

Features of wastewater treatment systems of the oil and gas field infrastructure

Elena Vialkova and Svetlana Maksimova

Industrial University of Tyumen

Abstract. When creating the oil and gas field infrastructure, the question arises of collection, storage, transportation, treatment and disposal of waste generated as a result of people's activities. One of the important tasks is the design, construction and operation of a reliable water disposal system for rotators' camps, stable under the northern conditions and including wastewater treatment plants. Technological and technical-economic analysis of existing facilities has shown that the efficiency of the existing small wastewater treatment plants is rather low, while the cost of operation is several times higher than that of stations with high capacity. This trend is also characteristic of existing technologies for treatment and disposal of sludge. In order to prevent anthropogenic impact on the nature of the North of the Tyumen Oblast (region), to increase the efficiency of small wastewater treatment plants and to reduce the costs of sludge disposal, it is necessary to apply new technological solutions and methods for treating the resulting domestic waste.

1. Introduction

The strategy for the development of the Arctic zone of Russia until 2020 suggests that the main areas for the formation of sustainable development of the Arctic include ensuring a favorable environment for residents by the rational and safe use of natural resources, preventing harm to the natural environment and the vital interests of the population. It is also about providing the population with drinking water of the required quality and reducing the negative impact on water sources due to the modern approach to the design and construction of water disposal networks. [1].

A fairly large part of the Russian territory is in the Arctic conditions (or close to the Arctic), including the North of the Tyumen region. Severe climatic conditions, frozen mobile soils, and swampy terrain create serious problems in the design, construction and operation of various facilities. When creating the infrastructure of oil and gas fields, the question arises of the collection, storage, transportation, treatment and disposal of waste generated as a result of people's activities. One of the important tasks is the design, construction and operation of a reliable domestic wastewater treatment system, stable under the northern conditions, including external networks, pumping stations and wastewater treatment plants. [1-4]

2. Overview of the problem and solutions

Construction of wastewater treatment plants in rotators' camps of the northern climatic zone has a number of features associated with low temperatures in winter, permafrost soils, a lack of access roads to construction sites, and a drastic change in the number of personnel. Shift work causes the unevenness of water consumption and water disposal, which is exacerbated by the peak nature of the flow of wastewater for treatment. Biological treatment of cold wastewater with a peak intake is a difficult task [4].



The problem of qualitative wastewater treatment with subsequent disposal of sludge is relevant for small towns and villages in Russia. Small amounts of wastewater, as a rule, have higher concentrations of organic substances. For example, the wastewater of rotators' camps in the oil fields of the Tyumen North contain elevated concentrations of BOD, COD, nitrogen-containing substances [4-6]. Such wastewater contains technogenic pollutants: anionic surfactants, petroleum products and others [7]. There is a problem of treatment and disposal of sludge formed at small treatment plants. The necessary number of units of traditional equipment, the volume of consumables, and the cost of electricity are unreasonably high, especially under the conditions of the northern climate. To solve the problem of wastewater and sludge treatment in wastewater treatment plants of low capacity, it is necessary to introduce new energy saving methods and technologies that allow obtaining high process efficiency.

The problem of protecting natural clusters of the Arctic is directly related to the state of water sources. There is an opinion that imperfect methods of calculation, inaccurately taking into account the self-cleaning ability of water bodies, have influenced the current ecological state of water bodies, including the northern regions. Most of them are classified as "dirty" and "very dirty" and cannot cope with residual contamination of poorly treated or untreated wastewater from rotators' camps in oil and gas fields.

According to researchers [8-10], the process of self-cleaning (self-regeneration) of water bodies which compensates for the anthropogenic impact is possible only up to a certain threshold level, while preserving the buffer properties of the system, its high capacity for inactivation and transformation of pollutants. If this threshold is exceeded, the biological environment loses its ability to stabilize the water quality in a water body, and local and global changes in the aquatic ecosystem begin.

The rate of self-cleaning of the water body and decomposition of carbon-containing compounds, including surfactants and petroleum products, depends on temperature, access to oxygen, the nutrient regime of the aquatic environment, i.e. on those factors that determine its microbiological activity. In oxygen-depleted water, decomposition of carbon-containing compounds tends to slow down. Self-cleaning of water bodies from petroleum is especially slow. For 2-7 days, the content of emulsified petroleum products in water decreases by 40% at 20 degrees Celsius, and at 5 degrees Celsius by only 15%. In the presence of aquatic vegetation in model experiments, the oil film disappeared in 4-6 days at its thickness of 0.06 cm, and at 0.6 cm - in 20-22 days. [8].

