EFFICIENCY OF HEAT RECOVERY FROM PIGSTY MANURE

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Abstract. In order to decrease the amount of heat energy necessary for maintenance of the optimum temperature in a pigsty and piglets resting places experimental investigation on heat recovery from the manure mass stored up in the pigsty and inside air brought out by the pigsty ventilation system has been carried out. The ground heat pump used for heating of piglets resting place during summer and autumn months was operating with the coefficient of heat transformation up to 4.5. The necessary power of electric energy for warming the new born piglets resting place floor was 30-40 W per farrow. The recovered from the manure amount of heat energy made only 10-20 % of all heat necessary for piglets resting place heating. Similar results were obtained using the same technology for heating fattened pigs. The ratio between the price of electric energy and fuel used for heating of premises, as well as the value of the coefficient of heat transformation of the heat pump are the main determining factors for the choice of the type of heating.

Keywords: heat pump, heat recovery, manure heat, expenses.

Introduction

As pigs are producing a big amount of biological heat and moisture, in order to ensure the necessary quality of inside air intensive ventilation of the premises is needed. At the air exchange a considerable amount of heat energy is brought out into the atmosphere. The heat loss has to be covered by the use of certain heat sources. An alternative solution for the heat deficit covering can be the use of heat exchangers, by means of which the incoming cold outside air is warmed up using the heat of the outgoing air. The experimental results have shown that at the heat exchanger average efficiency 65 %, even at low outside air temperature it is possible to maintain the necessary temperature level in the pigsty without using any heating equipment [1].

The use of heat exchangers does not solve the maintenance of the necessary temperature in piglets resting places. According to the results of our experimental investigation on the use of the outside air heat pump, in summer time the coefficient of heat transformation of the heat pump can reach 4. It means that for the maintenance of the necessary level of temperature in piglets resting places the consumption of heat energy is only 25-30 W per farrow. As a result there is an essential decrease in the heat energy expense for piglets resting place heating in comparison with the use of liquefied gas [2]. During low outside air temperature the evaporators of the outside air heat pump intensively become covered with hoarfrost and ice, and its coefficient of heat transformation drops. In the experimental investigation it is proved that the exploitation parameters of the heat pump can be improved by the diversion of the heat pump evaporator warmed air brought out by the ventilation system from pigsties, ensuring the coefficient of heat transformation above 3 even in cold weather days [3]. It is possible to recover the heat from manure mass in the pigsty, too. Such a solution is realized in a pigsty and exploitation parameters are registered. The objective of the research is on the base of the accumulated data about the heat pumps exploitation parameters to give the estimation of the possibilities and economic efficiency depending on the price of electric energy and more often used fuel price considering the coefficient of heat energy transformation of different heat boilers.

Materials and methods

Theinvestigation on the heat recovery from manure using the ground type heat pump with an outside collector was carried out in one of the pigsties of the pig farm “Ulbroka” with 92 sow farrowing pens and in the pigsty with 3600 places for fattening pigs. The pig farm is heated using wood chip granules and liquefied gas, which ensure automatic operation of the farm boiler house. The outside loop of the used heat pump was performedfrom a plastic tube with diameter 35 mm evenly located and fixed on the concrete floor of the manure canal under the pigsty floor (Fig. 1).

The main technical parameters of the objects and the used heat pump are presented in Table 1. The electric energy consumed for the heat pump operation was measured using 3-phase electric energy meters with accuracy 0.01 kWh. The consumed amount of heat was measured using the heat meter SONOMER^{TM} 1000 (accuracy 1 kWh).

Fig. 1. **Heat pump collector in under floor manure canal**

During the experimental investigation with 15 second interval thepiglets resting place floor panels heating hot water flow intensity, its temperature at inflow and outflow of the heating loop, as well as the produced by the heat pump heat flow and the outside and inside air temperature using the HOBO type measuring instruments have been registered. The operation of the heat pump in different exploitation periods was estimated by calculation of the ratio between the amount of the consumed electric energy (compressor and circulation pump of the outer collector) and produced by the heat pump heat energy as follows

$$K = \frac{Q}{P_c}, \quad (1)$$

where K – coefficient of energy transformation;
Q – amount of produced and consumed heat energy, kWh;
P_c – common amount of electric energy consumed for operation of the heat pump, kWh.

