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Effect of slurry lagoon redesign on reduction of ammonia emission during livestock manure storage

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Abstract. In accordance with the international and EU aims to reduce emissions of ammonia and other air pollution substances farm manure management, including its storage, especially for the animal breeding sector, is one of the most essential stages. One of the preventing steps is covering of the slurry lagoons. The most effective – hard covering can be provided only after the lagoon is constructed. The aim of the research: to develop methodology for calculations of emission reducing lagoon design volume and surface area. In the result of the theoretical research the possibilities of reducing the reflection surfaces at the same capacity of the lagoon have been discovered, as well as the changes of the reflection surface area, if instead of one lagoon several lagoons with less volume are installed and sequential filling of these lagoons is ensured. The article presents the calculation algorithms obtained during the research and recommendations for construction of low emission lagoons.

Key words: manure, lagoon capacity, modelling.

INTRODUCTION

For storage of slurry, cylindrical and lagoon type storages are used in Latvia. Still, in the recent years lagoons have become more popular as they can be more easily installed and they are also cheaper. Nevertheless, lagoon type storages have an essential drawback. They have a large upper surface area of slurry or reflection surface from which unfavorable gas emissions are discharged. Therefore, in the Regulations No. 829 of the Cabinet of Ministers of the Republic of Latvia it has been stated that the closed type storages for slurry have to be installed or the stored slurry should be covered with a permanent natural or artificially made floating covering layer that reduces evaporation.

These measures ensure only partial reduction of the undesirable gas emissions. It is proved, for instance, by the Convention of the Economic Commission for Europe on Transboundary Air Pollution in Large Distances, which states that naturally formed covering layer of the lagoon gives only 40% reduction of ammonia emissions, but covering with the floating layer ensures emission reduction of 60%. Therefore, it is advisable to evaluate also other methods of ammonia emission reduction regarding the reduction of the slurry surface.

Many studies have been conducted lagoon geometry. The criterion for the most part, is the safe and efficient handling of manure and wastewater and requires using proper construction criteria and sizing the structure large enough to meet at least the 180 day storage requirement for a specific size of the operation (Jons & Sutton, 2007, 6). Design parameters must be optimized to ensure greatest degradation of pollutants within the smallest volume possible (Hamilton et al., 2006). Circular or square lagoons facilitate mixing and are usually more economical to construct. Rectangular lagoons may be used, but length-to-width ratios of 3:1 or less are recommended (Pfost & Fulhage, 2000).

As it is shown by our previous research, optimization of the lagoon geometrical parameters is an important factor reducing ammonia emissions. For this purpose we have developed a methodology for calculation of lagoon capacity as well as stated the influence of the lagoon depth, wall sloping angle and side edge length proportion on the area of the reflection surface (Murikov & Priekulis, 2006; Priekulis & Murikov, 2008). In these investigations it was stated that the reflection surface reduces if the lagoon is built possibly deep and with a larger sloping angle as well as with the side edges of equal length. Still, the numerical values of these parameters depend on the particular situation. For instance, the depth of the lagoon is limited by the maximal level of the ground water, as according to the requirements of the Regulation No. 829 of the Cabinet of Ministers of the Republic of Latvia the ground water level should be at least 0.5 m lower than the bottom part of the storage. In turn, the side sloping of the lagoon is limited by the method of its construction as usually the side part of the lagoon is made of ground bank without additional fastening elements.

Still, there is another solution of this problem. Namely: there is a possibility to install several lagoons instead of one large lagoon, for instance, four proportionally smaller ones, the total volume of which is the same as of the large lagoon, but during exploitation to fill these small lagoons sequentially. In such case it is possible to prognosticate that installing the small lagoons the total emissions of ammonia will reduce as the area of the slurry reflection surface, from which the emissions come at the beginning of the slurry filling, is many times smaller than using one large lagoon.

Therefore, the aim of this research was to test the above mentioned hypothesis for this purpose specifying the calculation methods of the lagoon reflection surface as well as its capacity and to state the changes of the reflection surface area filling slurry in one large lagoon as well as in several smaller lagoons with the volume equal of the large lagoon.

MATERIALS AND METHODS

To compare the reflection surface area of slurry, two types of lagoons were examined: with equally long side edges or the square type lagoon and a lagoon with different length of the side edges or the rectangular lagoon.

