conventional heat exchanger as the gases (fluids) are exposed to a much larger surface area because the gases (fluids) spread out over the plates. This facilitates the transfer of heat, and greatly increases the speed of temperature change. Plate heat exchangers are usually used for low or medium pressure heat transfer applications; in our case we have low pressure application. The counter-flow arrangement was organized because this is the most efficient of all flow arrangements for single-pass arrangements under the same parameters. The developed experimental heat exchanger is made of polyvinylchloride cell boards as they allow simple construction and easy manufacturability, corrosion strength and high thermal conductivity of material (Ilsters, 2005). The heat exchanger WVT-120K produced in Germany was chosen due to its appropriate operational parameters (Table 1).

The aim of the research is, firstly, is to analyze the exploitation parameters of a recuperative outflow heat exchanger, which are obtained in conditions of production and, secondly, to analyze the effect of using an outflow air heat exchanger on heat balance in pigsty depending on outside air temperature.

OBJECTS AND METHODS

The experimental results obtained in previous years were used for calculation and analysis. The investigation was carried out in a 500 head stable for fattening pigs in Ogre region, Latvia. The size of the stable was 12 x 60 x 2.7 m. The stable has 1.5 brick thick walls, wood plank ceiling covered by straw. The resting places of pigs are littered by sawdust. The manure is removed by scraper conveyer. Up to now there was no equipment in the pigsty for warming up the inflowing fresh outside air. The scheme of heat exchanger location and air distribution pipes is shown in Fig.1.

During the investigation the temperature in the pigsty, the outside air temperature and relative humidity, the velocity of air flows and changes in its temperature before and after the application of heat exchangers was measured. For the acquisition of the abovementioned data in every 2 hours a HOBO type logger H08-007-02 and BoxCar computer program were used. The precision of measuring air temperature was ±0.2°C, for the relative humidity of air ±5%.

The main technical parameters of the experimental heat exchanger HE-PVC and the heat exchanger WVT-120K manufactured in Germany are given in Table 1.

Table 1. Main technical parameters of the industrially produced experimental heat exchanger WVT-120K

Indices	HE-PVC	WVT-120K
Type	Counter-flow, plate	
Location	horizontal	vertical
Distance between plates, m	0.010	0.025
Heat transfer area, m^2	100	52 (calculated)
Productivity of heat flows, $m^3\ h^{-1}$	2,200	2,200 – 4,800
Power of heat energy at ΔT=30°C, kW	under 17	under 27

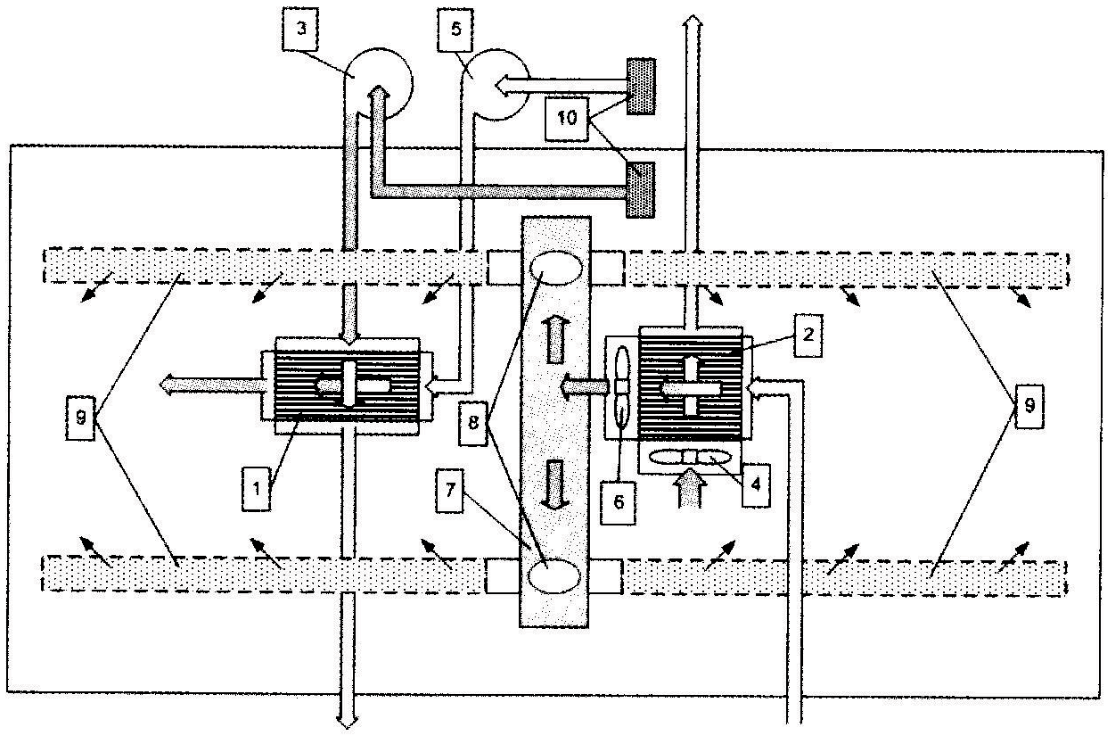

Fig.1. Location scheme of heat exchangers and air distribution canals in sty with 500 fattening pigs**:** 1 – experimental heat exchanger; 2 – heat exchanger WVT-120K; 3, 4 – air outlet ventilators; 5, 6 – air inlet ventilators; 7 – air distribution

