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## EFFECT OF HEAT RECOVERY FROM DEEP LITTER PIGGERY ON GREENHOUSE GASES AND AMMONIA EMISSIONS

### Summary

The aim of this study was to determine the effect of cooling deep litter in a pen for pigs by using the heat recovery system on greenhouse gases and ammonia emission from piggery and residential building. The research was carried out in farm located in Wielkopolska Voivodeship, where the heat recovery system from deep litter was installed. Fermenting manure stored on the floor of piggery was the heat source and central heating, domestic hot water system in residential building were the heat sink. Cooling manure in deep litter pen for pigs resulted in reducing greenhouse gas emissions from piggery by about: 11,424 kg·yr<sup>-1</sup> (12,1%) for CH<sub>4</sub>, 662 kg·yr<sup>-1</sup> for N<sub>2</sub>O (16,2%) and 3,532 kg for NH<sub>3</sub> (15,7%). The use of heat recovered from the deep litter to supply central heating and domestic hot water system in residential building reduced carbon dioxide emissions by 7,377 kg·yr<sup>-1</sup> (35%). Weighted average reduction of greenhouse gas emissions from the researched farm, taking into account the mass of each gas was 13.7%.

**Key words:** greenhouse gas emission, ammonia emission, deep litter piggery, heat pump, cooling manure

## WPLYW ODZYSKU CIEPŁA Z GŁĘBOKIEJ ŚCIOŁKI NA EMISJĘ GAZÓW CIEPLARNIANYCH I AMONIAKU

### Streszczenie

Celem pracy było określenie wpływu schładzania obornika w kojcu z głęboką ściółką przez zastosowanie instalacji do odzysku ciepła z głębokiej ściółki na emisję gazów cieplarnianych i amoniaku z tuczarni oraz budynku mieszkalnego. Badania prowadzono na terenie gospodarstwa rolnego, zlokalizowanego w województwie wielkopolskim, w którym zamontowano instalację do odzysku ciepła. Głównym źródłem były instalacje centralnego ogrzewania i ciepłej wody użytkowej budynku mieszkalnego. Schładzanie obornika w kojcu z głęboką ściółką przez zastosowanie instalacji do odzysku ciepła spowodowało ograniczenie emisji gazów cieplarnianych z tuczarni: CH<sub>4</sub> o 11424 kg·rok<sup>-1</sup> (12,1%) i N<sub>2</sub>O o 662 kg·rok<sup>-1</sup> (16,2%) oraz amoniaku (NH<sub>3</sub>) o 3532 kg rocznie (15,7%). Wykorzystanie ciepła pobranego z głębokiej ściółki do zasilania instalacji c.o. i c.w.u. budynku mieszkalnego ograniczyło emisję dwutlenku węgla o 7377 kg·rok<sup>-1</sup>, czyli o 35%. Średnia redukcja emisji gazów cieplarnianych z badanego gospodarstwa, uwzględniając ich udział ilościowy, wynosiła 13,7%.

**Słowa kluczowe:** emisja gazów cieplarnianych, emisja amoniaku, tuczarnia, głęboka ściółka, pompa ciepła, schładzanie obornika

### 1. Introduction

Agriculture is a significant source of greenhouse gases and ammonia. The global greenhouse gas emissions from agriculture, forestry and fisheries have doubled over last 50 years and amounted to more than 10 billion tonnes of CO<sub>2</sub> eq in 2012. FAO (Food and Agriculture Organization of the United Nations) estimates that without taking more efforts to reduce their emissions it may grow by next 30% till 2050. The livestock production sector has a 18% share in the anthropogenic emissions of greenhouse gases [10, 22]. Pig farming is the second largest source of greenhouse gas emissions from this sector, with a share of about 13% [25]. Whereas European Environment Agency estimated that about 80% of ammonia emissions from agriculture come from animal production [8].

