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CONTINUOUSLY WORKING SCREW METHANE-TANK

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Advantages and disadvantages of conventional anaerobic digester (methane-tank) constructions, which are in use for sewage water sediments neutralization, were examined in this article. A new continuously working construction of the device was proposed that is based on modern conceptions about fermentation processes. It's principle of operation takes into consideration results of previous researches. It was shown that the device allows to reduce fermentation time significantly and to improve sanitary and hygienic characteristics of the neutralized sediment.

Keywords: methane-tank, stabilization, sediment, sewage-purification facilities, sewerage, fermenting, stage.

Posing the problem

Sewage treatment facilities of Ukrainian towns and cities generate about 45 mln m^3 sediments annually. These sediments need to be utilized.

Considerable microbial pollution of these sediments (overall pollution is 10^7 … 10^8 ml^{-1}, salmonellae content is about 10^3 l^{-1}, helminthes' eggs content is up to 100 kg^{-1} [7]) does not allow to consider it as safe fertilizer for agriculture without its preliminary stabilization (disinfection).

Sanitary and hygienic standards do not allow presence of these causative organisms in fertilizers. However, only insignificant part of all sewage-purification facilities in Ukraine includes special structures for sediments disinfection (methane-tanks). The structures stabilize sediments by implementation of anaerobic fermentation with production of biogas which contains certain percentage of methane. According to [1] in case of stabilization only a half of sediments, that are produced in Ukraine, it is possible to obtain additionally around 200 mln m^3 of biogas (about 140 thousand tons of equivalent fuel).

Increasing in amount of sediments that are subjected to stabilization is an urgent task, since not only does it allow producing more ecologically friendly fertilizers but in addition it allows generating considerable amount of gaseous fuel.

Researches and publications analysis

Methane-tanks, which carry out this process, suffer from grave shortcomings. One of the major shortcoming is the fact that implemented in these methane-tanks fermentation techniques do not factor in all peculiarities of anaerobic fermentation that are known to date. In these techniques there is exploited the principle of separation different fermentation stages in space [3]. Accordingly, there are single-stage and two-stage (sometimes three-stage) methane-tanks).

A single-stage methane-tank is a uniform leakproof container. If fermentation takes place there periodically than on application of mesophilous conditions total process takes from 15 to 50 days, on application of thermophilous conditions this period is slightly shorter.

Continuity of fermentation process is ensured by periodical removing a portion of the fermented sediment from the container and simultaneous bringing in an equal portion of new unfermented sediment.

Mixing fermented and unfermented sediments results in "skipping over" causative microorganisms. It means that there is a certain amount of viable causative microorganisms in removed portions of fermented sediments.

Two-stage and three-stage methane-tanks operate according to the principle. But they have respectively two or three containers connected in consecutive order to separate in space the process of fermentation with respect to its intensity.

In the first container (first stage) intensive fermentation with active releasing of biogas takes place.

In the second container (second stage) fermentation process is failing, biogas releasing comes to a stop gradually and the sediment exfoliates partially with separating of sediment water.

In a three-stage methane-tank separation of sediment water takes place in the third container (third stage) or in an open reservoir [2]. This technology decreases a volume of output sediment at the expense of sediment water separation and improves sanitary and hygienic characteristics of fermented sediment. In spite of this it does not allow to exclude “slip over”. In addition it does not shorten total periods of fermentation.

In modern conception microbiology of anaerobic fermentation consists of four consecutive phases: enzymatic hydrolysis of organic compounds, during which water-soluble elementary substances are produced; acidogenesis – a phase when volatile fatty acids, amino acids, spirits, hydrogen and carbon dioxide appear; acetogenesis – a phase when volatile fatty acids, amino acids and spirits are transformed into acetic acid which dissociates latter into acetate anions and hydrogen cations; methanogenesis – a final phase when methane is generate out of acetic acid and by carbon dioxide reduction with hydrogen.

In papers of some authors [2; 6] there is shown that rate and quality of each fermentation phases depend on many factors. In particular they depend on sediment’s temperature, medium’s pH, presence of ferments etc. The best values of the factors which allow intensifying fermentation can be different for different phases. Five major groups of bacteria take part in fermentation processes. The first group – enzymatic bacteria of primary types: Micrococcus, Bacillus, Pseudomonas, Clostridium at alias. They are rapidly growing anaerobes which carry out hydrolysis and acidogenesis. The best value of pH for their functioning is 6.5 … 7.6. Rate of enzymatic hydrolysis depends on nature of organic compounds which are underdone the process.

