Treatment of Wastewater of Small Sewerage Facilities

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Abstract. The complexity of treating wastewater of small sewerage facilities lies in the small volumes of treated water, considerable irregularity of their inflow to treatment facilities, inhomogeneity of their composition by hours of inflow to treatment facilities, as well as high requirements for treated wastewater discharged usually into low-power water bodies or to the surface. The treatment facilities should exercise the functions of purifying wastewater from pollutants according to regulatory requirements. A sewerage system and wastewater treatment technology have been considered by the example of the town of Fort-Shevchenko. A technology for purifying similar wastewaters using clarifiers with a sludge blanket formed by activated sludge flakes has been proposed. This technology has been introduced at several treatment facilities in the East Kazakhstan region that are successfully operating in compliance with the technical and engineering operation requirements. The treated wastewater quality indicators are given.

1. Introduction
Currently, along with the increasing requirements for ensuring comfortable conditions and a high level of life quality outside the megacities, striving to create full-fledged living conditions in rural settlements, country houses, and recreation centers is quite natural since the level of environmental pollution by human wastes reaches sometimes critical values.

There are 59 towns in Kazakhstan, the population of which does not exceed 50 thousand people. These towns are officially called small. Of these, 41 small towns are the administrative center of the appropriate regions, which makes 68 and 25 % of the small town and rural region numbers, respectively.

By geographical location, the following town types can be distinguished:
1) settlements located in the agglomeration influence zone – Akkol, Alga, Kandyagash, Esik, Kapshagay, Kaskelen, Talgar, Lenger,

2) settlements located along the highways and railways of republican and international importance – Akkol, Atdasar, Ereymentau, Esil, Makinsk, Shchuchinsk, Alga, Kandyagash, Shalkar, Zharkent, Kapshagay, Kaskelen, Sorkand, Ayagoz, Shu, Priozersk, Aralsk, Emba, Usharal, Ushtobe, Zaaysan, Shar, Shemenoiakha, Arys, Saryagash, Bulaev, Mamlyutka, Tayinsha,

3) settlements located in the border areas – Zharkent, Usharal, Zaaysan, Saryagash, Shardara, Shar, Shenonaiakha, Mamlyutka, Bulaev [1].

The lack of centralized sewerage systems and treatment plants for small sewerage facilities leads to pollution of surface water bodies, soil, water horizons, and ecosystem imbalance. However, with a competent, responsible approach, the dissonance between the growing needs of people and the negative impact on the environment is quite solvable.

2. Relevance and scientific importance of the issue
With the growing construction of small sewerage facilities, e.g., small enterprises, recreation centers, cottages, and small settlements, the need for sewerage systems with wastewater treatment and discharge into surface water bodies or to the surface increases. Therefore, issues related to the sewerage of small settlements and the ineffective operation of small wastewater treatment plants attract the attention of water management experts in different countries [2-4].

At all stages of design, construction, and further operation of small facilities, the entire range of engineering support issues should be considered, including the arrangement of water supply and sewerage systems. Often, under the small settlement development programs, the drinking water provision issues are only solved by arranging centralized water supply systems. The issue of arranging centralized sewerage systems is sometimes not solved. Buildings, where water is supplied, are equipped with septic systems or wastewater receiving tanks, from which they are removed by specialized trucks to treatment plants as accumulate.

Among the main reasons for the ineffective operation of small sewage treatment plants, uneven discharge of wastewater (volley) and their unstable composition can be distinguished [5, 6]. In this regard, special engineering solutions are required to determine the treatment techniques (mechanical and biological) and the plant composition. Biological treatment can be performed under artificial and natural conditions [7, 8]. Wastewater treatment in biological treatment facilities (nitrification) is based on the decomposition and oxidation of organic pollutants in wastewater by saprobiont microorganisms. In biological treatment technology development, the technique of aerobic treatment in aeration tanks occupies an important place. It is economically feasible to use local prefabricated structures [9].

To achieve a high quality of treated wastewater, post-treatment is required. As a rule, post-treatment on the sand on membrane filters or in lagoons is recommended [7].

3. Problem statement, research objective
The research objective is to determine the optimal process flow sheets for the treatment of wastewater from small sewerage facilities. The problems set: 1 – theoretical studies to choose the wastewater treatment process flow sheets; 2 – the analysis of the sewerage system and wastewater treatment technology on the example of the town of Fort-Shevchenko; 3 – using the available experience in the field of highly efficient wastewater treatment technologies.

4. Key research findings
One of such sewerage systems is arranged in the town of Fort-Shevchenko. Fort Shevchenko is the seventh most populous town of cultural and historical significance in the region. In 1857, it was Fort-Aleksandrovsk, after the October Revolution, it began to be called Fort-Shevchenko, and acquired the status of a town in 1928. Since 1972, it has been the center of the Tupkaragan region. It is located 130
km from the Aktau regional center. At the beginning of 2019, the town population was 6,376 people [10].