From this point of view, small amounts of wastewater generated in oil and gas fields are subject to compulsory treatment and their discharge should be controlled by environmental organizations. The choice of the technological scheme for treating industrial and municipal waste waters of enterprises and infrastructure facilities is carried out on the basis of several parameters: the quality of the source water and the required degree of wastewater treatment (stress-strain state concentrations); given daily capacity of WWTPs; local geographic and climatic conditions, available resources, environmental conditions, construction experience and other conditions. In Russia, there are unified requirements for treatment plants, regardless of their capacity and operating conditions. In European countries, less stringent standards are set for small wastewater treatment facilities, and state programs for reconstruction of such structures are being developed [11,12].

The problem of disposal of liquid municipal waste of northern rotators' camps remains unresolved to the full. In the oil fields of the Tyumen North, it is often not possible to discharge municipal wastewater from temporary settlements to water bodies for several reasons: there is no suitable water body for this purpose; the water body is located too far, and laying the discharge line is not cost-effective; the water body is shallow and freezes in the winter. In a number of fields, domestic wastewater from small production sites is periodically transported by sewerage machines to central wastewater treatment plants to the nearest major population center. With the scattered placement of small treatment plants, their operation is quite complicated. [11, 13]

In this case, discharging wastewater into the reservoir pressure maintenance system in conjunction with treated production and bottom water is considered. The reservoir pressure maintenance system is a complex of process equipment necessary for preparation, transportation, and injection of a working agent into the reservoir of an oil field in order to maintain reservoir pressure and achieve maximum oil

extraction rates from the reservoir. According to regulatory requirements, joint treatment and injection of formation and waste water is allowed only after complete biological treatment and disinfection of domestic wastewater at a flow rate of not more than 100 m³/day.

However, the municipal treated wastewater may not meet the requirements of the industry standard, especially for the dissolved oxygen content downstream of the aeration biological treatment facilities. Untreated effluents contain a large amount of organic substances, creating a nutrient medium for bacteria, including sulfate-reducing bacteria. Therefore, in order to discharge wastewater of rotators' camps into the reservoir pressure maintenance system, the following measures should be envisaged: complete biological treatment of wastewater with post-treatment and mandatory decontamination at the last stage of the WWTP; additional treatment of effluents to remove residual dissolved oxygen, hydrogen sulfide and ferric iron.

Disposal of industrial and municipal liquid waste in the deep subsoil horizons is also an option. The main criterion for selecting burial sites is environmental safety of construction and operation [11, 14, 15].

Creation of areas for disposal of industrial wastewater (liquid waste) of oil and gas fields includes several stages: selection of an area and a site for construction of an underground storage facility, exploration, design and construction of a disposal site. At each stage, as well as during the operation of the site, great attention is paid to protection of groundwater. Underground disposal of petroleum-containing wastewater is a complex process which includes preparation of waste for burial, delivery and injection into absorbing wells. Geological and hydrogeological conditions of the subsoil are very complex, therefore, the project on justifying the burial of industrial wastewater cannot foresee in advance all the peculiarities of filling the underground storage with liquid waste [16,17].

In order to reduce the number of places of storage of liquid municipal and industrial waste, a method of burning treated domestic wastewater mixed with industrial and rain effluents is used for gas fields, for example, at the gas fractionation units (GFU) of TyumenNIIGigrogaz [11,16,17]. However, this method is associated with the emission of combustion products into the atmosphere and with the irretrievable use of water resources. In order to avoid the above drawbacks, according to current regulations, in oil and gas fields modern wastewater treatment plants in block-modular design must be used to ensure the required degree of treatment, taking into account the subsequent disposal of treated wastewater and sludge.

Process schemes of small towns have recently become more complex: new treatment stages are introduced; separation of the aerotank into nitrification-denitrification zones is applied; various types of reagents are added at several stages at one plant. All these measures are justified from the point of view of achieving the required treatment effects. For example, introduction of such a facility as an equalizing tank into the process scheme of a small WWTP of a shift camp makes it possible to reduce the irregularity of wastewater supply for treatment, and prevent "peak" discharges of contaminants. As a result, the volume of subsequent settling, desilting and post-treatment facilities decreases; the stability of bioreactors increases [4,11,18]. In order to achieve high quality and reduce space occupied by equipment, and, consequently, construction and operation costs, small WWTPs include membrane plants: filters, MBR reactors and others. But, as a rule, all these innovations significantly raise the cost of treatment. [19-22]