Total fermentation time depends directly on duration of the first phase. The reason is that it is impossible for acidogenesis, acetogenesis and methanogenesis to begin unless enzymatic hydrolysis of organic compounds is over. During the second phase organic compounds that have already turned into solutions become feed sources for types of enzymatic bacteria mentioned earlier. Their activity during acidogenic phase leads to accumulating volatile fatty acids in the sediment and to decreasing its pH.

The second and the third groups of bacteria provide realization of acetogenic phase. The second group forms acetate out of products of previous phase, releasing hydrogen in the meanwhile. The third group forms acetic acid, using hydrogen for reducting carbon dioxide. During this process medium’s pH can be reduced down to 5.2 … 5.5.

The forth and the fifth bacteria groups are responsible for the last phase of fermentation – methanogenesis. The forth group generates methane by decomposing acetate. The fifth group does it by reducting carbonic acid with hydrogen. The best value of medium’s pH for functioning of methane-oxidizing bacteria is 7.0 … 7.5. Therefore, decreasing of medium’s pH during acidogenic and acetogenic phases can considerably slow down the process of methane generation.

Rate and quality of each anaerobic fermentation phases depend also on great number of other factors:

- temperature of the medium and it’s fluctuation;
- concentration of oxygen, nitrates, sulphide, sulphates and ammonia dissolved in the sediment;
- presence of different microelements, providing their contacts with organic compounds.

In case of providing the best values of the factors during each phases of fermentation mentioned earlier, the total duration of the fermentation process can be shortened down to 7 days [2]. According to [5] in conditions of scientific laboratory they managed to achieve total accomplishment of fermentation in 3 days.

For providing the best values of factors design of a methane-tank has to meat the next requirements [3]:

- to separate different phases of fermentation in space;
- to provide possibilities of introducing quantum satis of required ferments into the sections where each particular phase takes place;
- to maintain the best values of medium’s pH and temperature separately in each particular section;
- to organize running of each phases of fermentation with respect to it’s kinetics;

- to make possible to take samples of sediments from each section quickly for active controlling the process and on-the-fly factor correction;
- to maintain continuity of the fermentation without mixing sediments from different sections (during different phases).

The purpose of the article is to propose a design concept of a methane-tank, which can meat the requirements mentioned earlier [4].

Design concept of continuously working screw methane-tank

The design concept of continuously working screw methane-tank is a four-section methane-tank which is formed with a horizontal screw conveyor situated inside of a rigid cylindrical case (fig. 1). The screw conveyor and the case perform two tasks: they are boundary constraints for different sections of the device; they perform as an Archimedean screw pump and while rotating around their horizontal axes move fermenting sediment progressively from previous section to the next section.

The rigid horizontal cylindrical case 11 of the proposed design concept is mounted on several pairs of track rollers 21. The design concept demonstrated on the fig. 1, has two pairs. Since there is shown a side elevation it is possible to observe just one roller of each pair. This kind of bearings provides possibilities for the case to rotate. To provide a rotating stability it is necessary to equip the case with a guide bearing. There is a mechanism that puts the case into rotation. It consists of an engine 28 (for example electromotor) and a mechanical transmission 27 (for example tooth gear). Inside of the cylindrical case there is a coaxial hollow shaft 12, which is connected to the case with the horizontal screw conveyor 13. This design resembles a screw that is put inside of a pipe. At one end of the case there is a loading hatch 2. Through this hatch by the instrumentality of a load device 1 prepared for fermenting sediment is supplied into the methane-tank.