In 2012, the share of agriculture in Polish hazardous gases emission was 98% for ammonia, 85.2% for nitrous oxide and 27.8% for methane [13, 14]. For this reason,

modern livestock production technologies must ensure not only its economic effectiveness, but also reduce the negative impact on the environment and provide appropriate welfare of animal [19].

Greenhouse gas emissions are positively correlated to inside temperature and ventilation system efficiency. Ni et al. showed that increasing the air temperature inside the piggery from 15 to 20°C resulted in doubling of the carbon dioxide emission [16]. While, Ngwabie et al. observed doubling of CH<sub>4</sub> emissions resulting from the increase of air temperature in piggery from 16.8 to 22.8°C [15]. Chae et al. [4] found that lowering the temperature from 35°C to 25°C caused a reduction in methane emission by 17.4% [4].

Granier et al, Jugowar, Oenema et al., Stelt et al., Cortus et al. found a strong correlation between ammonia emissions and air temperature inside piggeries [5, 9, 12, 17, 23]. Cortus et al. studied in special balancing chambers the influence of inside temperature on ammonia emission and noted that its emissions doubled while increasing the tem-

perature from 10 to 20°C [5]. The research carried in pigery by Granier et al. showed the increase in ammonia emission from 12.8 to 14.6 g·day<sup>-1</sup>·pig<sup>1</sup> while changing the temperature from 17 to 28°C [9].

Litter housing systems for pigs characterized lower methane emissions and higher carbon dioxide, nitrous oxide and ammonia emissions in comparison to the fully-slatted floor systems [2, 3, 7]. However, keeping pigs on deep litter has a positive effect on welfare [24]. In addition, exothermic reactions occurring in fermenting litter may be source of energy used to heating livestock or residential buildings [6].

The aim of this study was to determine the effect of cooling deep litter in a pen for pigs by using the heat recovery system on greenhouse gases and ammonia emission from pigery and residential building.

## 2. Material and methods

The research was carried out in farm located in Wielkopolska Voivodeship, where the heat recovery system from deep litter was mounted. Fermenting manure stored on the floor of pigery was the heat source, which characteristic is presented in tables 1 and 2.

Table 1. Characteristic of pigery [1]

Tab. 1. Charakterystyka budynku tuczarni [1]

| Parameter                  | Unit              | Value |
|----------------------------|-------------------|-------|
| Length of the building     | (m)               | 36.0  |
| Width of the building      | (m)               | 14.3  |
| Building height            | (m)               | 5.2   |
| Building area              | (m <sup>2</sup> ) | 504   |
| Number of chambers         | (item)            | 2     |
| Number of pens             | (item)            | 8     |
| Total area of the pens     | (m <sup>2</sup> ) | 357.8 |
| Area of single pen         | (m <sup>2</sup> ) | 44.7  |
| Area of deep litter in pen | (m <sup>2</sup> ) | 34.4  |

Table 2. Technological characteristic of pigery [1, 21]

Tab. 2. Charakterystyka technologiczna tuczarni [1, 21]

| Parameter                  | Unit                      | Value |
|----------------------------|---------------------------|-------|
| Number of pens             | (item)                    | 8     |
| Number of pigs in pen      | (item)                    | 60    |
| Length of production cycle | (month)                   | 4     |
| Number of cycles           | (cycle·yr <sup>-1</sup> ) | 3     |
| Final weigh of pig         | (kg)                      | 105   |

The heat from manure was recovered by horizontal heat exchangers placed in floor pens. In each pen were two exchangers made of polyethylene pipes (Φ=32 mm). The total length of the heat exchanger in pigery was 1,304 m. The exchangers of each pen were connected to water flow controller. It allowed controlling the heat source ia. to recover the energy only from exchangers in which temperature of water was higher than the water temperature returning from heat pump. The energy taken from deep litter was transferred to the heat pump (16.8 W), which moved thermal energy opposite to the direction of spontaneous heat flow. The low temperature energy from deep litter was changed in warm temperature thermal energy which may be used in heat sink: central heating and domestic hot water system of residential house. In boiler room, there were also double jacket water heater to which were connected central heating, domestic hot water system heat pump and coal boiler circuit. The coal boiler was reserve source of heat (Fig. 1) [6, 23].

