The study of metal oxidation process when metal is exposed to waste products of farm animals

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Abstract. The article is devoted to the study of the corrosion process rate of steel parts in livestock and poultry buildings, primarily, dung removers, which are operated and exposed to a chemically aggressive environment. The issues of metal loss of parts which are in contact with waste products of cattle, pigs and poultry are considered. The results of the influence of corrosion processes on loosening torque increase of the threaded joints of dung removing equipment for livestock and poultry farms are also presented. The research results can be used in design and repairs of farm dung removers.

1 Introduction

Since food is a primary human need, food security of the country is a key task of the state [1, 2]. The volume of food consumption by the population and food qualitative composition is one of the main indicators characterizing the well-being of the nation. The livestock sector makes a significant contribution to ensuring food security of the country [3-5].

Moreover, crop production and livestock industries are closely connected, because crop products are largely produced for animal feed, and animal by-products are used as organic (environmentally friendly) fertilizers for agricultural plants.

Dung removing equipment is an integral element of modern livestock and poultry farms. The microclimate of farms contributes to rapid oxidation of metal surfaces due to high humidity, water vapors, ammonia compounds, etc. In addition, the working parts of dung removers are constantly in contact with animal waste products, which contribute to active corrosion processes [6].

Corrosion processes of farms are particularly acute in the cold season, because, in order to maintain heat in the premises where animals are kept, windows and doors are insulated and sealed, leaving only gates for people to enter and for feed distributors to arrive.

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In the coldest months of the year, recirculation systems are used to save heat, since a lot of energy resources are spent on heating the air entering the buildings. As a result, increased humidity is observed in the animal keeping premises, in addition, when the feeder enters and leaves the room, cold air enters the room and it devaporates on all surfaces of the farm [7].

In the warm season, corrosion processes occur to a much lesser extent, since the premises are constantly ventilated and excess humidity is removed through the ventilation windows.

2 Materials and methods

Animal waste products contain corrosive substances in their composition, the content of which is determined by metabolism in the animal body [8]. Thus, for example, the waste products of cattle may contain 500...2800 mg/l of sulfate ions, pigs - 190...210 mg/l. The content of magnesium salts in cattle dung is about 840 mg/l and more, pigs - not more than 480 mg/l, the content of magnesium salts is very small in poultry litter. The content of chlorine ions in cattle manure can reach quite significant values - up to 6000 mg/l, pigs - up to 340 mg/l, the content of these substances in poultry litter is negligible.

Table 1. The content of acids, mineral and organic substances in the waste products of cattle, pigs and poultry [9-12].

Substances and their concentration	**poultry**	**pigs**	**cattle**
Organic Substances, %			
uric acid	57	1.8	7.3
hippuric acid	minimum value	none	15.0
glucoronic acid	none	6.9	16.8
glutamine	12.3	5.0	23.0
benzoic acid	150	5.0	3.0
Amines (purine bases), % of total nitrogen content	10	5.8	0.7
Mineral salts, mg/l			
phosphates, nitrates	Up to 68000	Up to 9500	Up to 29000
magnesium salts	minimum value	150…480	800…880
sulfates	none	190…210	500…820 (recurrent increase up to 2800)
chlorides	minimum value	150…340	900…1500 (recurrent exceedance to 6000)
Volatile organic acids, ketones, mg/l	none	3.9	none
Sulfur-containing organic substances, mg/l	none	1.4	150

As Table 1 shows, the content of mineral salts: nitrates, phosphates in the waste products of cattle can reach 29000 mg/l, pigs - up to 9500 mg/l, poultry - 68000 mg/l. It should be noted that there are no chlorides and sulfates, as well as volatile organic substances, ketones, and sulfur-containing organic substances in poultry litter.

Sulfur-containing organic substances, which are represented by cystine, methionine, cysteine, which contain thio groups, easily turn into disulfides. The decomposition of disulfides produces sulfuric acid and a number of ether sulfuric acids, such as indoxyl

sulfuric, phenyl sulfuric, and a number of volatile sulfur-containing acids. Sulfur in urine composition of animals causes acidic reaction. The composition of cattle faeces contains taurine, represented by salts of sulfur-containing anoxic mineral acids. The mechanism of disulfide decomposition directly affects the corrosive activity of animal waste products on metals.

In addition to the above elements, animal waste products contain substances that are part of the amino nitrogen group - uric acid, purine bases, allantoin. The highest content of amino nitrogen is in poultry faeces (can be up to 60%), while it is insignificant in the faeces of pigs and cattle. Organic amines in manure lead to a decrease of the water surface tension at the liquid-metal boundary, which enhances water affinity of the metal. Concurrently, there is a dependence: the higher the concentration of amines in fecal effluents, the greater the decrease of the surface tension and the stronger the water affinity of the metal surface by fecal effluents. This intensifies the interaction between the dung aggressive components and the fasteners of livestock and poultry farm machines [13]

Organic acids in animal waste products are also aggressive components in relation to the metal. Chemical interaction of steel parts with organic acids leads to formation of the corresponding salts, which are highly soluble in water.