Problems with disposal of sludge formed at municipal wastewater treatment plants remain relevant. One of the promising methods, especially in low-temperature areas, is exposing the waste of the treatment plant to electromagnetic super-high frequency radiation. As a result of this short-term process, not only the amount of sludge decreases, but also its properties are significantly improved: ash content, resistivity, water-yielding capacity and others. Special attention should be paid to super-high frequency treatment due to complete disinfection of liquid domestic waste. [23-25]

3. Research

Researchers at the Department of Water Supply and Wastewater Disposal (Industrial University of Tyumen) apply a comprehensive approach to solving the identified problems of water disposal

systems for rotators' camps of oil and gas fields. Scientific interests include issues relating to collection, transportation, treatment and disposal of liquid municipal waste generated at infrastructure facilities. Below are the process and technical and economic indicators of the surveyed wastewater treatment plants.

Table 1 presents comparative data for a number of rotators' camps, small towns and cities of the Tyumen region.

Table 1. Quality of wastewater entering treatment facilities on an example of settlements in the Tyumen region.

Treatment plants	Capacity, m ³ /day	Suspended substances, mg/dm ³	BOD ₅ , mg/dm ³	COD, mg/dm ³	N-NH ₄ , mg/dm ³
Septic tanks of rotators' camps	Up to 5	300-6000	300-1500	600-11000	85-200
Rotators' camps of oil fields	10-250	200-1000	250-600	500-1000	70-85
Vagay (village)	400	140	390	500	52
Labytnangi (city)	3 000	200	180	250	50
Yugorsk (city)	7 000	150	120	160	18
Nefteyugansk (city)	12 000	182	131	215	50,4
Tobolsk (city)	40 000	190-200	250	400	25-27
Tyumen (city)	210 000	180-250	140-250	290-400	30-37

At the same time, the specific reduced mass of contaminants entering the treatment facility reduces significantly as the plant capacity increases (Figure 1).

In the period from 2007 to 2015, 15 operating small wastewater treatment plants for small towns in Western Siberia were studied. The capacity of wastewater treatment plants was in the range of 10 to 250 m³/day. As a result of the study, a serious problem was identified, related to the unsatisfactory quality of biological treatment and the poor exploitation of these facilities. It turned out that the lower the plant capacity, the lower the efficiency of water treatment by main indicators (Table 2).

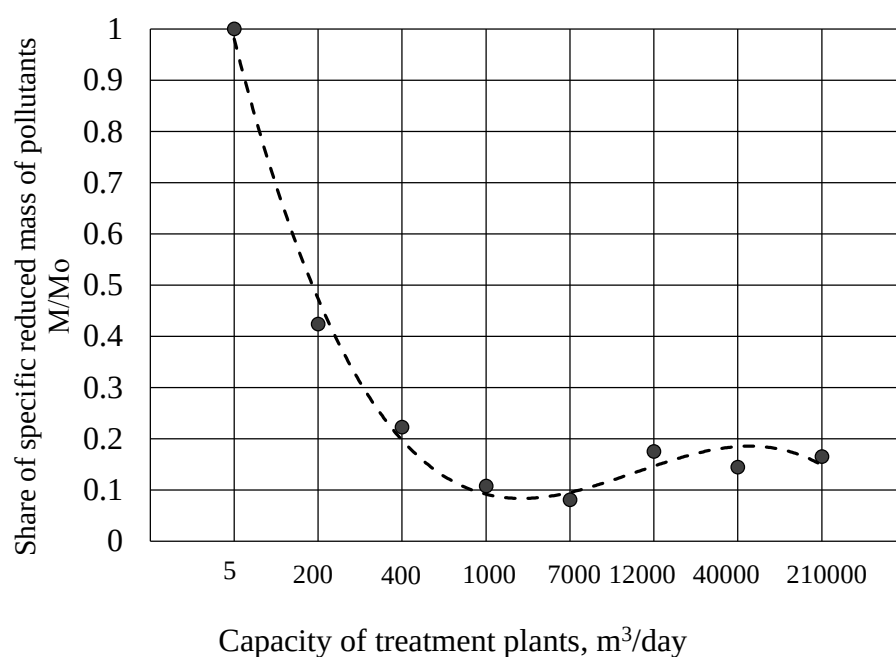


Figure 1. The change in the specific reduced mass of pollutants (cond.t/m³) entering with wastewater, depending on the plant capacity.

Table 2. Average annual efficiency values of small WWTPs.