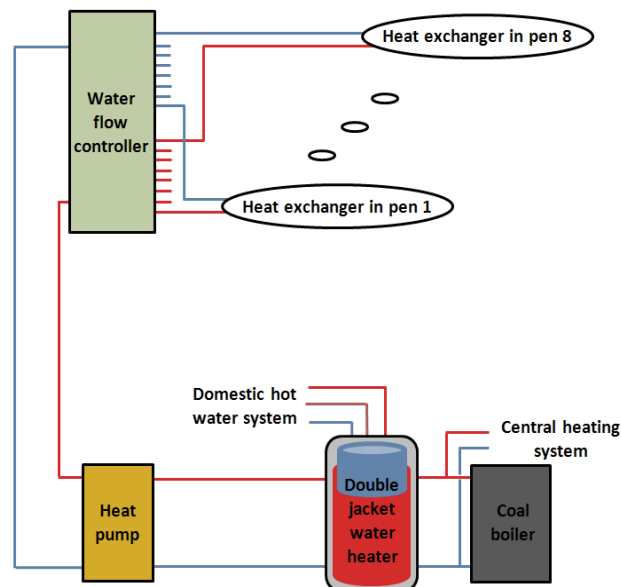


Fig. 1. Schematic view of heat recovery system [1]

Rys. 1. Schemat instalacji do odzysku ciepła z głębokiej ściółki [1]

Research of the effect of heat recovery from the deep litter on greenhouse gases was divided into two stages. The first consisted in a study of limiting greenhouse gases and ammonia emissions from pigery. Annual emissions of greenhouse gases and ammonia from the researched pigery were calculated in two cases for switch on and switch off the heat recovery system, using the equation (1):

$$E = m_r \cdot W_e, \quad (1)$$

where:

$E$  – emission of researched gases (kg·yr<sup>-1</sup>),

$m_r$  – annual pig production (kg),

$W_e$  – emission factor of researched gases (kg·yr<sup>-1</sup>·kg body mass<sup>-1</sup>).

The total annual emissions of greenhouse gases emitted from pigery were expressed as CO<sub>2</sub> equivalent ( $E_{T_{eq.CO_2}}$ ). According to the IPCC (Intergovernmental Panel on Climate Change), the Global Warming Potential was adopted at 23 for methane and 296 for nitrous oxide [11]. Emission of carbon dioxide was not included in calculating the greenhouse gas emissions from researched pigery. For agricultural sources is assumed that the carbon dioxide emitted from livestock buildings is used for photosynthesis during the growth of plants which are used as feed and bedding for pigs.

Second stage consisted in a study of reducing carbon dioxide emission from residential building. The limitation resulted from the change in heat source. The energy from coal combustion in boiler was replaced by energy recovered from deep litter. The amount of energy that can be recovered from the deep litter was calculated from equation (2):

$$Q = P_{1kg} \cdot m_r \cdot t, \quad (2)$$

where:

$Q$  – energy recovered from deep litter (kWh),

$P_{1kg}$  – heat power related to 1 kg of body mass of fattening pigs (kW·kg body mass<sup>-1</sup>),

$m_r$  – annual pig production (kg),

$t$  – number hours in year - 8760 h

and the electric energy consumed by the heat pump from the equation (3):

$$\varepsilon_{el} = \frac{Q}{COP}, \quad (3)$$

where:

$\varepsilon_{el}$  – annual electricity consumption (kWh·yr<sup>-1</sup>),

$COP$  – coefficient of performance.

Carbon dioxide emission from the residential building ( $E_{BM}$ ) was calculated as the product of the energy needed to power the central heating and domestic hot water system and the rate of carbon dioxide emissions relative to 1 kWh of energy obtained from the combustion of coal (heat recovery system is off) or 1 kWh of electricity from the national power system (the heat recovery system is on).

