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Role of wastewater sludge treatment by anaerobic stabilization for Rostovvodokanal company

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Introduction. The article deals with the problems of treatment of organic sludge from the purification of municipal wastewater in Rostov-on-Don. To solve this problem, a method of anaerobic (methane) digestion of sewage sludge was proposed.

Problem Statement. The objective of this study is to determine the role of anaerobic stabilization for Rostovvodokanal company.

Theoretical Part. The differences between mesophilic and thermophilic modes of sediment digestion were determined, a technological line for preparing biogas for use was proposed. Calculations of the main parameters of the anaerobic digestion process in the digester have been made.

Conclusion. The results of the analysis showed that with the help of this modernization, the main problems are solved.

Keywords: anaerobic sludge digestion, sewage sludge, anaerobic stabilization, heated digestion tank, biogenic gas.

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Introduction. Rostov-on-Don is a large industrial city with a population over one million people, which leads to the formation of a huge amount of wastewater that is treated at the city's treatment facilities (Rostovvodokanal). In wastewater treatment technology, one of the most pressing environmental problems is the treatment and disposal of sludge. This is especially true for organic sludge of urban wastewater treatment. Until now, activated sludge waste is stored in the territories near the Rostov aeration station in Rostov-on-Don and is a real ecological and biological danger. According to the data of the Rostov aeration station (RAS), about 60-70 tons of compacted mixture of raw sludge and waste activated sludge with a dry matter humidity of 94-97% is formed per day, which leads to the need to increase the territories for silt detention ponds. The opportunities to increase this area are limited due to the rapid growth of the city and suburbs. At the moment, sewage sludge after the mechanical dewatering shop is first delivered to the silt sites for further dewatering, and then to the territories adjacent to the RAS. At the same time, it is noted that the activated sludge, having good adsorption characteristics, contains a large number of polluting components, including heavy metals, etc. Since sludge is not subjected to the disinfection process, it can serve as a source of not only chemical, but also microbiological contamination. According to the monitoring data, it was found that this sludge negatively affects the Don river water quality, since the storage areas are located on the shore. The degree of negative impact increases when it gets wet. Thus, sewage sludge is a sanitary and environmental problem of Rostov-on-Don that requires immediate solution.

Problem Statement. Sewage sludge is a separate type of waste. It makes about 1/3 of the total amount of production and consumption waste in large cities [1]. Permanent contamination of underground and surface waters and soils located on the territory occurs due to sludge storage at treatment facilities. The problem is the accumulation of huge amounts of sludge at silt detention ponds. To solve this problem, it is proposed to use anaerobic digestion of sewage sludge and waste activated sludge in order to reduce environmental pollution and use the entire volume of organic matter. During anaerobic digestion, we get biogas and decontaminated sediment.

Theoretical Part. Anaerobic digestion of sewage sludge. For processing and fermentation of sewage sludge, septic tanks, double-deck setting basins and sludge digesters are most often used. With small capacity, septic tanks are used, with the help of which the sludge is digested and the water is clarified. For settling of waste water, fermentation and compaction of the sludge, double-deck setting basins are used. However, the most common are sludge digesters, which are used for sludge digestion with simultaneous heating and intensive mixing.

Sludge digester is a tank with a conical bottom without access to oxygen. They are used to produce biogas and decontaminate sediment. During fermentation, the chemical composition of sludge changes in the sludge digester. As a result, the ash content increases and the concentration of carbohydrates, fats, proteins decreases, and biogas is released.

Anaerobic stabilization can be performed in two temperature modes:

— mesophilic — from 30 to 38°C;

— thermophilic — from 50 to 60°C.

When comparing the two temperature modes, the following advantages of thermophilic fermentation were revealed [2, 3]:

— the required volume of the sludge digester is 2 times less;

— significantly less energy is spent on the anaerobic process;

— the total gas output is 2 times higher;

— sludge fermentation time is 3 times less;

— pathogenic microorganisms and helminths are completely destroyed;

— the unpleasant smell of sludge practically disappears;

— the dewatability of the stabilized sludge is much better.

The performance of anaerobic stabilization is determined by the chemical composition of the sludge, the degree of decomposition of organic matter, the mode of sludge loading and unloading, the mixing method, temperature, loading dose, volume and composition of biogas [4]. Biogas is produced by the breakdown of the main part of organic matter (proteins, fats and carbohydrates): fat — 60-65%; protein and carbohydrates — 40-35%. Therefore, more gas is obtained from the sludge of primary settling tanks due to the significant fat content. The breakdown rate increases with increasing temperature, but the temperature does not affect the breakdown limit. The residence time of the sludge and the amount of sludge loaded correlate with the temperature mode of fermentation. Due to inefficient mixing of the sludge in the sludge digester, the residence time of the sludge, the actual volume of the sludge digester, and the output of biogas are reduced. There goes the consumption of organic matter.