Currently, residents and small businesses use household septic systems since the town has no centralized sewerage system. Its institutions are equipped with departmental septic systems to intake wastewater. A septic system comprises several tanks connected in series, in which the effluent settles, and the anaerobic reproduction of organic matter occurs without oxygen (anaerobic conditions). Wastewater is pumped out of septic systems by special sewage cesspool tank trucks as they are filled and transported to the existing wastewater treatment plants (WWTP) with a capacity of 400 m$^3$/day (Fig. 1).

The trucks discharge wastewater into a 150 m$^3$ receiving septic tank. Before being discharged into the septic tank, wastewater flows through an inclined grate with manual treatment. Waste detained on the grates is collected in a container, neutralized, and stored at the waste storage site. Wastewater from the septic tank is pumped through the pressure supply pipeline into the settling part of a tangential degritter (2 pcs). Grit dewatering bays on an artificial concrete base with an asphalt coating are located under the degritters and have a bottom slope towards the drainage pit fed with drain mix. Drainage water from the grit dewatering bay is fed to the sewerage pumping station SPS No. 4. The existing two grit dewatering bays are capable of passing a wastewater flow of 400 m$^3$/day without deviations from the rated water velocity limits (0.15-0.3 m/s). At these velocities, the wastewater will stay in the grit dewatering bay during the recommended 30-60 seconds, which will ensure the required mineral particle detention effect. Actually, the alternating wastewater supply by pumps of the SPS No. 1 does not allow meeting the required wastewater velocity limit of 0.15-0.3 m/s in the grit dewatering bay, which in turn leads to a deterioration of biological wastewater treatment in aeration tanks due to the increased transfer of the mineral contaminants from the grit dewatering bay into the aeration tanks. Such a situation is often observed at other wastewater treatment plants.

After the sand traps, the wastewater enters an aeration tank – a settling tank. This is a compact unit designed for complete biological treatment of domestic wastewater by aeration with aerobic stabilization of activated sludge. Wastewater flows into the aeration zone quite unevenly during the day, and at night, the flow stops at all. Such a wastewater intake mode negatively affects the biological

Figure 1. Overview of the Fort Shevchenko WWTP.
treatment facility operation. Despite the achieved treatment effect in terms of BOD$_{ult}$ due to a sufficient aeration tank capacity, the activated sludge biocenosis is poor since the amount of nutrients required for the vital activity of microorganisms in the wastewater inflow is insignificant, and wastewater is supplied with long interruptions. For effective aerobic biological treatment of household wastewater contaminated with biodegradable organic compounds, according to p. 9.3.1.3 [11], the content of biogenic elements should be at least 5.0 mg/L nitrogen N and 1.0 mg/L phosphorus P per 100 mg/L BOD$_{ult}$ with short breaks in the wastewater supply. Also, such a wastewater inflow mode does not ensure sufficient activated sludge growth, and, therefore, the biological treatment effect is not provided. Herewith, the constant supply of compressed air to the aeration tank in the absence of wastewater supply causes strong oxidation of activated sludge microorganisms, which affects their condition and the inability to participate in biological treatment to the full extent.

Several prefabricated (compact, modular) plants designed for the complete biological treatment of domestic wastewater have been developed to treat small wastewater flows [9]. The advantages of prefabricated treatment facilities include relatively small size, high operational reliability, and quick installation. In [12], the authors propose modular treatment facilities in combination with a reagent for deeper wastewater treatment. In [13], the author notes that biological treatment is an environmentally friendly and effective way to remove organic contaminants, despite the development of other technologies.

At the Fort-Shevchenko treatment plant, two compact KU-200 plants are installed with a capacity of 200 m$^3$/day each. The compact plant is a tank consisting of three zones: an aeration tank (nitrifier), a 6-hopper settling tank, and an anaerobic mineralizer (Fig. 2). Optimal conditions for the most efficient life of microorganisms are created in aeration tanks. Organic pollution in the form of a fine suspension in a colloidal state and solution is removed from wastewater in the course of biochemical processes initiated by a complex (biocenosis) of microorganisms (activated sludge) in aeration tanks. Organic acids, alcohols, proteins, carbohydrates, mineral salts, etc. are used by bacteria to obtain carbon, nitrogen, phosphorus, potassium, etc. to build their body, as a result of which the activated sludge grows [14].