Total greenhouse gases emission was calculated from equation (4):

$$E_C = E_{T\theta q CO_2} + E_{BM}, \quad (4)$$

where:

$E_C$  – total greenhouse gases emission from farm (kgCO<sub>2</sub>·yr<sup>-1</sup>),

$E_{T\theta q CO_2}$  – greenhouse gases emission from piggery (kgCO<sub>2</sub>·rok<sup>-1</sup>),

$E_{BM}$  – carbon dioxide emission from residential building (kgCO<sub>2</sub>·rok<sup>-1</sup>),

Calculation of greenhouse gases and ammonia emissions were done for on and off heat recovery system from deep litter, which allowed the determination of the reduction level for researched gases, resulting from its use.

### 3. Results

The annual pig production, which amounted to 151200 kg·yr<sup>-1</sup> was determined based on the data from table 2. Emission factors of researched gases related to 1 kg of body mass obtained by Rzeźnik [21] were used to calculate greenhouse gases and ammonia emissions from piggery. Their values were calculated based on the annual comparative measurements conducted at the same piggery and are presented in Table 3.

Table 3. Emission factors of researched gases from piggery when heat recovery system is on and off [21]

Tab. 3. Współczynniki emisji badanych gazów z tuczarni przy odzyskiwaniu ciepła i bez odzysku [21]

| Type of gas                      | Emission factor (mg·day <sup>-1</sup> ·kg body mass <sup>-1</sup> ) |       |
|----------------------------------|---|-------|
|                                  | On  | Off   |
| Nitrous oxide (N <sub>2</sub> O) | 62  | 74    |
| Methane (CH <sub>4</sub> )       | 1 506   | 1 713 |
| Ammonia (NH <sub>3</sub> )       | 344   | 408   |

The value of annual emissions of greenhouse gases and ammonia from piggery were calculated from equation (1) and are presented in table 4.

The use of heat recovery system limited emission of all studied gases. Emission from piggery decreased by 16.2% for nitrous oxide, by 12.1% for methane and by 15.7% for ammonia.

To determine the emission reductions associated with the conversion of the heat source for central heating and domestic hot water system in residential building, amount of energy recovered from deep litter during the year and electricity consumed by heat pump were calculated from the equations (2) and (3). The heat power related to the 1 kg of pig body mass and the average coefficient of perfor-

mance for the heat pump was adopted with Rzeźnik [20] and Adamczyk et al. [1].

Table 4. Annual emissions of greenhouse gases and ammonia from piggery

Tab. 4. Roczne emisje gazów cieplarnianych i amoniaku z tuczarni

| Type of gas                      | Annual emission (kg·yr <sup>-1</sup> ·kg <sup>-1</sup> ) |        | Reduction (kg·yr <sup>-1</sup> ) |
|----------------------------------|--|--------|----------------------------------|
|                                  | On   | Off    |                                  |
| Nitrous oxide (N <sub>2</sub> O) | 3 422  | 4 084  | 662                              |
| Methane (CH <sub>4</sub> )       | 83 113   | 94 537 | 11 424                           |
| Ammonia (NH <sub>3</sub> )       | 18 985   | 22 517 | 3 532                            |

Source: Own work / Źródło: opracowanie własne

Their values reached respectively 4.6·10<sup>-5</sup> kW·kg<sup>-1</sup> and 3.61 and were determined during two-year study conducted in 2009-2010, in the same piggery. Using researched heat recovery system 60,928 kWh of thermal energy per year can be obtained, while 16,876 kWh electricity consumption. The value of carbon dioxide emission rate relative to 1 kWh of energy obtained from the combustion of coal adopted according to IPCC and 1 kWh of electricity from the national power system according to KOBIZE (National Centre for Emission Management) [11, 18].

