Substantiation of optimum relative humidity of slurry when applying the batch-type gravity flow system for its removal

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Abstract. The batch-type gravity flow system for slurry removal is most commonly installed on the new and reconstructed pig farms. The newly designed system is characterized by the presence of plastic sewing pipes under each slurry-collecting canal. Such a system allows for complete automation of slurry removal and, under proper operation, mitigates the negative impact of pig farms on the environment through the lower annual output of slurry. The paper presents the calculation of the main design parameter of the system, such as the depth of slurry pits and the burial depth of longitudinal and transverse slurry collectors. Under the increase of pig manure humidity from 88% to 90%, the height of the residual layer decreases owing to lower manure shear stress in the part, where the manure moisture content increases. Under the relative humidity above 91%, the height of the residual layer in the pit increases rapidly due to the intensive stratification of slurry into fractions. Thus, the minimum height of the residual layer in the pit is achieved at the relative moisture content of 89-91%. Slurry should be accumulated in the pits to the 3/4 or 4/5 of the height (depth) of the pit. The accumulation period must be a multiple of the operating cycles of housing of various age and gender groups of pigs.

1. Introduction

The experience of operating a gravity manure removal system in Russia and abroad shows that it makes special demands on the technologies of housing and feeding pigs, on the size of the baths (length, width and depth) and their elements, on the tightness of the baths, and also requires special attention during the start-up period. Currently, at pig breeding enterprises, the most common gravity system for removing manure of periodic action is a batch-tube type. The difference from the gravity system is that plastic collectors are laid under each manure channel. Tees are installed in the channel connecting the manure channel with the collector. The horizontal part of the tee is connected with a gravity pipeline of the required diameter by means of rubber O-rings, and the vertical part, mounted flush with the base of the bowl, is closed off with a plug fitted with a porous rubber seal.

Plastic pipes are also used as transverse collectors. Longitudinal plastic pipes are connected to the transverse manifold through a tee. They are placed in the direction of the manure receiver with a slope of 0.004-0.005. The capacity of the manure collection channels in pigsties for farrowing sows with piglets ensures the accumulation of manure during the entire period of housing pigs in them. The
emptying of the manure channels is carried out after the completion of the cycle of growing and disinfection of the premises before setting up the next technological group of pigs.

When a gravity-flowing manure removal system is put into operation, a one-time water saturation of concrete manure channels and their leak test is required. In this case, the water, after testing the channels, can be considered conditionally clean and it can be drained into the storm sewer [1].

Taking into account the regulatory requirements when using a gravity system of periodic action of the batch-pipe type, advanced domestic and foreign experience in the operation of such manure removal systems, the introduction of an additional amount of water is required [2].

The gravity-flow system of manure removal of periodic action fully ensures the observance of sanitary and veterinary requirements in pigsties for housing all gender and age groups of pigs. Manure from the manure collection tanks is fed by gravity through the laid collectors to the receiving manure collector. The capacity of the receiving manure collector should be greater than the capacity of the manure tanks of one isolated section for keeping animals.

2. Materials and methods

The research was carried out using expert assessments of specialists from production, design methods and systems analysis. The main constructive dimensions of the manure collection baths of the gravity (drain) system of periodic action are: length $L_b$, width $B_b$ and depth $h_b$. The length of the baths depends on the size of the pigsty, its space-planning solution and the adopted technology for housing pigs. The amount of baths depends on the capacity of the pig farm.

The length of one longitudinal channel of a gravity system of periodic action in pigsties for housing pigs in individual and group pens is determined by the formula:

$$L_c = n_p \times B_p,$$

where $n_p$ – amount of pens located along one gravity channel; $B_p$ – width of pen, m.

The length for several channels of the manure removal system is determined by the formula (2), taking into account the amount of channels $n_c$:

$$L_{sc} = (n_p \times B_p) \times n_c$$

The channel of a gravity-flowing manure removal system of periodic action consists of manure baths separated from each other by concrete partitions, therefore, further calculation is given for a manure bath (figure 1 and figure 2).

![Figure 1. Fragment of the channel of a gravity system for removing manure of periodic action: 1 - concrete partition; 2 - manure bath; 3 - slatted floor; 4 - cork valve; 5 - tee; 6 - longitudinal collector; 7 - transverse collector.](image-url)
Figure 2. General view of the manure bath.