The economic efficiency of the use of the heat pump is determined by a large amount of different factors [4].From the consumers of the heat pump point of view the main factors determining the economic efficiency of the use of heat pumps are:

- price of electric energy and fuel used to replace electric energy;
- coefficient of energy transformation of the heat pump and its load during a year (produced and consumed amount of heat energy).

Table 1

Technical parameters of the heat pump used and objects of its application

Parameters	**Farrowing section**	**Sty for fattening pig**
Heat power of ground-water type heat pump, kW	17	60 pens (120 in perspective)
Drive power of heat pump, kW	5	2 x 7.5
Area for outer collector loop, m^2	400	3600
Length of outer collector, m	850	6200
Number of piglets resting place panels	92	-
Number of fattening pigs in the sty	-	3600
Amount of manure produced per day, kg	2000	27000

The less is the ratio between burned in the boiler fuel price and the price of the electric energy consumed for the heat pump operation, the higher the coefficient of energy transformation *K* has to be in order to get some economic effect. It is determined by coherence

$$K \geq \frac{c_e \cdot \eta_k}{c_k}, \qquad (2)$$

where c_e – price of electric energy, EUR·kWh-1;
c_k – price of the fuel replaced, EUR·kWh-1;
η_k – efficiency of the heat boiler.

Results and discussion

Experimental envestigation in real production conditions on the use of the heat pump for new born piglets resting place floor panels heating was carried out in 2011 from June till November during three farrowing cycles. The hot water temperature for piglets resting place heating within the range of temperature 40-45 ºC was kept. With lowering the outside temperature the temperature of the heat carrier liquid into the heat pump outer loop diminished from 19 ºC in June to 12 ºC at the end of October. The results on the consumed amount of heat and electric energy for the heat pump operation are summarized in Table 2.

Table 2

Results of the use of recovered heat from pig manure using the ground-water type of heat pump for sucking piglets resting place heating in the 5th section of the pig sty in 2011

Indicators	1^{th} cycle 881 hour (June 11 to July 22)	2^{nd} cycle 816 hours (August 1 to September 8)	3^{rd}cycle 910 hours (September 26 to November 3)	On the average 870 hours
Average outside air temperature, ºC	19.2	17.3	9.4	15.3
Consumption of heat in the period, kWh	10702	11184	14241	12040
Consumption of heat, kWh·h^{-1}	12.15	13.71	15.65	13.86
Heat power per floor panel, kW	0.13	0.15	0.17	0.15
Consumption of electric energy in the period, kWh	2445	2503	3342	2760
Consumption of electric energy, kWh·h^{-1}	2.78	3.07	3.66	3.17
Coefficient of energy transformation, K	4.38	4.47	4.27	4.36

The need of heat for sucking piglets resting place floor panels heating in summer and autumn months during three farrowing cycles gradually decreased corresponding to the fall of the outside air temperature. The average heat power necessary for a panel heating was 150W. In accordance to the fall of outside air temperature also the coefficient of energy transformation diminished. Its average value was 4.36, what has to be evaluated as high for ground-water type heat pumps. Comparing and analyzing the real need of heat energy for sucking piglets resting place heating with the calculated amount of the recovered heat from accumulated into the manure mass in the underground manure canal, essential difference is stated. A sow with a farrow on the average produces 22 kg manure per day, which comes into the manure canal with the temperature near the inside air temperature of the pigsty what is around 20^{o}C.The heat content of this manure is 184 kJ. The amount of the heat energy recovered during an hour is 77 kJ, what corresponds to the heat power 21 W and is only 14 % from the necessary heat power for heating a panel. Therefore, the rest of the necessary amount of heat the outside collector of the heat pumpreceives from theheat transferred through the layer of manure from the under floor manure canalsurroundings, like concrete walls, the layer of ground and pigsty air. The partial recovery of the heat energy from the inside air of the pigsty for piglets resting place floor panels heating does not affect the pigsty temperature regime negatively, because the main part of heat from the panel surface returns back into the room inside air. As the heat recovery comes from the environment with small fluctuation of temperature, the change of the value of the coefficient of energy transformation is small, but corresponding to the temperature fall during the autumn months the consumption of heat increases.