Treatment efficiency of WWTPs by main indicators:	WWTP capacity, m ³ /day			
	10 m ³ /day	40 m ³ /day	120 m ³ /day	250 m ³ /day
Suspended substances	84%	86%	92%	97%
BOD	60%	70%	83%	85%
Ammonia nitrogen	46%	50%	56%	58%
Anionic surfactants	52%	57%	86%	87%
Petroleum products	38%	64%	85%	90%

At all the small plants studied, there are increased input concentrations of petroleum products and anionic surfactants, not typical for domestic wastewater of stations with high capacity (Table 3). At the same time, many standard designs of small WWTPs do not take into account the presence of anionic surfactants and oil products in this water, which enter the water disposal system in considerable quantities from the process of washing contaminated work clothes and with surface drains from the territories. In the wastewater of rotators' camps, the content of petroleum products is high compared to the requirements of engineering plants, and this has a significant effect on biological treatment.

Table 3. Input parameters of wastewater at WWTPs of the Tyumen region.

Indicator	WWTP 10 m ³ /day	WWTP 40 m ³ /day	WWTP 120 m ³ /day	City WWTP up to 10 thousand m ³ /day	City WWTP up to 50 thousand m ³ /day	City WWTP up to 200 thousand m ³ /day
Petroleum products	9.33	8.85	7.48	8	6.8	4.9
Anionic surfactants	6.3	8.7	12.5	1.7	2.4	3.7

A more detailed analysis of the situation identifies many identical facts, combining which, one can draw a general conclusion that there are:

- a sharp deviation from the average concentrations for a number of contaminants (suspended substances, BOD, ammonium nitrogen, phosphates) in the incoming wastewater;
- an increase in concentrations of petroleum products associated with the appearance of surface runoffs in the domestic wastewater network and, as it turned out, with the washing of the work clothing of oil workers;
- an increase in concentrations of anionic surfactants associated with the increased use of household chemicals;
- a low temperature of incoming wastewater (during the cold period 6-10°C) as a result of their long stay in the system;
- a high coefficient of hourly wastewater supply unevenness for treatment.

The consequence of this is an incorrect choice of process schemes and composition of WWTP at the design stage, and unsatisfactory operation after putting the facility into operation.

The technical and economic analysis of the operation of small WWTPs showed that the cost of cleaning 1 m³ of wastewater is very high for plants with a capacity of 200 m³/day or less (Figure 2). For example, for plants with a capacity of 10-20 m³/day, the prime cost is about 8 times higher than that for a plant with a capacity of 700 m³/day. This is due to the high costs of electricity, reagents, transportation and other operating costs. Moreover, the analysis of a number of operating wastewater treatment plants has shown that the efficiency of wastewater treatment by small plants is often much lower than that by plants with higher capacity (Figure 3).

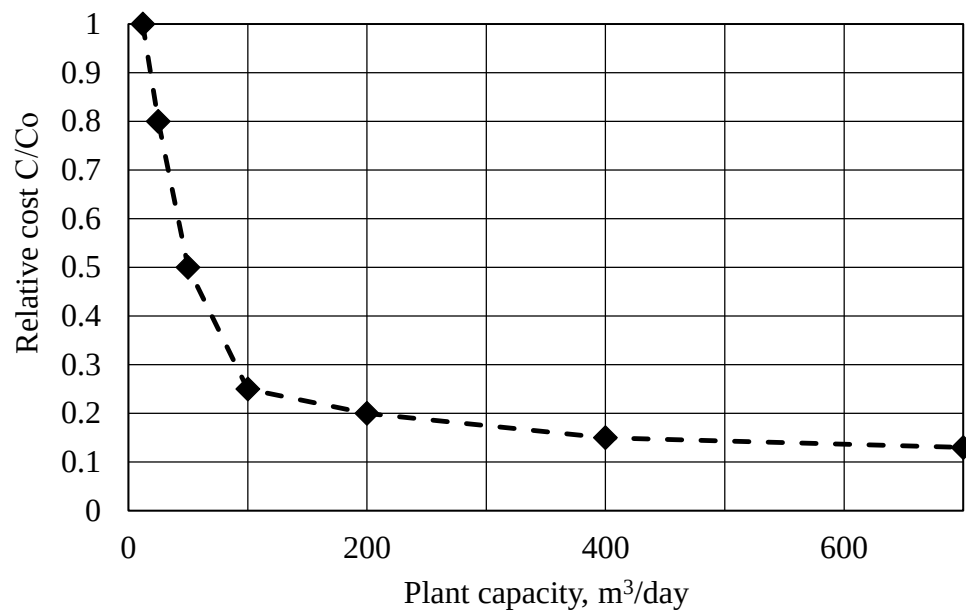


Figure 2. Dynamics of the water treatment cost reduction with an increasing plant capacity.