The width of the manure bath of the manure removal system is determined depending on the dimensions of the slatted floor panels, and as a rule, it is taken no more than 3 meters. For the housing of adult broodstock, boars and fattening pigs, concrete slatted floor panels are used. For the housing of suckling piglets and weaning piglets, prefabricated slatted floors made of plastic panels 400 × 600 mm in size are used, which are placed on beams made of composite materials (Figure 3).

Figure 3. Plastic slatted floor panels mounted on composite beams.
The depth of a bath with a horizontal bottom is determined by the formula:

\[ h_b = h_1 + h_2 + h_3, \]  

where: \( h_1 \) - maximum height of the residual layer in the corners of the manure bath, depending on the physicomechanical and rheological properties of the manure mass and the structural elements of the bath, meter; \( h_2 \) - thickness of the layer of manure mass accumulating in the manure bath, meter; \( h_3 \) - the distance between the maximum level of the manure mass and the slatted floor, meter (taken equal to (0.01-0.15 m)):

\[ h_1 = \sqrt{\frac{2\tau_0 \times L}{\rho}}, \]

where \( \tau_0 \) - ultimate shear stress, Pa; \( \rho \) - density of manure, kg/m\(^3\); \( L \) - length from the edge to the center of the manure bath (in longitudinal projection) (\( L = L_c/2 \)).

The height of the slurry layer in the bath (channel) is determined by the formula:

\[ h_2 = \frac{\sum n_i q_i t_i}{F_b}, \]

where: \( n_i \) - amount of pigs of the corresponding gender and age group, from which manure comes into the manure collection bath, head; \( q_i \) - daily manure yield, kg/head (see Table 1); \( t_i \) - period of accumulation of manure in the bath before removal, days (\( t_i \) is taken 14 days based on considerations of ensuring veterinary welfare); \( F_b \) - area of the bottom of the manure bath, m\(^2\).

The size of the area of the manure bath is determined by the formula:

\[ F_b = B_b \times L_b, \]

where \( B_b \) - width of manure bath, m.

Substituting the decoded values from formulas (4), (5) and (6) into formula (3), after transformation we obtain:

\[ h_b = \sqrt{\frac{2\tau_0 \times L}{\rho}} + \frac{\sum n_i q_i t_i}{B_b L_b} + h_3. \]

The main structural dimensions of the longitudinal and transverse collectors are:

- \( D_{lc} \) - diameter of the longitudinal collector, m; (\( D_{lc} = 0.2-0.25 \) m);
- \( D_{tc} \) - diameter of the transverse collector, m; (take \( D_{tc} = 0.25-0.4 \) m);
- \( h_{dcl} \) - initial depth of the longitudinal collector, m;
- \( h_{dcl} \) - final depth of the longitudinal collector, m;
- \( h_{dtr} \) - initial depth of the transverse collector, m;
- \( h_{dtr} \) - final depth of the transverse collector, m.

Initial depth of the longitudinal collector calculated by the formula:

\[ h_{dcl} = h_b + b + b_s + D_{lc}. \]
where: \( b_p \) - thickness of the bottom of the concrete manure channel (bath), m \((b_p = 0.15-0.2\) m); \( b_s \) - thickness of the sand layer at the beginning of the longitudinal collector, m \((b_s = 0.05-0.1\) m).

The final depth of the longitudinal collector is calculated by the formula:

\[
h_{f,lc} = h_{idc} + L_{lc} \times i_{lc},
\]

where \( i_{lc} \) - longitudinal collector slope \((i_{lc} = 0.003-0.0045)\).

The initial depth of the transverse collector is calculated by the formula:

\[
h_{idc} = h_{f,lc} + 2h_{stc} + D_{tc},
\]

where \( h_{stc} \) - height of the vertical section of the tee, m.

The final depth of the transverse collector is calculated by the formula:

\[
h_{f,tc} = h_{idc} + L_{tc} \times i_{tc},
\]

where \( L_{tc} \) - length of the transverse collector, m; \( i_{tc} \) - transverse collector slope \((i_{tc} = 0.0045-0.006)\).

\[
L_{tc} = \sum l_{stc} n_{stc} + l_{mr}
\]

where: \( l_{stc} \) - length of the sections of the transverse collector between each pair of longitudinal collectors, m; \( n_{stc} \) - amount of sections of the transverse collector between each pair of longitudinal collectors; \( l_{mr} \) - distance from the longitudinal collector closest to the manure collector to the receiving manure reservoir, m.