The moisture content significantly affects the corrosion processes. In case of moisture increase of animal waste products, the degree of their dissociation and the electrochemically active area of metal in them also increases. In addition, more intensive diffusion occurs, which leads to corrosion rate increase. In case of excessive humidity rise, a certain slowdown in corrosion rate is observed due to a decrease of oxygen flow from the air to the metal surface [14].

To study the corrosion process of steel surfaces under the influence of wastes of farm animals, plates of St.3 steel 3 mm thick were made, as well as fasteners, including washers, bolts and M8 nuts also made of St.3 material.

a)

b)

Fig. 1. Fasteners before (a) and after testing (b).

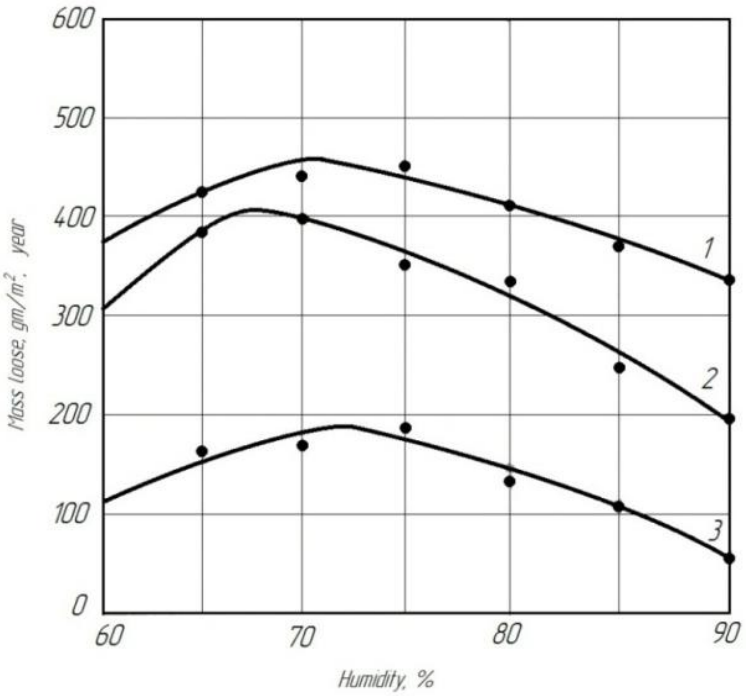
To study the effect of moisture on the corrosion processes of steel in animal wastes, the first part of the plates was placed in sealed containers in order to maintain constant humidity. The execution time was 1 year.

The second part of the plates with fasteners tightened with a torque of 20 N·m, were placed on the working bodies of the conveyors of dung removers at the training farm of the Federal State Budgetary Educational Institution of Higher Education Ulyanovsk State

Agrarian University and were removed monthly to assess the loss of metal due to corrosion, as well as loosening torque changes.

3 Results

Figure 2 shows the dependence of the corrosion rate of St.3 metal on dung moisture content of various animals.



1- chicken litter; 2 - pig dung; 3- cattle excrement

Fig. 2. Dependence of the St.3 metal corrosion rate on moisture.

The data presented in Figure 2 indicate that the lowest rate of metal corrosion when placed in the waste products of farm animals is typical for cattle excrement (up to 190 g/m^2 per year), pig and poultry wastes are characterized by a higher intensity of corrosion processes (up to 310 gr/m^2 and 460 gr/m^2 per year).

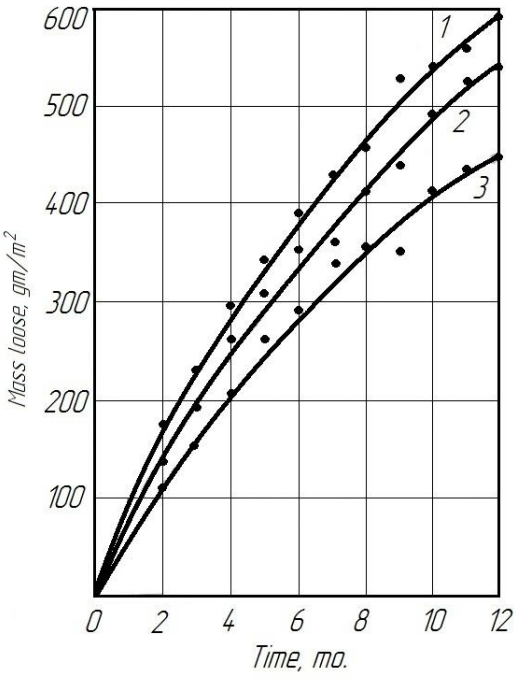
The maximum corrosive activity of waste products of agricultural animals is observed at the following moisture: chicken litter - 70 ... 72%, pig dung - 66 ... 70%, cattle excrement - 70 ... 74%.

Due to peculiarities of the fractional composition of waste products of agricultural animals, the presence of undigested plant residues and humidity, the contact of wastes with a metal surface does not occur over the entire area, but at discrete points. In case of lack of moisture, the corrosion process is only possible at the points of contact with wet particles of the dung, the area of corrosion damage decreases, but penetration of corrosion deep into the metal is observed.