After that the summary area of the lagoon reflection surface was evaluated in two different cases:

- installing one large capacity lagoon;
- installing four correspondingly smaller lagoons with equal depth, equal volume and equally large side edge angles, but with the total volume equal with the volume of the large lagoon.

In the research it was assumed that slurry filling intensity would be regular and equal. It was also considered that the maximal level of slurry in the storage should be at least 0.2 m lower than the upper edge of the lagoon (Ed. Priekulis, 2012).

Square type lagoon

The first type is a lagoon with a square bottom with the volume V. The task is to fill the given amount of slurry in four equal square type lagoons of a smaller size with equal maximal depth h_0 and the wall angle α (Fig. 1). Lagoons of such kind can be considered as a truncated pyramid and their volume can be calculated accordingly (Priekulis & Murikov, 2008):

$$V = \frac{h_0}{3} \cdot (S_p + S_v + \sqrt{S_p \cdot S_v}) \quad (1)$$

where V – volume of the lagoon, m^3; S_v – surface area of slurry at the highest (maximal) slurry level, m^2; S_p – bottom area of the slurry lagoon, m^2; h_0 – maximal height of the slurry layer in the lagoon, m.

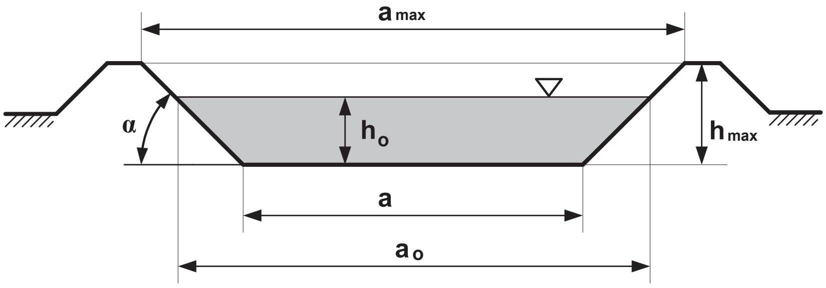

Figure 1. Scheme of lagoon type slurry storage cross section: a – length of the bottom edge; α_{max} – length of the upper edge; h_0 – variable height of the slurry layer in the lagoon $0 \leq h_0 \leq h_{max}$; α_0 – variable length of one edge of the square surface $0 \leq a_0 \leq a_{max}$.

The volume of the large storage is equal to the volume of four equal smaller storages V_m with equal height and wall angle, i.e. $V = 4V_m$:

$$\frac{h_0}{3} \cdot (x^2 + y^2 + \sqrt{x^2 \cdot y^2}) = \frac{4 \cdot h_0}{3} \cdot (a^2 + b^2 + \sqrt{a^2 \cdot b^2}) \quad (2)$$

where x – length of the bottom edge of the large lagoon, m; y – length of the reflection surface edge of the large lagoon at the highest (maximal) level of slurry, m; α – length of the bottom edge of the small lagoon, m; b – length of the reflection surface edge of the small lagoon at the highest (maximal) level of slurry, m.

Filling a part of slurry, the length of the lagoon surface edge will increase by Δ and Eq. (2) takes the following form:

$$x^2 + (x+\Delta)^2 + (x+\Delta)\cdot x = 4\cdot(a^2 + (a+\Delta)^2 + (a+\Delta)\cdot a) \tag{3}$$

where Δ – value by which the length of the surface edges has increased compared to the bottom, m;
The simplification of Eq. (3) is below:

$$3x^2 + 3x\cdot\Delta + \Delta^2 = 4\cdot(3a^2 + 3a\Delta + \Delta^2) \tag{4}$$

The volume of one small lagoon is 0.25 of the volume of the large lagoon, i.e. $V_m = 2.25V$, or:

$$3a^2 + 3a\cdot\Delta + \frac{3}{4}\Delta^2 = \frac{3}{4}x^2 + \frac{3}{4}x\cdot\Delta \tag{5}$$

As $\Delta = \frac{2h_0}{\tan\alpha}$, it is possible to calculate the corresponding bottom edge length of the small lagoons α, if the bottom edge length of the large lagoon *x* is given. For this purpose the quadratic Eq. (5) in relation to the bottom edge α of the small lagoon should be solved:

$$3a^2 + 3\frac{2h_0}{\tan\alpha}a + \frac{3}{4}\left(\frac{2h_0}{\tan\alpha}\right)^2 - \frac{3}{4}x^2 - \frac{3}{4}x\cdot\frac{2h_0}{\tan\alpha} = 0 \quad \text{or}$$

$$a^2 + \frac{2h_0}{\tan\alpha}a + \left(\frac{h_0}{\tan\alpha}\right)^2 - \frac{1}{4}x^2 - \frac{1}{2}x\cdot\frac{h_0}{\tan\alpha} = 0 \tag{6}$$

