

CHOICE OF CATTLE MANURE REMOVAL SYSTEM DEPENDING ON MANURE PHYSICAL PROPERTIES

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Abstract. Cattle manure is a mixture of solid and liquid animal excrement, bedding material, process water and feed residues. Essentially, this is a polydisperse suspension, the density and viscosity of which depend on the manure composition and the time it stays in the livestock house. Animal excrement is the most unstable manure component; its composition varies with animal diets and productivity. The study aim was to identify the optimal technical device for removing manure from the livestock house with due account for the physical properties of cattle excrement/manure. At the first stage, the mass of manure produced and its moisture content were calculated by the mass balance method, taking into account the diets, animal productivity, and the mass of moisture-absorbing material and process water, which gets into manure in the animal house. At the second stage, the optimal technical device for manure removal was identified, its parameters and technical and economic indicators were determined. Calculations were made for a cattle complex with the total stock of 1249 heads with the loose housing of animals on sawdust bedding. The estimated daily output of manure was 56 t with the integral moisture content of 90 %. After the review of different manure removal systems, the hydraulic scraper unit, with the scraper moving in steps, was found optimal for the calculated manure properties. It ensured 98 % or above manure removal, the specific energy requirement of manure transportation within 0.3-0.5 kWh·t⁻¹, and error-free life of at least 700 hours. Under the manure canal width of 3400 mm, depth of 200 mm and length of 75 000 mm, the scraper height of 180 mm, and the moving speed of 4.3 m·min⁻¹, the power consumption of one scraper ranged from 1.28 to 1.52 kW. Under the given moisture content of the manure removed and the cleaning interval of 4 hours, the maximum length of manure heap transferred in the canal for a distance of 50-60 m was 3.4 m. The average productivity of the scraper unit was 4.3 t·h⁻¹.

Key words: manure, balance method, manure removal, scraper.

Introduction

In the Russian Federation, the manure output is calculated by the mass of animal excrement (faeces and urine). The excrement mass, humidity and NPK content values for each animal category are specified in the relevant guidance documents, which also define the age and gender groups of animals [1-4]. These regulatory data are used when designing new cattle complexes.

Over the past 10 years, a database on the nutrient content in cattle excrement has been maintained at IIEEP-branch of FSAC VIM. The data are taken from the laboratory analysis protocols of the research laboratory of analytical methods of environmental engineering of the institute as a part of research and cooperation with enterprises in the North-West Federal District.

Comparison of regulatory data on quantitative and qualitative characteristics of cattle excrement with the average factual data from the database showed the difference to be up to 40 % [5]. Therefore, the calculation method of these characteristics needs an upgrade.

The mass balance method is used to calculate the quantity and quality properties of excrements in Finland, Estonia, Latvia, Poland and Sweden [6]. Comparison of the calculated and actual data proves the accuracy of the mass balance method [7].

In an animal house the excrements mix with bedding and process water resulting in manure. The technology of manure removal from the livestock house and the applied equipment are selected with regard to the characteristics of the manure produced.

The study aim was to identify the optimal technical device for removing manure from the livestock house with due account for the physicals properties of cattle excrement/manure.

Materials and methods

The study was divided into two stages. At the first stage, the mass of manure produced and its moisture content were calculated by the mass balance method, taking into account the diets, animal productivity, and the mass of moisture-absorbing material and process water, which gets into manure in the animal house [8-13].

The excrement mass per one animal was determined by the formula:

$$M_E = M_F + M_U, \quad (1)$$

where M_E – excrement mass per one animal, $\text{kg}\cdot\text{day}^{-1}$;
 M_F – faeces mass per one animal, $\text{kg}\cdot\text{day}^{-1}$;
 M_U – urine mass per one animal, $\text{kg}\cdot\text{day}^{-1}$.

The faeces mass per one animal was determined by the formula:

$$M_F = (M_{R1} - M_{R2}) \cdot \frac{100}{100 - MC_F}, \quad (2)$$

where M_{R1} – mass of feed dry matter received within the diet per one animal, $\text{kg}\cdot\text{day}^{-1}$;
 M_{R2} – mass of digested feed dry matter received within the diet per one animal, $\text{kg}\cdot\text{day}^{-1}$;
 MC_F – faeces moisture content, %.