The production process of sewage sludge treatment is as follows:

— preliminary mechanical sludge thickening;

— anaerobic (methane) fermentation in sludge digesters;

— mechanical sludge dewatering;

— use of methane gas obtained in sludge digesters for the operation of a cogeneration plant (Block CHPP);

— burning of excess methane gas with a torch (flare) in emergency situations.

Use of biogas. The resulting biogas during anaerobic stabilization of sewage sludge has the following composition: methane — 55-70%; carbon dioxide — 27-45%; nitrogen and hydrogen sulfide — 3%; hydrogen — 1% [5]. In accordance with the composition of the biogas, it is necessary to carry out preliminary cleaning and drainage.

The biogas processing line consists of: a gravel filter; a cooler; an adsorber with zeolite; a compressor; gas engine generators, a gas tank and a gas combustion torch.

Biogas (methane) is fed to a gravel filter [5] designed for pre-dewatering and filtration (rough cleaning) of gas. Gas drying is carried out to protect and prevent rapid wear of gas cleaning equipment and gas pipelines [6]. For this purpose, a method is provided for cooling the gas to a temperature below the dew point in the heat exchanger with the removal of the condensed water, and the cooled gas is passed through the second heat exchanger and reheated to the operating temperature. Biogas contains toxic hydrogen sulfide, which damages the gas engines of a block thermal power plant [6], and carbon dioxide, which increases the heat of combustion. Therefore, after cooling, the gas enters the adsorber with artificially synthesized zeolites (permutites), which are now available for a good price and quality. The remaining biogas, mainly methane, is supplied to compressor units for compression and liquefaction [5]. Further, it is directed to the compact block thermal power plants for generating electric and thermal energy in cogeneration plants. The gas tank is designed for averaging the consumption of biogas and is designed for a two-hour gas output. The gas flaring torch is used in emergency situations and when the plant is stopped for preventive maintenance.

Technological calculation. Three types of sludge are delivered to the sludge digester for decontamination: screenings, which are first crushed on crushers; sludge from primary settling tanks; waste activated sludge, which is pre-processed in silt compactors.

The amount of sludge dry matter (t/day) is calculated using the following expression [7]:

$$Q_{\text{сух}} = \frac{M(100-W)\rho}{100}, \quad (1)$$

where M — the amount of sludge, m^3/day.; W — moisture content of raw sludge, %; ρ — the density of sludge equal to 1 t/m^3 [7].

Screenings:

$$Q_{\text{сух}} = \frac{1.55(100-90)1}{100} = 0.155.$$

Sludge from the primary sedimentation tanks:

$$Q_{\text{сух}} = \frac{1423(100-96.5)1}{100} = 49.81.$$

Compacted waste activated sludge:

$$Q_{\text{сух}} = \frac{6378(100-99.25)1}{100} = 47.84.$$

1. The flow of sludge and silt on the ash-free basis (t/day) is determined by the formula [7]:

$$Q_{\text{без}} = \frac{Q_{\text{сух}}(100-B_{\text{г}})(100-S_{\text{ос}})}{100\cdot 100}, \quad (2)$$

where $B_{\text{г}}$ — hygroscopic moisture content of sludge, 5%; $S_{\text{ос}}$ — ash content of dry matter for waste from screenings and sludge from primary sedimentation tanks 30 %, for activated sludge 25 % [7].

Screenings:

$$Q_{\text{без}} = \frac{0.155(100-5)(100-30)}{100\cdot 100} = 0.1.$$

Sludge from the primary sedimentation tanks:

$$Q_{\text{без}} = \frac{49.81(100-5)(100-30)}{100\cdot 100} = 33.12.$$

Compacted waste activated sludge:

$$Q_{\text{без}} = \frac{47.84(100-5)(100-25)}{100\cdot 100} = 31.81.$$

Table 1

Sludge supply to the sludge digester

Sludge concentration	M, m^3/day	W, %	$Q_{\text{сух}}$, t/day	$Q_{\text{без}}$, t/day	Bг, %	$S_{\text{ос}}$, %
Screenings	1.55	90	0.155	0.1	5	30
From the primary sedimentation tanks	1423	96.5	49.81	33.12	5	30
Compacted waste activated sludge	6378	99.25	47.84	31.81	5	30
Total	$M_{\text{общ}}$=7802.55		$M_{\text{сух}}$=97.8	$M_{\text{без}}$=65.03		

2. The average moisture content of the mixture, %, is calculated by the formula [7]:

$$B_{\text{см}} = 100\left(1-\frac{M_{\text{сух}}}{M_{\text{общ}}}\right), \quad (3)$$

$$B_{\text{см}} = 100\left(1-\frac{97{,}8}{7802.55}\right) = 98.7.$$

3. The average ash content of the mixture,%, is expressed in [7]:

$$З_{см} = 100\left(1 - \frac{М_{без}}{Q_{сух}\left(\frac{100-В_г}{100}\right)+И_{сух}\left(\frac{100-В'_г}{100}\right)}\right), \quad (4)$$

where $О_{сух}$ total dry matter of the screenings and dry matter sludge from primary sedimentation tanks, t/day.; $И_{сух}$ — the amount of dry matter, compacted waste activated sludge, t/day.; $В_г$ — hygroscopic moisture content of the mixtures of screenings and dry matter sludge from primary clarifiers, %; $В'_г$ — hygroscopic moisture content of compacted waste activated sludge, % [7].