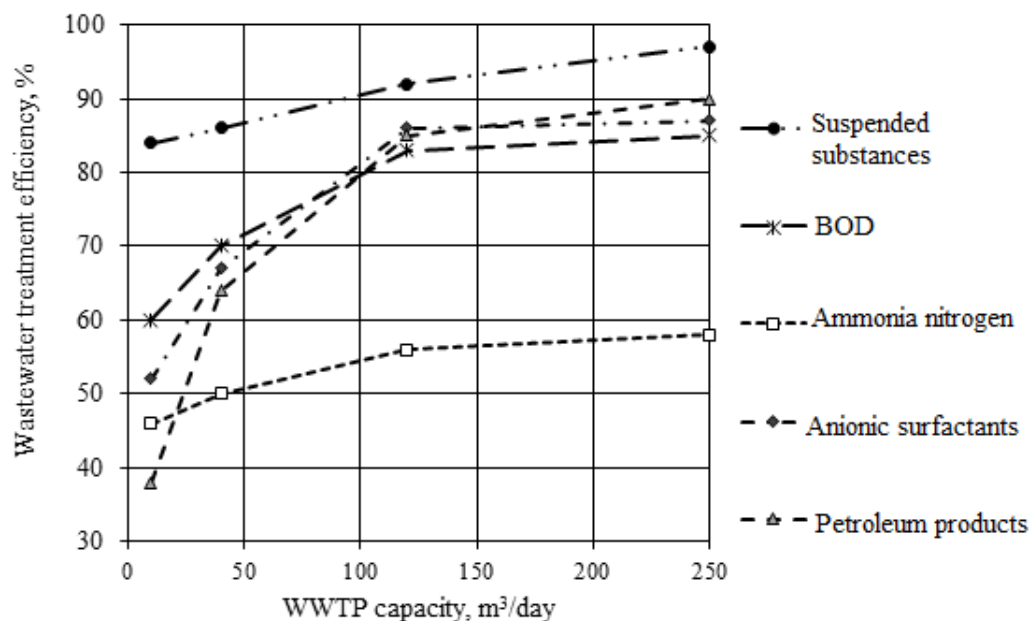


Figure 3. Efficiency of domestic wastewater treatment depending on the capacity of the treatment plant.

Process schemes of small wastewater treatment plants of the first generation were a repetition of household wastewater treatment schemes in conventional settlements: the initial wastewater goes successively to: rough water treatment facilities (coarse screens and grit chambers), biological treatment facilities (aerotanks), facilities for separating excess active sludge. Most schemes lack primary settling tanks since the high removal efficiency of suspended solids and, consequently, part of BOD can lead to inadequate organic feeding of bacteria-denitrifiers which remove nitrogen. In

construction regulations, installation of primary settling tanks is recommended at a capacity of 1000 m³/day and above.

The introduction of chemical plants and the feeding of a coagulant to intensify the process of separation of the sludge mixture into some schemes usually excluded the return of active sludge to the aerotank. Treated wastewater after disinfection, as a rule by ultraviolet irradiation, is discharged into a water body. Sludge pads were used to dehydrate the excess active sludge. When such schemes were developed, the following factors were not taken into account: increased concentrations of contaminants in small amounts of effluents, the presence of man-made pollution in domestic wastewater, and a decrease in the temperature of wastewater in winter. A consequence of this was the low efficiency of treatment facilities. [11]

The requirements for the degree of wastewater treatment of rotators' camps led to the inclusion of post-treatment facilities in the process schemes - a second stage of biological treatment or clarifying filters with quartz sand. As the experience of operating plants designed and built using a similar scheme showed, the efficiency of the facilities also depends significantly on the quality of the incoming wastewater and temperature in the biological treatment sections.

The development of next-generation process schemes goes along the path of improving biological treatment facilities, in particular, nitrification and denitrification zones. The constant tightening of the requirements for treated wastewater discharged to water brings about more complex post-treatment facilities. At present, post-treatment of wastewater has become a multi-stage process, which includes a sorption filter in addition to the usual granular filter. In a number of schemes, a membrane bioreactor (MBR) is proposed instead of a conventional secondary settler (Figure 4). [19, 22, 26]