![Figure 2. Photo of a Compact Plant.](image)

To respire, the activated sludge microorganisms use atmospheric oxygen, which is consumed for the oxidation and mineralization of organic matter. Compressed air is supplied to the aeration tanks and mineralizer by gas blowers.
The intensity of biochemical processes depends on several factors: temperature, solar radiation, oxygen supply, biocenosis composition, the presence of nutrients and toxic substances, etc. From the aeration zone, wastewater with an activated mixed liquor is fed through the slots in the aeration tank wall to the settling zone – the hoppers, where the activated sludge is separated from the wastewater. The activated sludge flakes settle to the bottom, and the treated wastewater rises upward, flows over triangular weirs into collecting gutters, and is discharged from the plant through a drainage pipe to post-treatment. Part of the activated sludge after settling is returned to the aeration tanks (return sludge) using airlifts, and the other part equal to its growth in the aeration tanks (excess sludge) is fed to the aerobic mineralizer. Mineralized activated sludge from the mineralizer should be regularly (approximately once per 10 days) removed through the outlet pipe located in the lower zone to the sludge drying beds.

Since at this plant, as at most other treatment plants, the concentration of suspended solids at the secondary settling tank outlets reaches 25-30 mg/L or more than 15 mg/L by BOD₅, the treatment effect is within 40-56 %. Such water clarification indicators do not meet the current requirements for water discharge, which requires post-treatment of water after secondary settling tanks.

At this plant, after the biological treatment unit, wastewater flows through a 150 mm diameter gravity pipeline to the receiving tank of SNS No. 2, where submersible pumps are installed, supplying water to filtration (post-treatment) on clarifying (mechanical) filters to remove activated sludge flakes from the water. Water is supplied under a pressure of up to 0.4 MPa to the filter through the upper water distribution system and flows through a layer of granular filtering material from top to bottom. Filters are placed in an insulated container.

Upon the filtration cycle completion (recorded by up to 0.5 atm pressure difference and the total amount of water treated during the filtration cycle), the filter is switched off for rinsing with clarified water flowing from bottom to top until the visible clarification of the rinsing water discharged into the drainage. The water is supplied to upwash cleaning by submersible pumps placed in a contact tank. After the upwash cleaning, water is removed outside the container to SPS No. 3 and then pumped to the sludge drying beds. After the rinsing, the filter is put into operation, while the first filtrate is discharged into the drainage (sewer) for 2 minutes, then the filter is switched to the supply of clean water.

After post-treatment, water is fed to a contact tank, where a disinfecting solution of sodium hypochlorite is supplied, obtained from technical salt by direct electrolysis on a non-flow-through electrolysis unit with titanium electrodes UOE-E-15G. The resulting sodium hypochlorite solution is pumped into the ready-made sodium hypochlorite solution collecting tanks, from where it is fed by dosing pumps to SPS No. 2 for primary disinfection and a contact tank for secondary disinfection with the provision of 30-minute contact of water with a disinfecting reagent. The electrolysis unit (module 2) is placed in an insulated container.

Wastewater is pumped from the contact tank to 8 evaporation fields (lagoons), including those for emergency discharges. Evaporation fields are designed and built with an anti-filtration screen made of polyethylene film. Lagoons Nos. 1, 2, 3, 4, 5, and 6 are operating.

Two sludge drying beds are provided to dehydrate and dry sludge from SPS No. 3. The sludge drying beds are designed on an artificial base with a hard surface and tubular drainage. The working height of filling the stabilized sediment with a moisture content of 98 % is 1.0 m. The design sludge flow is 5.57 m³/day. The actual sludge flow is less than the design value due to the uneven supply of effluents to the biological treatment unit. Drainage water from the sludge drying beds is supplied to SPS No. 4 pumping drainage wastewater to the degritter.

5. Experimental research
The high water clarification effect after post-treatment filters is as follows: the concentration of suspended solids and BOD₅ is reduced to 5-8 and 8-10 mg/L, respectively. However, these structures have a complex design and a high cost of construction and operation, which significantly increases the water purification cost. Potential biological treatment with activated sludge requires further
improvement of biotechnology through the use of fundamentally new solutions. Improving the technical and economic characteristics of wastewater clarification is very promising in the field of developing technologies that make the most of the advantages of biological techniques for purifying and filtering water through a sludge blanket. A way to intensify the water clarification, i.e., separation of mixed liquor, is the use of clarifiers with sludge blankets of activated sludge flakes, which can simultaneously replace both secondary settling tanks and additional post-treatment facilities, e.g., filters.

