DEVELOPMENT OF AUTOMATED SPRAYING SYSTEM FOR PIGS TO NORMALIZE THEIR WELFARE

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Abstract

The mathematical model of automated spraying system can be used and integrated into the infrastructure of pig farms, providing constant monitoring of the microclimate and animal health, keep pigs clean, cool them effectively, reduce skin contamination and prevent infectious diseases. The following parameters were considered for mathematical analysis of an automated pig spraying system under different conditions: animal size, contamination level, volume of sprayed liquid and cleaning efficiency. The cleaning efficiency E can be represented as a function of the ratio of liquid volume to surface area and the contamination level, and E should be as close to unity as possible. The efficiency of spraying to reduce infectious diseases in pigs and improve their living conditions during climate change takes into account the factors: ambient temperature, relative humidity, optimal temperature for pigs, optimal relative humidity for pigs, growth rate of a bacterial population under certain ambient conditions, efficiency of cooling by spraying, infection risk index. The model shows that the reduction in the infection risk index directly affects animal welfare. The lower the level of stress and infection risk, the better the living conditions for pigs. The automated spraying system will significantly improve the conditions for pigs on farms and their welfare, and reduce the risk of disease providing the required temperature and humidity levels on the farm.

Key Words: Pig welfare, spraying system, mathematical model, stress level

The problem of ensuring the welfare and health of pigs on farms is increasingly important due to global climate change. Increasing average annual temperatures, as well as the frequency and intensity of temperature fluctuations significantly induces heat stress in animals, which, in turn, leads to lower productivity and higher risk of their infection (Llonch et al., 2024; Niu et al., 2024; Vermeer and Aarnink, 2023; Smith and Eastwood, 2023; Guevara et al., 2022; Scriba and Wechsler, 2021). This is especially relevant in modern industrial livestock farming, where animals are kept in large numbers in a limited area, and high temperatures and humidity can create a favorable environment for pathogenic microorganisms spread and reduce animal welfare.

The following measures are suggested to minimize the impact of heat and increased temperature, and to optimize climate management (Vermeer and Aarnink, 2023):

- Maximize ventilation rate.
- Use “ground tubes” for the inlet of fresh air, cooled by the soil.
- Use evaporative cooling of fresh air: water spraying (fog/mist) in the air inlet.
- Maximize space allocation per pig.
- Check drinkers (flow rate, fresh, clean, cool).
- Increase rate of showering if showers/ sprinklers are present.
- At heavily heat stress, directly spray water on the pigs and increase air velocity (circulation fans).

- Insulate windows or use white chalk; chalk or moisten the roofs (note: sufficient insulation of the roof is important to prevent solar heat from entering the pig house), but maintain sufficient light.
- Be sure that the emergency system works in case of technical problems with the ventilation system.
- Clean ventilators, air ducts, air scrubbers and air inlet to reduce resistance.

Currently, farms use various spraying methods and hygiene equipment to wash and disinfect pigs and other animals according to protocols, mostly manually (*CID LINES, An Ecolab Company, Belgium; MS Schippers, Netherlands;* DeLaval Limited, *United Kingdom;* SwineTech Inc., USA; Štukelj et al. (2021), and others).

Heat stress can be reduced in dry climate by drip or spray cooling. The water absorbs the pig body heat as it evaporates to cool their bodies (HOFMAN, 2024; Spray and drip cooling systems for piggeries).

In contrast to traditional methods of keeping animals clean and cool, the development and implementation of automated spraying systems optimises the pig care process, reduces the need for manual labor, and also provide precise control of the animal housing conditions, which is a key factor in maintaining their health. Automated spraying systems can be used and integrated into the infrastructure of pig farms, providing constant monitoring of the microclimate and animal health. The real benefits of implementing automated spraying systems on pig farms depend on the specific requirements, climate, farm specifications and pig breed.

Results and Discussion

There are hardly climatic legal requirements for pigs in the EU-regulations. However, on a national level rules can be stricter, but often formulated as “open norms”. Directive 98/58/EC states that the accommodation should “not be harmful” to the pigs, which can only be checked by animal based indicators given in section 4.2. However, legal limits are not available in most countries, with difficult enforcement as a consequence (Vermeer and Aarnink, 2023).