The urine mass per one animal was determined by the formula:

$$M_U = \frac{M_F}{K}, \quad (3)$$

where K – conversion factor of the faeces mass into the urine mass, dimensionless. This factor is generally calculated for each animal category in accordance with management [1].

Moisture content of animal excrement is calculated by the formula:

$$MC_E = \frac{MC_F \cdot M_F + \frac{M_U}{K} \cdot MC_U}{M_E}, \quad (4)$$

where MC_E – moisture content of animal excrement, %;
 MC_U – moisture content of animal urine, %.

In an animal house, the excrements mix with the bedding and process water producing manure. The total mass of manure is calculated by the formula:

$$M_{Manure} = \sum_{j=1}^m (M_E + M_W + M_B) \cdot nj, \quad (5)$$

where M_{Manure} – manure mass per animal, $\text{kg}\cdot\text{day}^{-1}$;
 M_E – daily output of excrements (faeces and urine), $\text{kg}\cdot\text{day}^{-1}$;
 M_W – daily process water consumption, $\text{kg}\cdot\text{head}^{-1}\cdot\text{day}^{-1}$;
 M_B – daily bedding consumption, $\text{kg}\cdot\text{day}^{-1}$;
 nj – number of animals in each category;
 m – number of animal categories.

In the Russian regulatory documents the rates of process water consumption are set in $\text{l}\cdot\text{head}^{-1}\cdot\text{day}^{-1}$ but in our calculations we used $\text{kg}\cdot\text{head}^{-1}\cdot\text{day}^{-1}$ as the value of water density was 1.

The moisture content of manure per one animal was determined by the formula:

$$MC_{Manure} = \frac{MC_E \cdot M_E + 100 \cdot M_W + MC_B \cdot M_B}{M_{Manure}}, \quad (6)$$

where MC_{Manure} – moisture content per one animal, %;
 MC_B – moisture content of bedding, %.

At the second stage, in order to select the optimal manure removal system and to justify this choice, various possible technological and technical solutions, both for tied stable and loose housing, were analysed. For the optimization criterion we used the minimal total costs of removing one ton of manure with specific physical properties. It was established that the optimal technical device for manure removal was a push-rod manure remover with the hydraulic drive in case of the tied stable

housing and a hydraulic scraper unit with the scraper moving in steps in case of the loose housing [14].

The optimal technical device for manure removal from the animal house was identified with the use of the below dependences.

Correlation between the manure transportation zone and the filling degree of the manure channel is expressed as follows:

$$\begin{cases} L_{TR} = 2.93 \cdot \Delta + 2227 \\ L_{Fill} = -3.28 \cdot \Delta + 638, \\ L_O = -1.7 \cdot \Delta + 451 \end{cases} \quad (7)$$

where L_{TR} , L_{Fill} , L_O – zones of active manure transportation, closing and opening of the scrapers, correspondingly, mm;

Δ – filling degree of manure channel, unit fraction.

The correlation between of the dragged manure heap length and the spacing of scrapers is expressed as follows:

$$\begin{cases} L_1 = 0.0113 \cdot \Delta + 1.0667 \\ L_2 = 0.0043 \cdot \Delta + 1.0933, \\ L_3 = 0.0027 \cdot \Delta + 1.0333 \end{cases} \quad (8)$$

where L_1 , L_2 , L_3 – lengths of the dragged manure heap under the spacing of scrapers of 0.5, 1.0 and 1.5 m, correspondingly, m.

The following correlations were established for calculating the performance of a push-rod manure remover depending on the spacing of scrapers and the filling degree of the manure channel:

$$\begin{cases} C_1 = -0.104 \cdot \Delta^2 + 92.708 \cdot \Delta - 851.5 \\ C_2 = -0.558 \cdot \Delta^2 + 142.82 \cdot \Delta - 1899.3, \\ C_3 = -0.064 \cdot \Delta^2 + 69.28 \cdot \Delta - 546 \end{cases} \quad (9)$$

where C_1 , C_2 , C_3 – performance of the device under investigation under the spacing of scrapers of 0.5, 1.0 and 1.5 m, correspondingly, $\text{kg} \cdot \text{h}^{-1}$.