$$З_{см} = 100\left(1 - \frac{65.03}{49.965\left(\frac{100-5}{100}\right) + 47.835\left(\frac{100-5}{100}\right)}\right) = 30$$

4. The volume of the sludge digester, m^3, is determined by [7]:

$$V = M_{общ}\frac{100}{Д}, \quad (5)$$

where $М_{общ}$ — daily sludge consumption, m^3/day.; Д — daily amount of input of sludge in the digester, %. Depending on the mode of digestion of sludge and the moisture content of the sludge mixture that enters the digester, at sludge thermophilic mode and the humidity of 97% the sludge input Д=19 % [7].

$$V = 7802.55\frac{100}{19} = 41\,066.$$

We have three 9000 m^3 sludge digesters. The total volume of sludge digesters will be higher than the required one, and the actual input Д, %, will decrease [7]. Therefore

$$Д' = \frac{VД}{V_м n}, \quad (6)$$

where n — the number of sludge digesters, pcs.; $V_м$ — the volume of one sludge digester, m^3.

$$Д' = \frac{41066 \cdot 19}{9000 \cdot 3} = 29.$$

5. The mixture breakdown limit, %, is defined as [7]:

$$a_{см} = \frac{a_o Q_{без} + a_и U_{без}}{M_{без}}, \quad (7)$$

where $a_о$, $a_и$ — sludge breakdown limit 53 % and silt 44 %; $М_{без}$ — total volume of ash-free sludge and silt, t/day.; $Q_{без}$ — total volume of ash-free sludge, t/day; $U_{без}$ — volume of ash-free silt, t/day [7].

$$a_{см} = \frac{53 \cdot 33.22 + 44 \cdot 31.81}{65.03} = 48.6.$$

6. The gas emission per 1 kg of the loaded ash-free substance, m^3, is determined by [7]:

$$y' = \frac{a_{см} - nД'}{100}, \quad (8)$$

where n — the coefficient depending on the sludge humidity of 97% and the thermophilic fermentation mode, assumed to be 0.17.

$$y' = \frac{48{,}6 - 0.17 \cdot 29}{100} = 0.44.$$

7. The total gas emission, m^3/day, so [7]:

$$Г = y' \cdot M_{без} \cdot 1000, \quad (9)$$

$$Г = 0.44 \cdot 65.03 \cdot 1000 = 28613.2.$$

8. Wet gas tanks are designed to smooth the gas pressure in the gas circuit, the capacity of which is Vг, m^3, we provide for 2-4 hours of gas output [7]:

$$V_г = \frac{3Г}{24}, \quad (10)$$

$$V_г = \frac{3 \cdot 28613.2}{24} = 3576.65.$$

We suppose that one gas tank is 1820 m^3.

9. The amount of ash-free substance in the fermented mixture, t/day, is calculated by [7]:

$$М'_{без} = \frac{М_{без}(100 - 100y')}{100}, \quad (11)$$

$$M'_{без} = \frac{65.03(100 - 100 \cdot 0.44)}{100} = 36.42.$$

10. The amount of dry matter in the digested mixture, t/day, is determined by [7]:

$$M'_{сух} = \left(M_{сух} - M_{без}\right) + M'_{без}, \qquad (12)$$

where ($M_{сух}$ — $M_{без}$) — ash part, which is not subjected to transformation in the process of fermentation [7].

$$M'_{сух} = (97.8 - 65.03) + 36.42 = 69.19.$$

11. The ash content of the fermented mixture,%, is determined by [7]:

$$З'_{см} = 100 - \frac{M'_{без} \cdot 100 \cdot 100}{M'_{сух}(100 - B''_{г})}, \qquad (13)$$

where $B''_{г}$ — the hygroscopic humidity of the fermented mixture, 6 % [7].

$$З'_{см} = 100 - \frac{36.42 \cdot 100 \cdot 100}{69.19(100 - 6)} = 44.$$

12. The moisture content of the fermented mixture is calculated by [7]:

$$B'_{см} = 100 - \frac{M'_{сух}}{M_{общ}} 100, \qquad (14)$$

$$B'_{см} = 100 - \frac{69.19}{7802.55} 100 = 99.1.$$

Conclusion. The paper considers one of the most serious environmental problems associated with the entry into the environment and long-term storage of sewage sludge. Active sludge is the greatest biological hazard, which occupies large areas near the urban area. For modernization, a technology for processing sewage sludge has been proposed, which also helps to solve two more problems. The resulting biogas can be used in the boiler shop of RAS, as well as cogeneration plants can use it to convert it into electrical energy and send it to treatment facilities. The fermented sludge after mechanical dewatering can be used as a fertilizer and, thanks to this, significantly reduce the area of silt detention ponds.

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