This is caused by the fact that the ions contained in the liquid phase cause destruction of the original oxide film on the metal, mainly in places of close contact of the metal with dung particles. In those places of the metal surface where the contact is less close, this film is almost completely intact. Conditions are created when a significant area of the metal

surface is not protected by a film (close contact), while another area remains covered with it. The initial distribution of the areas covered and not covered with a film is preserved during further corrosion process. Corrosion at the contact areas will penetrate deep into the metal, forming deep pittings.

Considering that the working bodies of dung removers are in constant contact with fresh portions of animal waste products in the conditions of livestock enterprises, metal plates were fixed on the working bodies of dung remover conveyors in the second experiment, and the results of weight loss are presented in Figure 3.



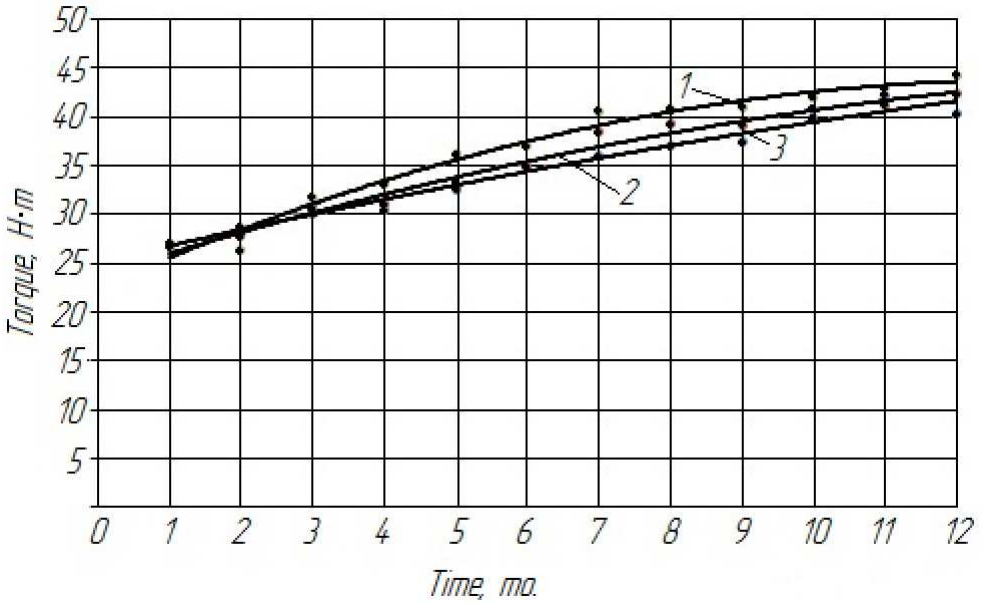
1- chicken litter; 2 - pig dung; 3- cattle excrement

Fig. 3. Dependence of corrosion of St.3 steel on the time of exposure to animal waste products (when fixed on dung remover conveyors).

Analyzing the data presented in Figure 3, it should be noted that when steel plates were fixed on the dung remover conveyor belt, the rate of corrosion processes increased several times compared to the corrosion rate of plates located in sealed containers at various humidity values (Figure 2): wastes of cattle by 2.3 times; pigs – by 1.8 times; poultry – by 1.3 times.

According to the results of the experiment, the greatest corrosive activity of animal waste products is revealed at the phase boundary under the conditions of recurrent wetting.

The results of the research on the change of the loosening torque of fasteners, under the influence of aggressive environment of waste products of farm animals, are presented in the form of a graph in Figure 4.



1- chicken litter; 2 - pig dung; 3- cattle excrement

Fig. 4. Dependence of the loosening torque of the nut on duration of exposure to waste products of farm animals.

The results of the experiment presented in Figure 4 indicate that there is an increase of the loosening torque by 2 ... 2.2 times over a year of exposure to animal dung aggressive environment.

4 Discussion

The waste products of farm animals are a very aggressive environment for metal parts of dung removing equipment, which is explained by the content of salts and organic acids. Corrosion processes occurring on the surface of steel parts lead both to metal loss and to increase of loosening torque of these joints due to penetration of moisture into the gap between the nut and bolt under the influence of capillary forces with subsequent film formation. Air components such as carbon dioxide, sulfur and nitrogen oxides gradually dissolve in this film resulting in formation of weak sulfuric and nitric acids. Waste products also contain uric, hippuric, glucuronic and benzoic acids, which ultimately intensify the metal corrosion process, it should not also be forgotten that there are mineral salts in animal waste products.

5 Conclusion

The results of the study of the effect of animal waste products on metal corrosion indicate that due to content of acids, mineral and organic substances in the waste products of farm animals, the most aggressive environment is poultry litter, with a decrease of metal weight by 600 g/m^2, dung of pigs - up to 540 g / m^2, cattle excrement - 440 g / m^2. Moreover, the maximum metal corrosion in chicken litter is observed at a moisture content of 71%, pig dung – at 68%, cattle excrement – at 72%.

Oxidation of threaded joints in waste products of animals for a year leads to an increase of the loosening torque by an average of 2.1 times.

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