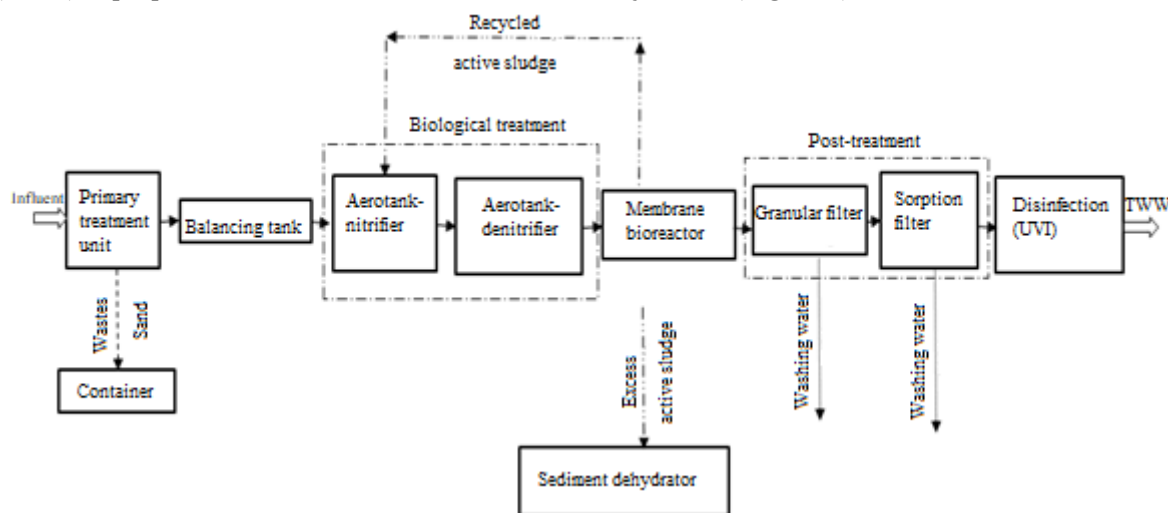


Figure 4. Process scheme of small wastewater treatment facilities with a membrane bioreactor.

Sequencing batch bioreactors (SBR-reactors) are of interest, but little used in Russia. Due to the sequencing process of biological treatment, this plant is virtually not affected by significant fluctuations in the volumes of wastewater entering the treatment facility, the composition and concentrations of pollutants. Over the last 15 years wastewater treatment technologies with SBR-reactors have been widely used in Eastern and Central European countries to modernize existing treatment facilities [20, 21, 27-29]. Along with the construction of new wastewater treatment technologies with SBR-reactors, it is possible to use existing tank facilities as SBR-reactors, such as wastewater pumping stations, settling tanks, aerotanks and other facilities. Evidently, this is the main advantage of such wastewater treatment facilities, especially in the conditions of seasonal fluctuations in the operation of rotators' camps. Taking into account the quality of the incoming wastewater from septic tank of rotators' camps and the possibility of automated process control, SBR-reactors deserve more attention of designers and developers of the infrastructure of oil and gas fields (Figures 5 and 6). [11, 27-29]

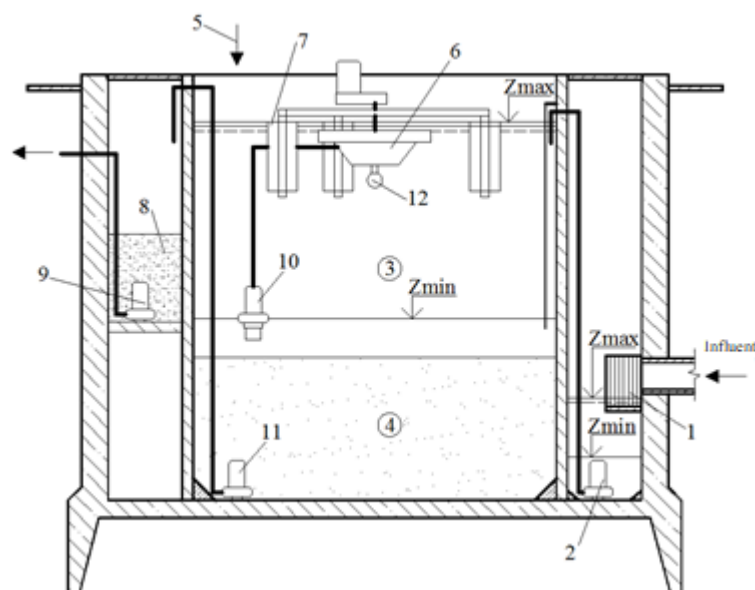


Figure 5. Transforming the existing wastewater pumping station into the SBR-technology system: 1 - screen-container; 2 - submersible wastewater pump; 3 - treated wastewater; 4 - active sludge; 5 - input of flocculant; 6 - floating turbo-aerator; 7 - pontoon blocks; 8 - settled sludge; 9 - wastewater sludge pump; 10 - decanter; 11 - excess active sludge pump; 12 - treated wastewater discharge.