A scraper manure removal unit was also considered, with the scrapers moving in steps, the hydraulic drive of the traction tool in the form of a steel band and the automatic reversal of the scraper at the extreme points of the channel. One hydraulic station can drive up to four traction tools. The scraper unit is controlled automatically according to the preset sequence. The performance of the scraper unit is calculated similarly to that of a push-rod manure remover.

Results and discussion

The current trends in the development of animal husbandry in Russia are larger farms and bigger animal stock on one site. As of the end of 2017, in Leningrad Region over 60 % of livestock farms have over 800 heads of animal stock (Fig. 1). The minimum number of animals on the complexes is 207 heads.

A cattle complex with the total animal stock of 1249 heads, located in Gatchina District of Leningrad Region, with loose housing on sawdust with zero grazing, was selected as a pilot enterprise in the study. The complex specialises in milk production and cattle breeding.

The calculation results of quantitative and qualitative characteristics of animal excrement are shown in Table 1. The calculated data were compared with the data specified in the manure management guidelines, (Fig. 2).

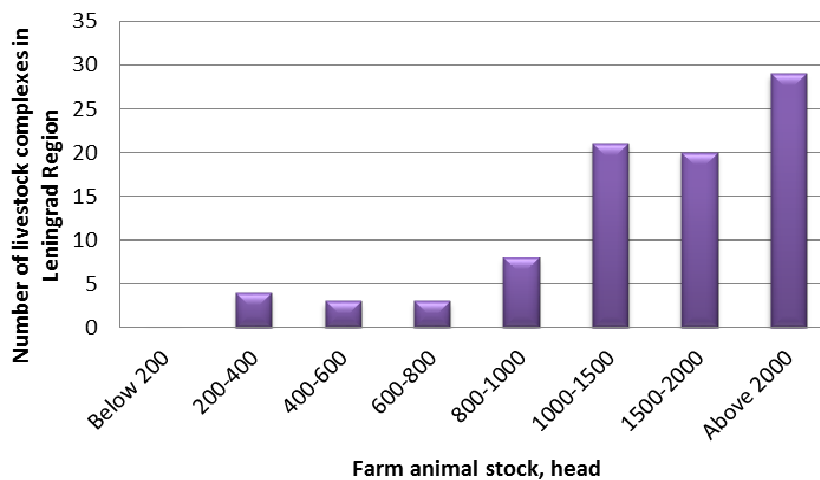


Fig. 1 Distribution of cattle by farm capacity in Leningrad Region

Table 1

Calculated characteristics of cattle excrement

Indicator	Value	Unit
Excrement mass per cow – early lactation	69.6	kg per cow per day
Excrement mass per cow – mid lactation	62.5	kg per cow per day
Excrement mass per cow – late lactation	61	kg per cow per day
Excrement mass per cow – dry period	40.7	kg per cow per day
Average excrement mass per cow (for all four lactation periods)	60	kg per cow per day
Average moisture content of excrement per cow (for all four lactation periods)	88.4	%
Excrement mass per 1 animal – calf (age 0–6 months)	5.7	kg per animal per day
Excrement moisture content – calf (age 0–6 months)	85.5	%
Excrement mass per 1 animal – heifer (age 6 months to calving)	28.1	kg per animal per day
Excrement moisture content – heifer (age 6 months to calving)	87.7	%

The comparison showed that the calculated excrement mass per cow exceeded the standard one by 9 %; the calculated excrement mass per calf (age 0-6 months) exceeded the standard by 21 %; calculated excrement mass per heifer (age 6 months to calving) exceeded the standard by 50 %. The calculated and standard values animal excrement moisture content differed by no more than 3 %.

To identify the optimal manure removal device, an important indicator is the excrement mass. Therefore, the calculated values of the excrement mass were taken to calculate the mass of manure, under which the continuous operation of the device is provided (Table 2).

As a result of calculations for the selected cattle complex, the daily output of manure with the integral moisture content of 90 % was found to be 56 tons.