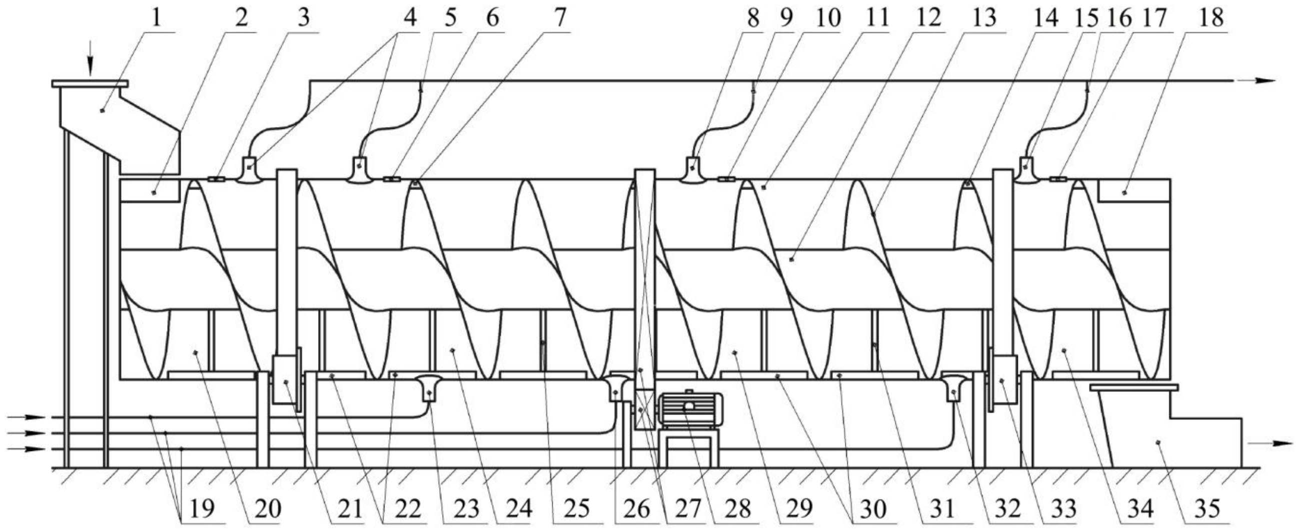

Fig. 1. Design concept of continuously working screw methane-tank

1 – load device; 2 – loading hatch; 3 – over-pressurization relief valve; 4 – nipple; 5 – flexible hose; 6 – over-pressurization relief valve; 7 – through hole; 8 – nipple; 9 – flexible hose; 10 – over-pressurization relief valve; 11 – rigid cylindrical case; 12 – hollow shaft; 13 – horizontal screw conveyor; 14 – through hole; 15 – nipple; 16 – flexible hose; 17 – over-pressurization relief valve; 18 – unloading hatch; 19 – flexible hoses; 20 – first gas hollow; 21 – track rollers; 22 – heat exchanger; 23 – injector; 24 – second gas hollow; 25 – stationary blade; 26 – injector; 27 – mechanical transmission; 28 – engine; 29 – third gas hollow; 30 – heat exchanger; 31 – stationary blade; 32 – injector; 33 – track rollers; 34 – fourth gas hollow; 35 – receiving device .

A portion of sediment is introduced into the methane-tank in an amount that fills up the first space between the screw conveyor and the cylindrical case to the upper level of the hollow shaft. “Starter culture” is added to the sediment. It is special substance enriched with ferments which initiate the fermentation process, in particular beginning of enzymatic hydrolysis and make it more active. Ferments prepared in advance as well as a part of the sediment taken out from sections of active fermentation that is enriched with such ferments can serve as “starter culture”. Before loading the next portion of sediment it is necessary to switch on the engine, which by the instrumentality of the mechanical transmission rotates the case of the methane-tank by 360^{o} about the axis. During rotating the portion of the sediment moves axially to the next space between the screw and the case vacating the previous space similarly to movement between blades of a screw pump. Rotating of the case and adding new portions of sediment should be repeated periodically. After each complete revolution isolated portions of sediment drifts by one section axially to the other end of the case. During this different phases of fermentation supersede each other.

At the other end the case has an unloading hatch 18. While rotating, when the hatch is in a down position, the door of the hatch opens and fermented sediment is unloaded into a receiving device 35. After that the sediment is taken away to utilization. The process becomes continuous.

Since sediment fills the case to upper part of the shaft there are hollows remain above it. These hollows are to accumulate biogas during fermentation. The amount of hollows as well as the amount of sediment’s sections is equal to amount of turns of the screw. Intensity of biogas releasing and its composition are different at different phases of fermentation. However, during a single phase this process can be maintained relatively uniform. To simplify the process of biogas removal there is proposed to combine adjacent hollows above the sediment by making through holes 14 in the blade of the screw. The through holes must be located in the upper parts of the blade at run position of the case. It allows creating four gas sections above the sediment. The process must be organized in the way that enzymatic hydrolysis takes place in the sections of the first gas hollow 20, acidogenesis takes place in the sections of the second gas hollow 24, acetogenesis – in the sections of the third gas hollow 29 and, finally, methanogenesis – in the sections of the fourth gas hollow 34. Therefore the design concept can be regarded as four-section device.