Council Directive 2008/120/EC (EU, 2008) Annex I, Chapter I, Article 3: The accommodation for pigs must be constructed in such a way as to allow the animals to have access to a lying area physically and thermally comfortable as well as adequately drained and clean which allows all the animals to lie at the same time.

Council Directive 98/58/EC (EU, 1998) Annex (Buildings and accommodation), Article 10: Air circulation, dust levels, temperature, relative air humidity and gas concentrations must be kept within limits which are not harmful to the animals.

One way to maintain an optimal indoor climate for pigs on a farm is using a spraying system.
Technological requirements for automated animal spraying systems on pig farms include the selection of a suitable type of sprayers, sensors for animal position detection and automation algorithms.

There are some standards using in agriculture and characterize the requirements for such systems.

ISO 16119 (Agricultural and forestry machinery – Environmental requirements for sprayers, Part 1 -4), ISO 16119-1:2013 (General) gives the minimum requirements for sprayers, with particular emphasis on minimizing environmental damage, focusing on the deposition of liquid on the target and distribution, a minimization of the unintentional spreading of plant protection products into the surrounding environment, and an improvement in the use and operation of plant protection equipment. The safety and environmental requirements for sprayers can be adapted for use on livestock farms.

ISO 5682-2:2017 (Equipment for crop protection – Spraying equipment) specifies test methods to assess sprayed liquid horizontal transverse distribution. Methods are based on sprayed liquid volume measurement, nozzle flow rate measurement or nozzle tip pressure measurement.

Although this standard addresses crop spraying, it also contains requirements that are applicable to animal spraying systems.

These technological requirements are the basis for the development of efficient automatic and automated spraying systems for farms, including pig farms. The standards ensure that such systems meet safety, efficiency and environmental requirements.

To mathematically analyze the performance of an automated pig spraying system under different conditions, the following parameters can be considered: animal size, contamination level, spray volume and cleaning efficiency.

The following parameters are used in the mathematical model:

A is the surface area of the pig body to be sprayed (m^2);

C is the contamination level of the pig (kg/m^2);

Q is the volume of liquid required for effective cleaning (l/m^2);

E is the cleaning efficiency, which depends on the contamination level and the volume of sprayed liquid.

The surface area of the pig body *A* can be calculated as follows:

$$A = 2 \cdot L \cdot W + 2 \cdot L \cdot H + 2 \cdot W \cdot H$$

where *H* is the height of the pig (m);

L is the length of the pig body (m);

W is the width of the pig body (m);

For simplicity, a formula for a cylindrical surface can be used, since the shape of the pig body is approximately cylindrical:

$$A = \pi \cdot D \cdot L$$

where *D* is the average diameter of the pig body (m).

The volume of liquid *V* required for spraying depends on the surface area and the contamination level:

$$V = A \cdot Q \cdot \left(1 + \frac{C}{C_{max}}\right)$$

where C_{max} is the maximum contamination level at which the maximum amount of liquid is required.

The cleaning efficiency *E* can be represented as a function of the ratio of liquid volume to surface area and the contamination level:

$$E = \frac{V}{A \cdot C}$$

Ideally, *E* should be as close to unity as possible, indicating optimal cleaning.

The system performance *P* depends on the time required to spray one pig, the number of animals and the total time for cleaning:

$$P = \frac{N \cdot A}{T}$$

where *N* is the number of animals, *T* is the total time for cleaning all animals.

Taking into account these parameters, we can estimate the performance of the system under different conditions:

- Small pig with low contamination: *L, W, H* and *C* are small, so *V* and *T* will be smaller.
- Large pig with high contamination: *L, W, H* and *C* are large, which increases *V* and *T*, reducing system performance.

In each case, the parameters *V, E* and *P* can be determined depending on the size of the pig and its contamination level.