The high water clarification effect in facilities operating based on the use of sludge blankets is achieved due to the physicochemical adhesion of microscopic particles of suspension, supplied with water to the previously formed relatively large flakes suspended in the upward flow of the treated water. Coagulation occurs when attractive forces of a molecular nature prevail between the particles. It has been established that removing suspended solids from water in a sludge blanket is based on the phenomenon of sorption of the sediment flakes on the surface while the sorption efficiency increases with an increase in the flake surface. Suspending a layer of particles in an upward flow begins after the flow velocity exceeds a certain critical value and the particles start moving, while the blanket thickness increases. In this case, the water is ‘filtered’ through the sludge blanket, being additionally purified from suspended solids. Also, when the wastewater passes through the biochemically active sludge blanket, additional oxidation of organic contaminants remaining in the water after biological treatment occurs, which allows achieving an additional effect of wastewater treatment by BOD. The flakes suspended in the flow move chaotically, but the entire layer is in a state of dynamic equilibrium due to the equality of the ascending water flow velocity and the average flake sedimentation rate. The following is typical of the clarifier operation: the concentration of activated sludge flakes in the clarifier’s sludge blanket may vary greatly with a change in the water quality (change in the content of suspended solids in the water fed into the clarifier (C_l) and its temperature). In [15], the author studied the separation of mixed liquor after aeration tanks in the sludge blanket clarifiers and found that the concentration of activated sludge in the blanket (C_{bl}) decreases with an increase in the ascending flow velocity in the blanket zone (V_{bl}) and a decrease in the concentration of the inflowing mixed liquor (C_l), and the clarifier stability improves with a decrease in the activated sludge concentration in the inflowing water (C_l). According to the author's data, the stable clarifier operation is observed when a mixed liquor with a concentration of C_l = 50-200 mg/L is fed into it. After the correlation, the dependence C_{bl} = f(V_{bl}) looks as follows (Fig. 3).

![Figure 3. Dependence of the Activated Sludge Concentration in the Blanket (S_{bl}) on the Ascending Flow Velocity in the Blanket Zone (V_{bl}).](image-url)

If the effluent with a high concentration is supplied unevenly, it is recommended to adopt a 2-stage treatment with a sludge recirculation system to eliminate the risk of sludge swelling. At the first stage, pollution by BOD and suspended solids is reduced, and in the blanket zone, denitrification occurs.
Then, the mixed liquor enters the second aeration stage, where further oxidation and nitrification of wastewater takes place, and then is fed to the second blanket stage, the denitrification zone. Such a flow sheet will ensure deep removal of nitrogen and phosphorus compounds with a purification effect of up to 90%.

The practice of sludge blanket treatment facilities, which are currently successfully operated at treatment plants of the Eastern Kazakhstan enterprises, shows a high water clarification effect, comparable to that of post-treatment on rapid sand filters, i.e., the concentration of suspended solids and BOD₅ in clarified water is within 2-6 and 5.6-8.3 mg/L, respectively [15]. The sludge blanket clarifiers at sewage treatment plants developed by the D. SerikbayevEast Kazakhstan Technical University (Ust-Kamenogorsk) are implemented at the biofiltration station of the Ust-Kamenogorsk Titanium and Magnesium Plant, Maleevsky mine of Zyryanovsky Mining and Processing Plant of Kazzinc LLP, the mine of the Ridder Mining and Concentrating Complex of Kazzinc LLP, the Bukhtarma Hydroelectric Power Plant of Kazzinc LLP, and treatment facilities of Novaya Bukhtarma settlement.

The need to build sewage treatment facilities with a capacity of 600 m³/day is determined by the increase in the total (forecasted) population of the town of Fort-Shevchenko to 10 thousand people and developing infrastructure in this town. When considering options, the technology of clarifying water in sludge blanket clarifiers can be used and recommended for other similar treatment plants.

Thus, the technology of biological treatment in combined facilities using sludge blanket clarifiers eliminates the need for post-treatment facilities, expensive in operation, in contrast to the biological treatment technology with post-treatment, while ensuring a high water purification effect. Treated wastewater can be used for irrigation of road carpets, trees, and bushes.

6. Conclusions
1. In the Republic of Kazakhstan, many rural settlements, small enterprises, and recreation centers in the areas remote from cities and other settlements require improving engineering equipment, associated with the construction of sewerage systems and treatment facilities to improve the protection of water bodies from pollution,
2. Strict requirements are imposed on the wastewater treatment quality since in most cases, they are discharged into small streams, rivers, or stagnant water bodies,
3. The engineering system of sewerage and wastewater treatment in the town of Fort-Shevchenko has been analyzed,
4. Analysis of studies under industrial conditions on the example of the operation of the East Kazakhstan household wastewater treatment facilities using sludge blanket clarifiers has shown that the concentration of suspended solids and BOD₅ in clarified water is within 2-6 and 5.6-8.3 mg/L, respectively,
5. When choosing the household wastewater treatment techniques and the composition of plants, the technologies ensuring high quality of treated water and allowing to use them to irrigate roads and green plantings (trees, shrubs) should be implemented.

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