According to the results of experimental and clinical tests carried out on several pig farms, additional water is technologically necessary for the normal operation of a gravity-flow system of periodic action, the amount of 1.5 liters per day per 1 pig [3-7]. This includes water to create a water "cushion" in the bath, which is necessary for the proper operation of the manure removal system, water in case of a possible malfunction of the drinker bowls and water for washing equipment. The water "cushion" is the volume of water to fill the sump and bottom of the bath.

Thus, the actual relative humidity of litterless manure in the bath will differ from the values in regulations [8]. The actual relative humidity of litterless manure is calculated using the following formula [9]:

\[
W_{ah} = \frac{M_m W_m + 100(M_w + M_{wc})}{M_m + M_w + M_{wc}}
\]

where: \( M_m \), \( M_w \) and \( M_{wc} \) are respectively the masses of manure, (feces and urine); water from drinking bowls and when washing equipment; water required to create a water "cushion", kg; \( W_m \) - humidity of manure, %.

3. Result and discussion

On the basis of the calculations, the actual humidity of the manure was determined, taking into account the water required for the proper functioning of the gravity-flow system for removing manure (Table 1).

The height of the residual layer in the bath increases intensively when the relative humidity of the manure is more than 91% (Figure 4), and decreases as a result of the decrease in the value of the limiting shear stress of the manure \( \tau_0 \) in this section of the increase in the relative humidity of the manure mass \( W \) from 88% to 90%. 
Table 1. Daily output of manure and humidity indicators.

| Gender group | The amount of excrement, kg/day | Including | Relative humidity of manure according to standards, % | Actual relative humidity of manure, % |
|--------------|---------------------------------|-----------|-----------------------------------------------------|-------------------------------------|
| Boars        | 11.1                            | 3.86      | 7.24                                                | 89.4                                | 90.7                                |
| Sows:        |                                  |           |                                                     |                                     |                                     |
| - single;    | 8.8                             | 2.46      | 6.34                                                | 90.0                                | 91.5                                |
| - farrowing; | 10.0                            | 2.6       | 7.4                                                 | 91.0                                | 92.2                                |
| - with piglets. | 15.3                      | 4.3       | 11.0                                                | 90.1                                | 91.0                                |
| Weaners      |                                  |           |                                                     |                                     |                                     |
| weighing up to 30 kg | 2.4                          | 0.9       | 1.5                                                 | 86.1                                | 91.4                                |
| Fattening pigs in weight: |                                  |           |                                                     |                                     |                                     |
| - up to 70 kg; | 5.0                           | 2.05      | 2.95                                                | 87.0                                | 90.0                                |
| - more than 70 kg. | 6.5                         | 2.7       | 3.8                                                 | 87.5                                | 89.9                                |

Figure 4. Dependence of the height of the residual manure layer $h_1$ on the relative humidity of the manure $W$.

The increase in the height of the residual layer occurs as a result of intensive stratification of manure into fractions. Thus, with a relative humidity of 89-91% manure, a minimum height of the residual layer in the bath is achieved. This confirms and complements previous studies [10].

Determination of the main parameters of manure collection channels depends on the size of the pigsty, its space-planning solution and the adopted technology for housing pigs.

4. Conclusions
The presented calculation of a gravity-flow system for removing manure of periodic action allows you to determine the main design parameters, such as: the depth of the manure baths; installation depth of longitudinal and transverse collectors.

For proper operation of a gravity-flowing batch manure removal system, the relative humidity of the manure should be 89-91%. In order to maintain the relative humidity of the manure within the specified limits, it is necessary to monitor the rational consumption of water on the pig farm and exclude it from getting into the manure collection baths as a result of malfunctioning technological equipment.

For the transportation of manure in gravity mode outside the pigsties and the farm, longitudinal and transverse PVC pipe collectors should be used. The main parameters of these collectors are the diameter, length of pipes and the slope with which they are laid. For longitudinal collectors, the
The recommended pipe diameter is 0.25 m. They are laid with a slope of 0.0035–0.0045. For transverse collectors, the recommended pipe diameter is 0.3–0.4 m. Their slope is 0.0045–0.006.

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