For example, for a pig with parameters *L* = 1.2 m, *W* = 0.4 m, *H* = 0.6 m, *C* = 0.1 kg/m^2, and *Q* = 0.05 l/m^2, the calculations are as follows:

$$D = \frac{0.4 + 0.6}{2} = 0.5\ (m)$$

$$A = \pi \cdot 0.5 \cdot 1.2 = 1.88\ (m^2)$$

$$V = 1.88 \cdot 0.05 \cdot \left(1 + \frac{0.1}{0.5}\right) = 0.12\ (l)$$

$$E = \frac{0.12}{1.88 \cdot 0.1} = 0.64$$

Using this model, it is possible to perform numerical analysis and optimize the spraying process by changing the parameters and taking into account their impact on system performance.

In order to develop a mathematical model that evaluates the efficiency of spraying to reduce infectious diseases in pigs and improve their housing conditions under climate change, several important factors need to be taken into account

T_{am} is the ambient temperature (°C);

H_{am} is the relative humidity (%);

T_{op} is the optimal temperature for pigs (°C);

H_{op} is the optimal relative humidity for pigs (%);

R_b is the growth rate of a bacterial population (infectious agent) under certain ambient conditions;

E_{cool} is the efficiency of cooling by spraying (%);

I_r is an infection risk index that depends on temperature, humidity and spraying level.

Pigs are sensitive to changes in climate conditions, and extreme temperatures can increase the infection risk. The calculation of temperature and humidity stress can be represented as follows:

$$S_t = (T_{am} - T_{op}) + 0.01(H_{am} - H_{op})$$

where S_t is the stress level. The higher the value of S_t, the more stress pigs experience, which increases the infection risk.

The infection risk index I_r depends on temperature and humidity stress and the growth rate of the bacterial population:

$$I_r = R_b\left(1 + \frac{S_t}{10}\right)$$

where R_b is the basic infection growth rate under optimal conditions.

Cooling efficiency E_{cool} can be calculated as the decrease in temperature on the pig body after spraying:

$$\Delta T = E_{cool}(T_{am} - T_{op})$$

where ΔT is the temperature change on the pig body after spraying.

Modified stress level taking into account spraying S_{new}:

$$S_{new} = (T_{am} - \Delta T - T_{op}) + 0.01(H_{am} - H_{op})$$

Modified infection risk index:

$$I_{new} = R_b\left(1 + \frac{S_t}{10}\right)$$

The overall spraying efficiency can be estimated as:

$$E_{cool} = \frac{I_r - I_{new}}{I_r} 100\%$$

This formula shows how the spray reduces the infection risk index.

The model can take into account the dependence of animal welfare on the stress level and infection risk:

$$W_{new} = W_{max}\left(1 - \frac{I_{new}}{I_{crit}}\right)$$

where W_{new} is animal welfare; W_{max} is the maximum welfare without stress; I_{crit} is the critical level of infection risk at which welfare is reduced to a minimum.

During the calculation, parameters such as ambient temperature and cooling efficiency can be varied to assess the impact on animal welfare and disease risk. For example, if $T_{am} = 35$ ^{0}C, $T_{op} = 24$ ^{0}C and $E_{cool} = 0.7$, then the change in temperature stress and a new risk index can be determined. This model allows to evaluate how spraying affects the reduction of stress and infection risk, which is especially important in the context of climate change.

Conclusions

Rising temperatures and changing climate conditions cause significant stress for pigs, which increases the risk of infectious diseases. Changes in environmental temperature and relative humidity create unfavorable conditions that negatively affect the health and welfare of animals.

The proposed mathematical model allows estimating the level of pig stress under different conditions of temperature and humidity. The model also takes into account the infection risk index, which directly depends on temperature and humidity stress, as well as on the growth rate of the bacterial population.

Cooling pigs using automated spraying is an effective method to reduce the heat stress in pigs, their body temperature, consequently, reduces the risk of infection. The calculated spraying efficiency shows how the risk of infections can be reduced by this process.

The proposed model allows conducting numerical analysis and optimization of spraying system parameters depending on the specific climatic conditions on the pig farm. It helps to determine the optimal cooling efficiency, which helps to maximize the reduction of infection risk and improve the welfare of pigs.

The model shows that a reduction in the infectious risk index directly affects animal welfare. The lower the level of stress and infection risk, the better the living conditions for pigs. The automated spraying system will significantly improve the conditions for pigs on farms and their welfare and reduce the risk of disease.

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This study was supported by the research project MZe-RO0723.