pipes; 8 – air distribution collector; 9 – perforated air distribution pipes; 10 – air filter.

While analyzing the heat balance of pigsty it is important to determine the outside air temperature in case of heat deficiency; in addition, it is necessary to determine the value of heat deficiency when the outside temperature goes below par. This T_d temperature was calculated (Ilsters et al., 2008):

$$T_d = -T_c - 2T_c \cdot Q_d \cdot \left(Q_{com} - Q_{vap}\right)^{-1}, \tag{1}$$

where T_c – inside air temperature, °C;

Q_d – heat deficiency at negative outside temperature value, when $2T_c = -2T_{out}$;

Q_{com} – total power of heat losses, W;

Q_{vap} – energy needed for liquid evaporation from the floor, W.

Calculations of heat exchanger performance according to well known heat transfer coherences have been performed (Celmins et al., 1967):

$$Q = D_1\left(i_1' - i_1''\right)\eta = D_2\left(i_2'' - i_2'\right), \tag{2}$$

where D_1, D_2 – consumption of heat transfer medium, (kg s^{-1});

i_1', i_1'' – initial and end heat capacity of inside air, J kg^{-1};

i_2', i_2'' – initial and end heat capacity of outside air, J kg^{-1};

η – coefficient of device efficiency (COP),

and the following heat transfer equation (Ilsters et al., 2007) has been used

$$Q = Fk\Delta T, \tag{3}$$

where F – area of heat transfer surface, m^2;

k – coefficient of heat transfer, W m^{-2}·K^{-1} ;

ΔT – average temperature between two heat carriers, K.

RESULTS AND DISCUSSION

During the experimental investigation over the winter months the weather conditions were typical of Latvian winter. The temperature dropped below -20° C interspersed with periods of thaw. A detailed analysis of experimental heat exchangers was carried out at negative temperatures, when more fresh air heating is necessary. The efficiency of the heat exchanger WVT-120K varied depending on the outside air temperature: at the outside temperature above -10° C, the productivity of ventilators was on average about 3,500 $m^3 h^{-1}$, but at the outside temperature below -10° C, the productivity of ventilators was from 2,200 to 2,500 $m^3 h^{-1}$. Therefore, at lower temperatures, it was possible to achieve the designed power of the heat exchanger WVT-120K, even though the heat transfer coefficient was comparatively high. As the distance between the heat transfer plates of the heat exchanger WVT-120K is 2.5 times greater (compared to the heat exchanger HE-PVC), the outflow air gives less heat energy to the inflow air. However, the greater distance protects the heat transfer plates more from icing, as icing of the experimental heat exchanger HE-PVC (Fig.2 and Fig. 3) started when the outside air temperature was about -15° C. The obtained results show that the structure of the heat exchanger WVT-120K (Fig. 4) with appurtenant technical parameters is more suitable for use in pigsties with superior heat insulation of boundary constructions. Vertical performance of the heat exchanger WVT-120K which contributes to the refinement of the heat transfer plates and equips the heat exchanger with axial ventilators operated with small power monophase engines, is more appreciated (Ilsters et al., 2008).

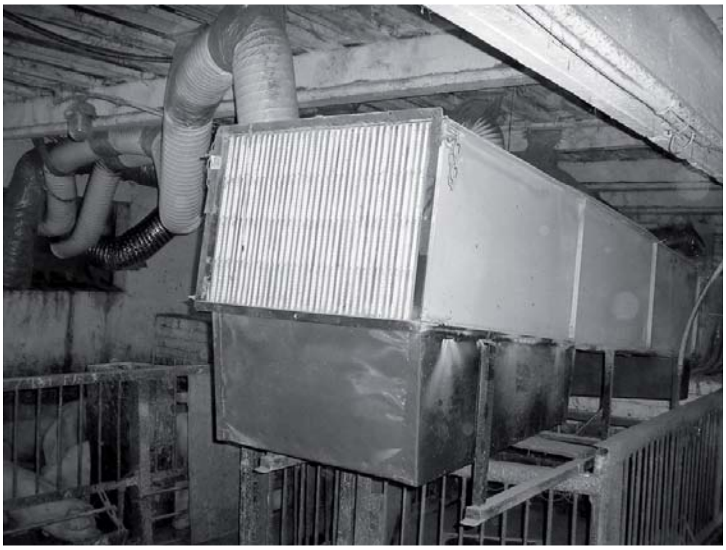

Fig. 2. Experimental heat exchanger HE-PVC testing in fattening pig barn of 500 animal places.