To find the reflection surface of the lagoon the equation system should be solved

$$\begin{cases} V_i = \dfrac{h_i}{3}\cdot(x^2 + z^2 + xz) \\[2ex] \dfrac{2h_i}{z-x} = \tan\alpha \end{cases} \tag{7}$$

where V_i and h_i – accordingly the volume of slurry filled in the lagoon and the height; *z* – length of the storage surface edge at the filling height h_i.
Changing the system, obtained equation:

$$(z-x)(z^2 + xz + x^2) = \frac{6\cdot V}{\tan\alpha}, \quad \text{or} \quad z^3 - x^3 = \frac{6\cdot V}{\tan\alpha} \tag{8}$$

It is possible to determine the length of the square reflection surface edge *z* and after that its area S_i, at a definite volume V_i and the length of the bottom edge *x*:

$$S_i = \sqrt[3]{\left(x^3 + \frac{6\cdot V_i}{\tan\alpha}\right)^2} \tag{9}$$

Rectangular lagoon

The second type is a rectangular lagoon with the volume V. Our task is to fill the given amount of slurry in four smaller rectangular lagoons with equal maximal depth h_0 and the wall angle α (Fig. 2).

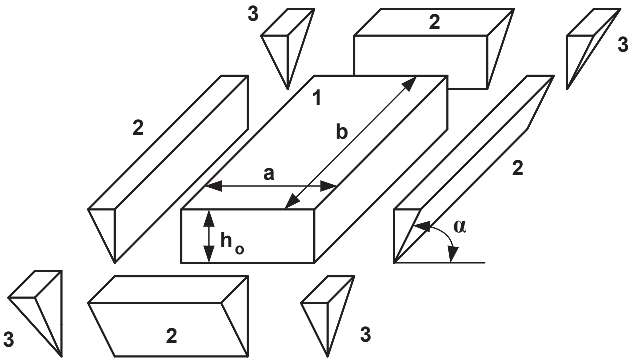

Figure 2. Scheme of calculation of lagoon volume in a general case dividing the volume in elementary components: 1 – parallellepiped; 2 – prism; 3 – pyramid.

The volume of such storages can be calculated:

$$V = a \cdot b \cdot h_0 + \frac{h_0^2}{\tan\alpha}(a+b) + \frac{4}{3}\left(\frac{h_0}{\tan\alpha}\right)^2 \cdot h_0 \ , \quad \text{or}$$

$$V = \frac{h_0}{3\cdot\tan^2\alpha}(3a\cdot b\cdot\tan^2\alpha + 3\cdot h_0\cdot(a+b)\cdot\tan\alpha + 4h_0^{\ 2}) \tag{10}$$

where a, b – lengths of the lagoon bottom edge.

It is assumed that the relation of the large lagoon bottom edges is known, i.e. $\frac{x_1}{x_2} = k$, that is equal with the relation of the small lagoon bottom edges, i.e. $\frac{a_1}{a_2} = k$, where x_1, x_2 are the lengths of the large lagoon bottom edges; a_1, a_2 are the lengths of the small lagoon bottom edges.

Using (10) and the relation of the given bottom edge lengths an equation can be developed that relates the volumes of the large and small lagoons:

$$\begin{aligned}&\frac{h_0}{3\cdot\tan^2\alpha}(3k\cdot x_2^2\cdot\tan^2\alpha + 3\cdot h_0\cdot(k+1)\cdot x_2\cdot\tan\alpha + 4h_0^{\ 2}) = \\ &= \frac{4h_0}{3\cdot\tan^2\alpha}(3k\cdot a_2^2\cdot\tan^2\alpha + 3\cdot h_0\cdot(k+1)\cdot a_2\cdot\tan\alpha + 4h_0^{\ 2})\end{aligned} \tag{11}$$