After the review of previously investigated different manure removal systems the hydraulic scraper unit, with the scraper moving in steps, was found optimal to handle cattle manure with the obtained quantitative and qualitative characteristics. According to previous investigations [13;14], in a cow barn with the sawdust bedding introduced at the rate of 1 to 3 kg per head per day, with the manure channel 3400 mm wide, 200 mm deep and 75 m long, with the scraper height of 180 mm and the moving speed of $4.3 \text{ m}\cdot\text{min}^{-1}$, the unit ensured 98 % -plus manure removal, specific energy requirement of manure transportation within $0.3\text{-}0.5 \text{ kWh}\cdot\text{t}^{-1}$, and error-free life of at least 700 hours; the power consumption of one scraper ranged from 1.28 to 1.52 kW.

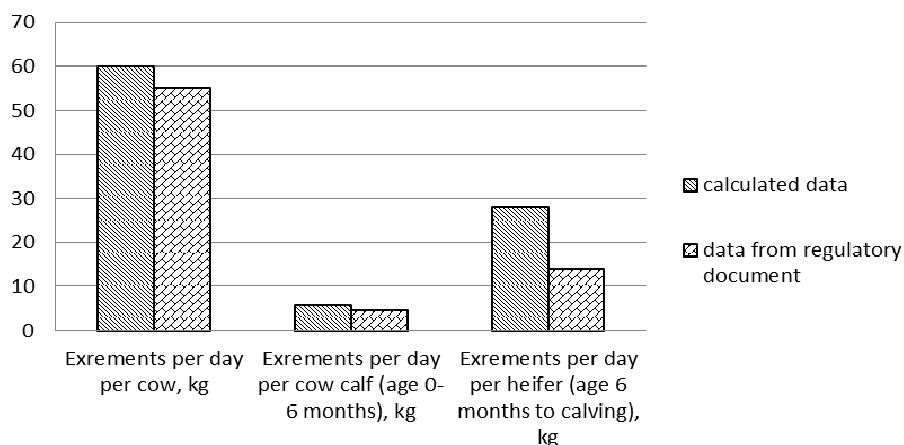


Fig. 2. Comparison of calculated and regulatory data in terms of excrement mass

Under the given moisture content of the manure removed and the cleaning interval of 4 hours, the maximum length of the manure heap transferred in the canal for a distance of 50-60 m was 3.4 m. The average productivity of the scraper unit was $4.3 \text{ t}\cdot\text{h}^{-1}$.

Table 2

Calculated characteristics of cattle manure

Indicator	Value	Unit
Manure mass per 1 cow	103	kg per cow per day
Manure mass per 1 calf (age 0-6 months)	14.7	kg per animal per day
Manure mass per 1 heifer (age 6 months to calving)	38.1	kg per animal per day
Moisture content of cow manure	91.2	%
Moisture content of calf manure (age 0-6 months)	84.8	%
Moisture content of heifer manure (age 6 months to calving)	87.2	%

Conclusions

Intensification of the livestock industry, cattle farming in particular, leads to an increase in the number of animals located on particular sites resulting in significant rise in manure volumes. In Leningrad Region, over 60 % of cattle-breeding complexes have an animal stock over 800 heads, with each complex producing above 70 tons of manure per day.

Quantitative and qualitative characteristics of cattle manure were calculated based on the daily mass of excrement, bedding material and process water by the mass balance method with due account for the used diets for each animal category. By the calculation results for the cattle complex with the loose housing of 1249 animals on the bedding, 56 tons of manure are produced daily with the integral moisture content of 90 %.

The hydraulic scraper unit, with the scraper moving in steps, was found optimal to remove manure with the calculated properties from the livestock house. In a cow barn with sawdust bedding introduced at the rate of 1 to 3 kg per head per day, with the manure channel 3400 mm wide, 200 mm deep and 75 m long, with the scraper height of 180 mm and the moving speed of $4.3 \text{ m}\cdot\text{min}^{-1}$, the unit ensured 98 % – plus manure removal, specific energy requirement of manure transportation within $0.3\text{-}0.5 \text{ kWh}\cdot\text{t}^{-1}$, and error-free life of at least 700 hours; the power consumption of one scraper ranged from 1.28 to 1.52 kW.

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