The experimental investigation on the use of the ground-water type heat pump for heat recovery from manure and use of it for fattening pigsty heating was performed in the winter months of 2014. For the pigsty heating tube type radiators placed at 1.7 m above the room floor level were used. The heat carrier temperature in the radiators heated by the heat pump within the limits of 50-55°C was kept. For the experimental investigation 1800 weaned piglets in four sections of the pigsty were placed. The heat energy was recovered from the manure canal under 7 sections occupied by pigs. The heat carrier temperature during the period of investigation was around 11°C on the average. The results on the recovered and consumed amount of heat and electric energy for the heat pump operation are given in Table 3.

Table 3

Results of the use of a ground-water heat pump for fattened pigsty heating by the heat energyrecovered from manure canals (January-February, 2014)

Period of time	Average outside air temperature, °C	Heat, $kWh \cdot h^{-1}$	Electric energy, $kWh \cdot h^{-1}$	Coefficient of energy transformation
01.01-16.01	+1.9	16.7	4.98	3.36
16.01-20.01	-8.1	23.9	7.19	3.32
20.01-23.01	-11.9	40.9	1.94	2.94
23.01-28.01	-12.7	24.0	7.08	3.40
28.01-31.01	-12.3	42.3	14.34	2.95
01.02-10.02	-2.6	37.6	12.18	3.09
10.02-24.02	+2.6	39.4	12.87	3.06
24.02-07.03	+2.9	34.7	11.93	2.95
Average in period	-2.8	30.8	9.97	3.09

From January 1 till March 7, 2014 for heating 4 sections of fattening pigs 48750 kWh of heat energy have been used, consuming for this 157900 kWh electric energy. The average coefficient of energy transformation was 3.09. This is less in comparison with the previous variant mainly because of the highest of the produced water temperature. Also for this case the calculated recovered from manure amount of heat energy, accumulated in the manure mass and gathered in the manure canals, was evaluated and compared. In the pigsty 7 sections simultaneously occupied by 3150 fattening pigs per day on the average 23625 kg of manure were produced with the average temperature 18 ºC. The heat content of this manure mass was 1781.8 MJ. Correspondingly, the recovered amount of heat was 74240 KJ or 20.6 kW per hour. Comparing the obtained amount of the heat with the consumed for 4 sections heating, what in cold days was 24-42 kW, it follows that the need for pigsty heating is greater (Table 3). In this case also the outer collector of the heat pump receives insufficient amount of heat from manure. Therefore, the part of the necessary heat energy is transferred from the surroundings of the manure canal, like the ground and pigsty inside air. Taking the part of the necessary heat energy from the inside air is not rational. The variant can be used when the warm air is taken from the manure canal instead of the pigsty air. The advantage of such solution will be verified in the following investigation. During the time period when the heat pump was used it was not necessary to consume other fuel for heating. The difference of the fuel price and the price of electric energy consumed for the heat pump operation is the determining factor for calculation of the economic efficiency of the heating mode. For the pig farm "Ulbroka" heating wooden chip granules for 150 EUR per ton, liquefied natural gas for 780 EUR per ton and electric energy for 0.107 $EUR \cdot kWh^{-1}$ as the fuel were used.

The obtained results on decrease of the expenses when the fuel was replaced by the heat pump in the period of investigation, in comparison with the electric energy used for the heat pump operation on the average per month are given in Table 4.

Table 4

Decrease of average monthly expenses using the heat pump in comparison to the expenses of the replaced fuel

Indicators	**Sucking piglets section with 92 panels**		**Weaned piglets sections with panels**	**Fattening pigsty**
Type of heat recovering	manure in canals	outside air	outside air and pigstyventilation air	manure in canals
Consumption of heat energy, kWh	9980	6689	6278	22176
Consumption of electric energy, kWh	2282	2210	1872	7178
Coefficient of energy transformation	4.36	3.02	3.35	3.09
Expenses of fuel: granules (0.036 EUR·kWh^{-1}) liquefied gas (0.069 EUR·kWh^{-1})	 359 689	 241 462	 226 433	 798 1530
Expenses of electric energy, EUR	244	236	200	768
Monthly economy (EUR) in comparison with: granules liquefied gas	 115 445	 5 226	 26 233	 30 762

The price of the fuel and electric energy in free competition conditions is changing. In order to state at what value of the coefficient of energy transformation of the heat pump it is useful to replace the corresponding fuel with the heat pump, Fig. 2 is analyzed.