Average values of operational parameters (which depend on outside air temperature) of the experimental heat exchanger HE-PVC and the heat exchanger WVT-120K were obtained during the experiment. Power of the recuperated heat from outside airflow of the experimental heat exchanger during the experimental investigation increased from 9.4 kW to 12.6 kW at temperature drop from 0° C to -

15° C. In the case of heat exchanger WVT-120K, power of recuperated heat from outside airflow increased from 9.7 kW to 13.6 kW. As for the heat transfer coefficient, the situation is similar. During the temperature drop from 0° C to -15° C, the heat transfer coefficient of the experimental heat exchanger increased from 13.3 W m^{-2} °C^{-1} to 10.1 W m^{-2} °C^{-1}, but in the case of the heat exchanger WVT-120K, the heat transfer coefficient decreased from 24.0 W m^{-2} °C^{-1} to 20.2 W m^{-2}°C^{-1}. The value of the coefficient of performance by recovered heat for the experimental heat exchanger fluctuated between 0.54 and 0.88, but the value of COP by recovered heat for the heat exchanger WVT-120K varied between 0.23 and 0.40, respectively, due to decrease in the outside air temperature. Better heat recuperation of the heat exchanger HE-PVC is achieved mainly due to lesser distance between the heat transfer plates (Ilsters et al., 2008).

After the analysis of operational parameters it is possible to draw the conclusion that the use of the heat exchanger HE-PVC is more suitable for Latvian weather conditions than the heat exchanger WVT-120K.

It is necessary to calculate the payback time of the PVC heat exchanger. The calculations were made using operational parameters of the heat exchanger which were determined experimentally at the average outside air temperatures of Latvia. The data is given at heat loss level through the building constructions 1.5 W m^{-2} K^{-1} (referred to the floor area).

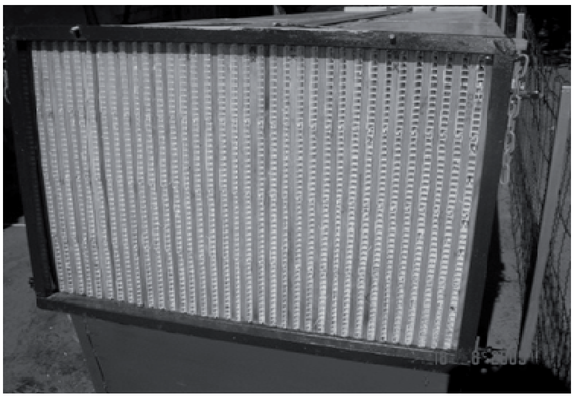

Fig. 3. Front view of the experimental heat exchanger HE-PVC.

Fig. 4. WVT-120K heat exchanger.

With reference to formula (1), the calculated outside air temperature at which the heat deficiency in the pigsty occurs if the heat exchanger for preheating the inflow of outside air is not used, is -5° C. But when the heat exchanger is used for preheating the cold inflowing outside air, the temperature is -12° C.

For calculating the economy of heating costs, the present liquefied gas price in Latvia 0.7 € kg^{-1} was taken. The price of the experimental heat exchanger is estimated at 600 €. The accounted economy value using the heat exchanger HE-PVC is about 130 € per year.

Considering the average monthly temperatures in Latvia (Borisovskij A., 1983), it is necessary to use the heat exchanger at full rate during the cold weather months from October to March. During the rest of the year, the use of heat exchangers is recommended only at night if the outside air temperature drops below -5° C. According to our calculations, the payback time of the experimental heat exchanger HE-PVC, not considering the interest rate, is about 4.6 years.

CONCLUSIONS

1. In the weather conditions of Latvia it is important to achieve a heat transfer as complete as possible, widening the interval of coverage of heat deficit towards lower outside air temperature.
2. In case of the experimental heat exchanger, more complete heat transfer from warm to cold air is achieved due to relatively small distance between the heat transfer plates.
3. Vertical location of recuperative counter-flow heat exchanger is favourable, facilitating the refinement of heat transfer plates during thickening of the condensate.
4. Calculations show that heat deficiency in a pigsty starts to occur at the outside air temperature -5° C if the heat exchanger is not used. If the heat exchanger is used, the heat deficiency starts to occur at the outside air temperature -12° C.
5. Calculation shows that payback time of the experimental heat exchanger HE-PVC is about 4.6 years, not considering the interest rate.

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