From Eq. (11) it is possible to find the bottom edge of the small lagoon α_2 that corresponds to the large lagoon, from which the other bottom edge α_1 can be found using the given relation k:

$$\begin{aligned}&12\cdot k\cdot\tan^2\alpha\cdot a_2^2 + 12\cdot h_0\cdot\tan\alpha\cdot(k+1)\cdot a_2 + \\ &+3[4\cdot h_0^{\ 2} - k\cdot x_2^2\cdot\tan^2\alpha - h_0\cdot(k+1)\cdot x_2\cdot\tan\alpha] = 0\end{aligned} \tag{12}$$

Filling a part of slurry V_i the length of the surface area edge varies compared to the bottom by $2\Delta_i$ and the height of filling in the lagoon by h_i, i.e.

$$V_i = h_i \cdot x_1 \cdot x_2 + \frac{4}{3} h_i \Delta_i^2 + h_i (x_1 + x_2) \Delta_i \quad (13)$$

As $\frac{h_i}{\Delta_i} = \tan\alpha$ and $h_i = \Delta_i \cdot \tan\alpha$ we can insert this expression in Eq. (13). After algebraic calculations the equation of the third degree can be obtained, that characterises the value of the surface area edge variations Δ_i depending on the lengths of the rectangular lagoon bottom edges $x_1$and x_2, the wall angle α and the volume V_i:

$$\frac{4}{3} \tan\alpha \cdot \Delta_i^3 + \tan\alpha \cdot (x_1 + x_2) \cdot \Delta_i^2 + \tan\alpha \cdot x_1 \cdot x_2 \cdot \Delta_i - V_i = 0 \quad (14)$$

Solving Eq. (11) it is possible to obtain the surface area of the lagoon S_i:

$$S_i = (x_1 + 2\Delta_i)(x_2 + 2\Delta_i) \quad (15)$$

RESULTS AND DISCUSSION

Applying the offered methods numerical experiments were carried out. A square type lagoon with the bottom parameters 15 x 15 m and the height 2 m and four small size lagoons with equal capacity to store slurry, equal depth and side angles $\alpha_1 = \frac{\pi}{4}$ and $\alpha_2 = \frac{\pi}{3}$ were chosen. Using the expression (6) the small storage bottom edge lengths $\alpha_1 = 6.44$ m and $\alpha_2 = 6.90$ m corresponding to the side angles were calculated.

The variations of the lagoon reflection surface during filling stated by calculations are summarised in Fig. 3.

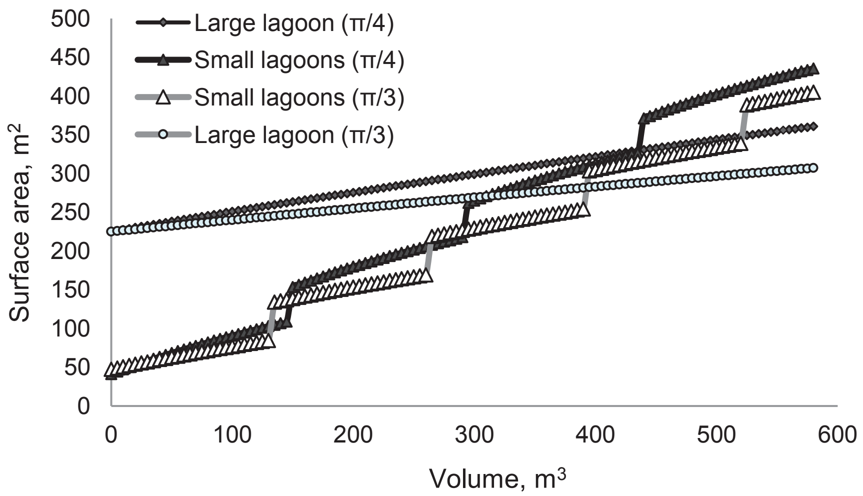

Figure 3. Comparison of the large square type lagoon and small square type lagoon summary reflection surface areas at different side edge sloping angles and the depth of storage $h_0 = 2$ m with varying amount of filled farm manure.

As it can be seen from the figure, the summary reflection surface of full small lagoons is larger than for the large lagoon. Still, it should be considered that at the beginning of filling the small lagoons, their reflection surface area increases considerably slower and more gradually than for the large lagoon. It is caused by the fact that at the beginning of slurry filling the bottom area of the lagoon is filled first and for the small lagoons it is considerably smaller than that of the large lagoon.