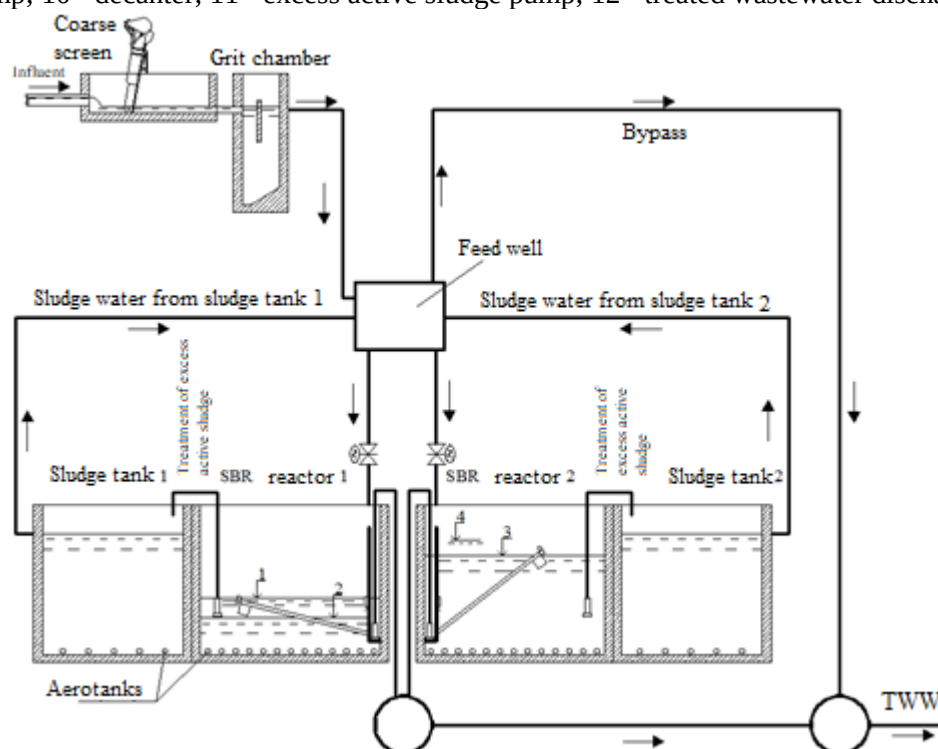


Figure 6. Process scheme of WWTPs with the Flexidiblok SBR-reactor [21]: 1- active sludge level, 2 - minimum water level, 3 - maximum water level, 4 - denitrification level

Small settlements, such as villages, urban-type settlements and rotators' camps of industrial enterprises, produce small amounts of wastewater sludge. However, this type of waste is produced daily, almost not processed properly, accumulates, and, eventually, the problem of disposal of municipal waste arises. It is especially difficult to solve this issue in winter at plants located in the Tyumen North.

Currently, there is no organization in the country that is responsible for waste disposal in the regions; there is no statistical recording of the amount of generated municipal wastewater sludge. Replacement of obsolete equipment and abandonment of low-efficiency methods of sludge processing and disposal is slow.

The amount of sludge formed depends mainly on the treatment plant's capacity (Table 4). Evidently, the greater the amount of wastewater treated, the greater the amount of sludge. However, the cost of processing 1 m³ of water and, accordingly, the sludge for small and medium-sized plants is much higher than for plants with a capacity of more than 50,000 m³/day (Figure 7).

On the example of four operating small wastewater treatment plants of different capacities, it is possible to compare all types of waste for each facility. The results are shown in Table 5.

Table 4. Amount of wastewater sludge formed in settlements.

Settlement type	Capacity of WWTP, thousand m ³ /day	Amount of wastewater sludge, m ³ /day	Amount of wastewater sludge, thousand tons/year
Rotators' camps with a population of 100-500 people.	0.01-0.25	0.1-1	0.04-0.4
Settlements with a population of 1000-5000 people.	0.4-1	2-10	0.7-3.7