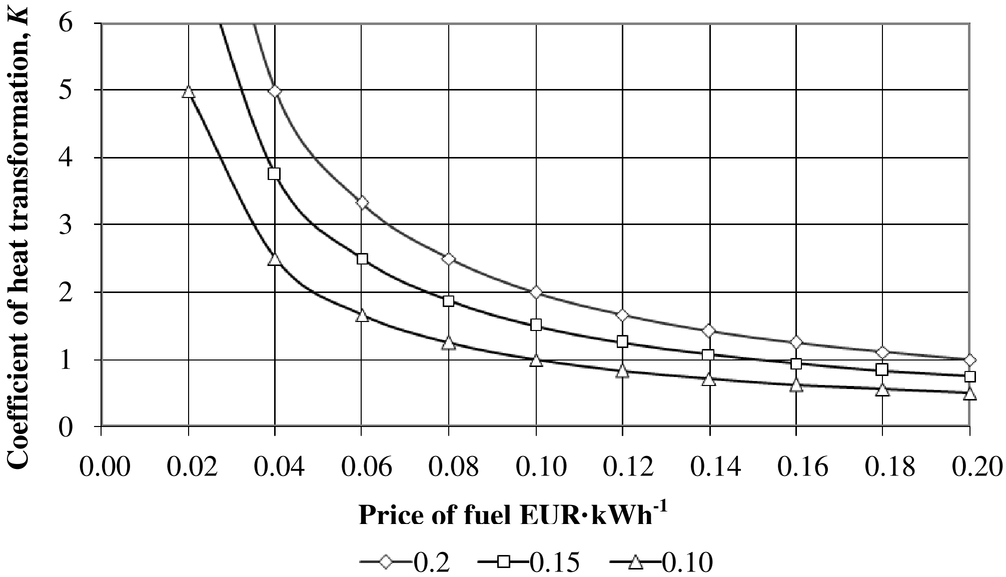

Fig. 2. **Coefficient of heat transformation at which the use of a heat pump starts to be economic at the price of electric energy 0.1; 0.15 and 0.20 EUR·kWh^{-1}**

For comparative evaluation the experimental results about the use of the outside air heat pump with a passive evaporator for new born und veaned piglets resting place heating are included in Table 4. From the indicators given in Table4 it follows that average monthly economy is grater for all variants, when the heat pump is used for heating instead of liquefied gas. Even in case when the coefficient of energy transformation of the heat pump is a little above 3, the piglets resting place heating expense was half as much. If the heat pump replaces relatively cheaper fuel like wooden chip granules, the economic efficiency was not big, and the coefficient of energy transformation was a little above 3. If the warm inside air from the pigsty brought out by the ventilation system is blown on the passive evaporator plates of the outside air heat pump, during cold weather periods the average economic efficiency increases up to EUR 220. It means that replacement of the liquefied gas boiler with the heat pump would pay back during 3-4 years. Fig. 2 shows at what value of the coefficient of energy transformation and the fuel price considering the efficiency of the boiler it is economically to replace it with the heat pump. For example, if at burning wood chip granules the price of the produced 1kWh of heat energy is 0.04 EUR, and the price of electric energy is 0.1 $EUR \cdot kWh^{-1}$, than in order to replace granules with the heat pump its coefficient of energy transformation has to be above 2.5. The higher isthe coefficient of energy transformationof the heat pump;the higher the efficiency will be. At the choice of the heat pump instead of some fuel burning several factors like decrease of harmful emission, fire resistance and others have to be taken into consideration.

Conclusions

1. The experimental results shown that in the pig farm using the heat pump which collector is placed into the manure canal, the coefficient of heat transformation can reach the value up to 4.5 depending on the necessary temperature.
2. The heating at the necessary level is ensured receiving 20-30 % of the recovered heat energy from manure, but the rest from the environment around the manure canal.
3. The heat recover from the manure canals is more useful for the case when piglets resting place is heated using floor panels; the part of the heat energy is returned back into the room.
4. The use of the heat pump for piglets resting place panels heating with recovered heat from the manure canals can be equivalent to the heat pump blown warm inside air brought out by the ventilation system from the pigsty.
5. The use of the heat pump at the present price of electric energy and fuel starts to be efficient at the coefficient of heat transformation of the heat pump above 2.5-3.0.
6. The influence of the heat recovery from manure in canals on the total temperature regime of the pigsty has to be investigated additionally.

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