Table 5. Annual carbon dioxide emission for residential building

Tab. 5. Roczna emisja dwutlenku węgla z budynku mieszkalnego

| Parameter   | Heat pump | Coal boiler |
|---|-----------|-------------|
| CO <sub>2</sub> emission rate (kg·kWh <sup>-1</sup> ) | 0,812     | 0,346       |
| Energy  | 16 876    | 60 928      |
| CO <sub>2</sub> emission (kg·yr <sup>-1</sup> )       | 13 704    | 21 081      |

Source: Own work / Źródło: opracowanie własne

Reduction of carbon dioxide emissions resulted from change of energy source of powered central heating and domestic hot water system amounted to 7377 kgCO<sub>2</sub>·yr<sup>-1</sup>, which in percentage was 35%. The total emissions of greenhouse gases expressed in CO<sub>2</sub> equivalent calculated according to equation (4) are presented in Table 6.

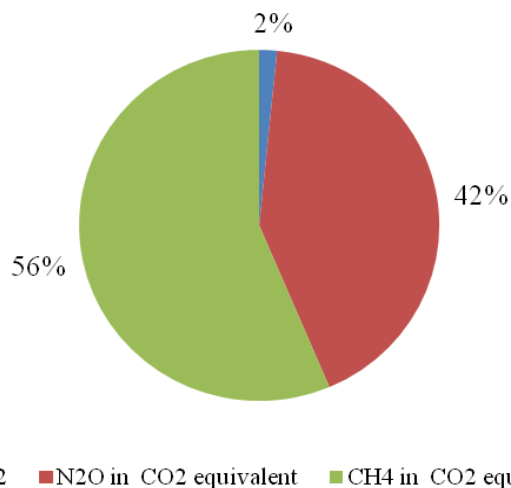
Table 6. Annual greenhouse gases emissions expressed in CO<sub>2</sub> equivalent

Tab. 6. Roczna emisja gazów cieplarnianych wyrażona w ekwiwalencie CO<sub>2</sub>

| Source of emission   | Type of gas                                    | Annual emission (kg·yr <sup>-1</sup> ) |                  | Reduction (kg·yr <sup>-1</sup> ) |
|----------------------|--|--|------------------|----------------------------------|
|                      |  | On                                     | Off              |                                  |
| Residential building | CO <sub>2</sub>                                | 13 704                                 | 21 081           | 7 377                            |
| Piggery              | N <sub>2</sub> O in CO <sub>2</sub> equivalent | 1 012 912                              | 1 208 864        | 195 952                          |
|                      | CH <sub>4</sub> in CO <sub>2</sub> equivalent  | 1 911 599                              | 2 174 351        | 262 752                          |
|                      | <b>Total</b>                                   | <b>2 938 215</b>                       | <b>3 404 296</b> | <b>466 081</b>                   |

Source: Own work / Źródło: opracowanie własne

Average reductions in greenhouse gas emissions from the researched farm, taking into account the mass of each gas was 13.7%. The share of studied greenhouse gases in the overall reduction is shown in Figure 2.



Source: Own work / Źródło: opracowanie własne

Fig. 2. The share of studied greenhouse gases in the overall reduction

Rys. 2. Udział badanych gazów w redukcji gazów cieplarnianych

The energy potential of the deep litter is the greatest in summer, but it could not be fully used by heat recovery system, due to the low heat requirement. Indication of another way to use energy produced in manure in this period would improve the environmental effect that result from the heat recovery system.

#### 4. Conclusions

Based on the study of effect of manure cooling in deep litter pen by heat recovery system on greenhouse gases and ammonia emissions the following conclusions were formulated:

- Cooling manure in deep litter pen for pigs resulted in reducing greenhouse gases emissions from piggery about: 11,424 kg·yr<sup>-1</sup> (12,1%) for CH<sub>4</sub>, 662 kg·yr<sup>-1</sup> by N<sub>2</sub>O (16,2%) and 3,532 kg for NH<sub>3</sub> (15,7%).
- The use of heat recovered from the deep litter to supply central heating and domestic hot water system in residential building reduced carbon dioxide emissions by 7 377 kg·yr<sup>-1</sup> (35%).
- Weighted average reduction of greenhouse gases emissions from the researched farm, taking into account the mass of each gas was 13.7%.

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