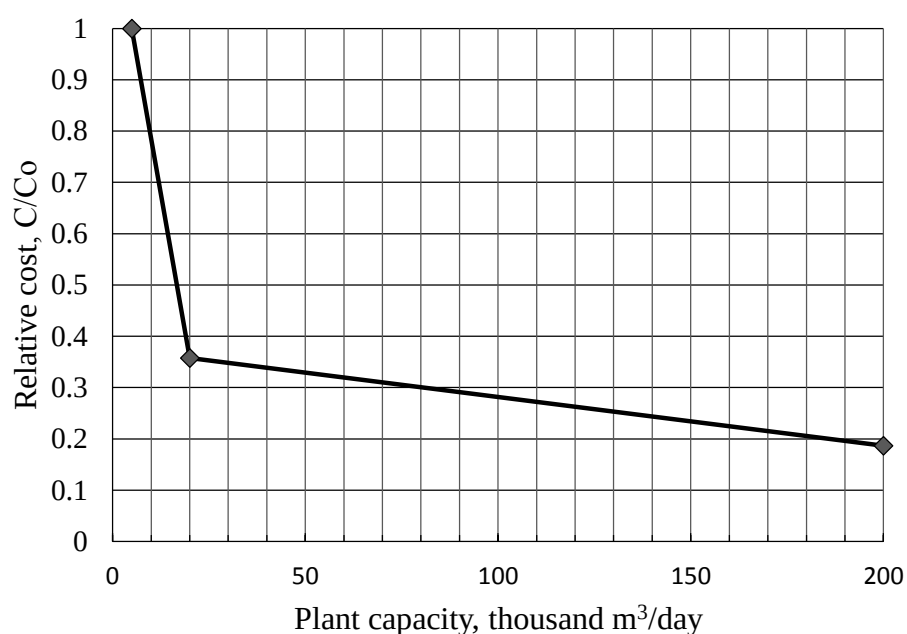


Figure 7. Dynamics of the wastewater sludge treatment cost reduction with an increasing plant capacity.

Table 5. Amount of waste collected and residue accumulated from rotator's camps in oil fields.

Waste type	Plant capacity for wastewater of rotators' camps, m ³ /day			
	20	40	110	150

Wastes, $\frac{m^3 / day}{m^3 / year}$	$\frac{0,0028}{0,52}$	$\frac{0,0059}{1,08}$	$\frac{0,008}{2,96}$	$\frac{0,011}{4,0}$
Sediment (including sand) $\frac{m^3 / day}{m^3 / year}$	$\frac{0,0013}{0,47}$	$\frac{0,0027}{1,0}$	$\frac{0,007}{2,7}$	$\frac{0,01}{3,65}$
Sludge, $\frac{m^3 / day}{m^3 / year}$	$\frac{1,23}{448,95}$	$\frac{3,12}{1138,8}$	$\frac{6,83}{2493}$	$\frac{9,32}{3402}$

For wastewater treatment plants of low capacity, the following process scheme is used:

- 1) Waste that are retained on screens, as they accumulate, are transported to a landfill site or disposed of (usually by incineration).
- 2) Sediment from grit chambers accumulated in sink-water traps is taken to a landfill site at least twice a year.
- 3) Excess sludge formed in the process of complete biological treatment, after preliminary dewatering to 80% humidity with the use of flocculent (filter bags) is transported to a landfill site or disposed of (usually by incineration).

The advantage of this process scheme is that the sediment dewatered in bags is almost immediately ready to be taken away and disposed of. Disadvantages are the following: no disinfection of sediments (excluding the incineration option), large expenditures on consumables and reagents (filter bags, flocculants). In this case, no useful disposal of the municipal waste is envisaged.

There are plants the process scheme of which provides for the treatment of sediments and includes aerobic stabilizers, dehydration, accumulation and disposal.

In this case, there is a system for supplying compressed air to the aerobic stabilizer. The sediment treatment time by air is from 8 to 24 hours, the temperature is from 8°C to 35°C. The main advantage of this scheme is that expensive reagents are not used. In this case, there is also no disinfection of sediments. And at the same time there are additional costs for the supply of compressed air. As a result, such sediments are also disposed of at the landfill site.

On sites of wastewater treatment plants, it is necessary to allocate a place for temporary storage of dewatered sludge (by the volume of accumulation for 6 months). In the event of failure of the equipment for mechanical dewatering, excess active sludge is supplied to the emergency tank. The volume of the emergency tank should not be less than the volume of wet excess active sludge accumulated per month.

The sediment formed after settling the washing water of the post-treatment filters is sent to dewatering together with excess sludge or accumulated in a special tank and, if necessary, transported to a landfill site. Dewatered sediments are classified as Hazard Class IV and are subject to recycling or disposal.

4. Conclusions.

A comparative technological and technical-economic analysis of wastewater treatment plants of rotators' camps of oil and gas fields and other settlements of the Tyumen region was carried out. Based on the results obtained, it can be concluded that the technologies used for treatment and disposal of domestic wastewater of rotators' camps of oil and gas fields are inefficient and uneconomic. In order to increase the efficiency of small WWTPs and reduce costs, it is necessary to apply new technological solutions and methods for treating wastewater and processing the generated waste.

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