To obtain more precise research results we assume that in all cases lagoons have been filled continuously and with stable intensity. Therefore, the lagoon filling degree can be replaced by the filling time. In turn, the possible value of emissions is characterised by the area integral depending on the filling time of the lagoon. It means that emissions:

$$E = \int S \cdot dt$$

where E – amount of emissions; S – area of slurry reflection surface filled in the lagoon; t – lagoon filling time.

For a large lagoon in a full filling cycle it can be evaluated:

$$E_l = \int_0^1 f(t)dt \tag{16}$$

where E_l – emissions from the surface area of the large lagoon; $f(t)$ – variations of the reflection surface during filling.

For filling the small lagoons, the filling of every lagoon should be evaluated that comprises 25% of the total volume, i.e.

$$E_{sm} = \int_0^{\frac{1}{4}} f_1(t)dt + \int_{\frac{1}{4}}^{\frac{1}{2}} f_2(t)dt + \int_{\frac{1}{2}}^{\frac{3}{4}} f_3(t)dt + \int_{\frac{3}{4}}^{1} f_4(t)dt \tag{17}$$

where E_{sm} – summary amount of emissions from the total surface area of the small lagoons; $f_i(t)$ – variations of lagoon reflection surfaces during filling. The functions $f(t)$ and $f_i(t)$ are found using the expression (6) for square type lagoons and (12), (14) for rectangular lagoons.

By integration it was stated that at the lagoon side sloping angle $\alpha = \frac{\pi}{4}$ usage of four small lagoons reduces emissions by 19% compared to one large lagoon, but at the angle $\alpha = \frac{\pi}{3}$ the reduction is 26%.

Similarly one large rectangular lagoon was compared to four correspondingly smaller lagoons of the same capacity. The bottom edge lengths of the large lagoon are 15 x 20 m, its maximal filling height – 2 m and the side angles $\alpha = \frac{\pi}{4}$, but the volume – 751 m^3. Besides, the large lagoon corresponds to four small lagoons with the bottom sizes 6.58 x 8.78 m (Fig. 4).

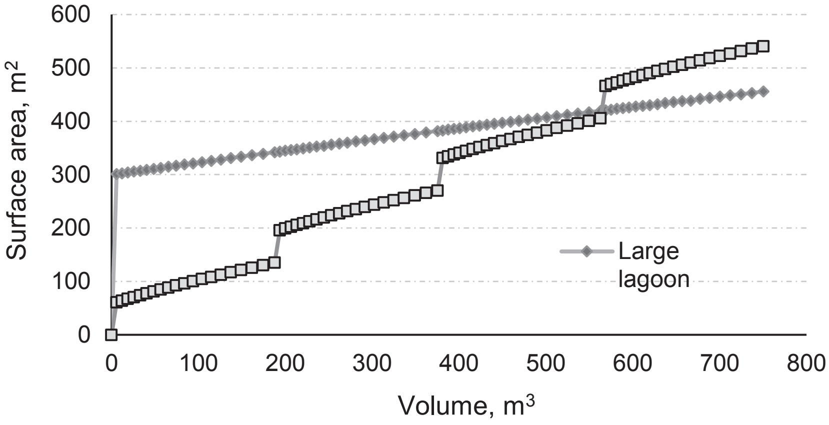

Figure 4. Variations of the reflection surface of the large rectangular lagoon and small rectangular lagoons depending on the filling of these storages if their depth h_0 = 2 m.

Using formulas (16) and (17), can be expected that using small lagoons and filling them sequentially it is possible to reduce ammonia emissions by 27% with accepted sizes in calculations.

If instead of one large volume lagoon four smaller lagoons with the same volume, equal depth and side sloping angles are installed and the small lagoons are filled sequentially, the slurry reflection surface areas from which unfavorable gasses are emitted are changing differently in both cases. Using a large volume lagoon this reflection surface quickly increases at the beginning until the whole lagoon bottom area if completely filled. After that the increasing intensity gets essentially lower as it is caused only by the influence of sloping of the lagoon sides. If, in turn, several smaller lagoons are used and sequentially filled, the increase of the reflection surface at the beginning is small, but its increasing intensity is faster. Therefore, at filling the third lagoon the area of the total reflection surface for the smaller lagoons is larger than for the large lagoon.

CONCLUSIONS

1.Methodology for calculation of volumes and reflection surface areas of different type slurry lagoons depending on their geometrical parameters has been developed.

2.It was found that within the input data used in the research replacing one large lagoon by four correspondingly smaller lagoons and their sequential filling can gives the possible ammonia emission reduction by 19–27%.

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