To remove the biogas from gas sections there is proposed to equip the case of the methane-tank with nipples 4, 8, 15, not less than one for each section. There is proposed to attach to the nipples flexible hoses 5, 9, 16. With biogas accumulating its pressure inside of the gas sections will increase, nipples will open and biogas will be removed for utilization.

To shorten the total duration of fermentation process each sediment section needs to have its own optimal conditions. To provide these conditions there is proposed the design concept of the methane-tank that is equipped with the next elements. To maintain in the sections optimal temperatures at the lower parts of the case at its run position there are placed heat exchangers 22, 30. They can operate independently from each other and, heating or cooling the sediment, can maintain the required for each phase of fermentation temperature regime. At the lower part of the case there is proposed to build in injectors 23, 26, 32 and to attach to them flexible hoses 19.

Injectors have to be located in the first sediment sections of each fermentation phase downstream the total process. They are assigned to inject into the sediment different ferments that are necessary for intensification of each fermentation phase.

The flexible hoses have to have easily detachable joints with the nipples and injectors. In case of periodical rotation of the cylindrical case the flexible hoses must be detached from the methane-tank.

In case of contingency there is proposed to place over-pressurization relief valves 3, 6, 10, 17 at the upper part of the case. The task of the valves is an emergency releasing part of the biogas into the atmosphere when pressure inside of the methane-tank goes over permissible. The amount of the valves must be not less than one for each gas section.

It is very important for intensification the process and for the achieving high completeness of fermenting is agitation of the sediment. It can be done using different methods. In the design concept (fig. 1) on the bottom part of each sediment section there is proposed to place stationary wide blades 25, 31. It is possible to attach them to the cylindrical case and to the interior hollow shaft or to adjacent areas of the screw conveyor. During periodical rotating the case of the methane-tank these blades will agitate the sediment.

Methane-tanks of the proposed design concept could be divided into another amount of sections. For example it is possible to make the device three-section. In this case the first section can be used for phases of enzymatic hydrolysis and acidogenesis. These two phases can be combined and done in one section under certain conditions [2].

To demonstrate possible appearance of the proposed methane-tank design concept there was assembled its demonstration model by the authors of the article (fig.2).

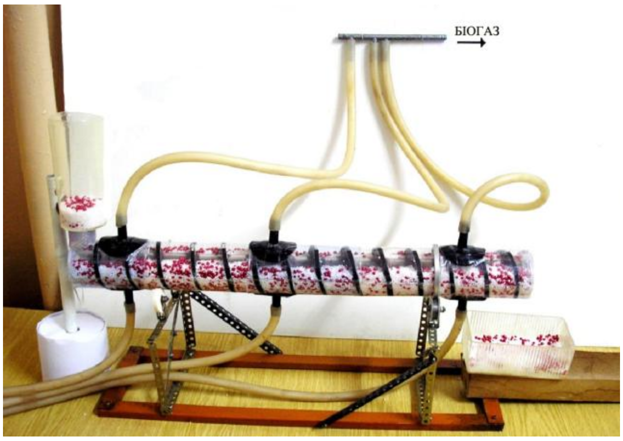

Fig.2. Demonstration model of continuously working screw methane-tank

The device can be constructed five-section. In this case the phase of methanogenesis can take place in the last two sections. The major section of methanogenesis can be intended for maintaining intensive process of fermentation with releasing and removing large amounts of biogas. The additional section of methanogenesis can be intended for completion the fermentation and partial separation of sediment water [3].

Conclusion

Multisectional methane-tanks have good prospects to be used in municipal engineering of Ukraine. But rate of fermentation and completeness of the process are pretty low in the methane-tanks of conventional design. The proposed design concept of the methane-tank has many advantages over conventional ones. In particular it provides possibility to separate different fermentation phases in space. Due to this it becomes possible to take into consideration kinetics of each phase and to maintain the best values of temperature, medium's pH and others factors for each particular phase of fermentation. The design provides possibilities to take samples of sediments at any time from each section of the process and to inject into the sediment special ferments that are necessary for improving fermentation process. By using the proposed methane-tank design it is possible to shorten the total duration of fermentation essentially and at the same time to provide obtaining fermented sediments of high sanitary and hygienic characteristics which can be safely used as organic fertilizers.

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