Automated damping tank of sewage pumping stations

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Abstract. In this paper, we consider the problems of operating facilities of the wastewater system. The technical equipment of the existing sewage pumping stations on the territory of the Russian Federation was analyzed and evaluated. The analysis of the regulatory and technical documentation and environmental standards governing the procedure for the discharge of wastewater from settlements in the Soviet Union during the period 1962-1985 has been carried out, and design solutions of this period have been compared to modern environmental requirements. The factors affecting the operation of sewage equipment are determined, taking into account its design capabilities and the actual state in the development of the urban environment. The innovative solution “Automated damping tank of sewage pumping stations” is presented as an additional structure for optimizing operating modes and improving the reliability of sewage pumping stations, as well as environmental protection. The conditions for the adaptation of innovative development in the technological process of existing wastewater systems are determined.

1. Introduction

The development of urban agglomeration, industrial centers, as well as improving welfare of the population produce an increase in drinking and industrial water consumption. Spot building in the border of the settlement contributes to the formation of a significant amount of wastewater, increasing the load on the existing sewer network. The most part of the water disposal (WD) systems of Russia were built in the second half of the 20th century, while a significant part of them have lost more than half of their resources and have a high accident rate [1-8]. In addition, the spring season of melting snow and precipitation in the form of high-intensity rains, that can’t be predicted, have a significant impact on the operation of the WD system [9].

The effects of peak loads on the WD system occur in hours of maximum water consumption, which are caused by the human life cycle and technological processes of manufacturing enterprises. Given the level of comfort of modern housing, due to the quality of life of the population, it is obvious that the consumption of wastewater from the areas of residential development was significantly higher than was projected onto these territories in the second half of the 20th century [10].
Taking into account the period of mass construction and commissioning of sewage networks and facilities this country in the 60-70s of the previous century, we can conclude that the parameters of the WD system are inconsistent with current loads nowadays [11-12].

Separately, we should consider the influence of weather conditions on the operational capabilities of WD systems. The most tangible destabilizing factors are torrential rains and spring thawed snow. Surface runoff infiltrates into areas of the upper reaches of the WD basin through unsealed sewer manhole covers and creates a significant expense in prefabricated gravity collectors of the WD economic and domestic system.

Analyzing technical regulations for the construction of external sewer networks and structures for the period of 1962-1986 [13-16] it should be noted that before 1986, the sewage pumping station (SPS) in Russia was equipped with emergency releases to water bodies. Thus, we can conclude that a significant part of the country's wastewater pumping stations have technical equipment that does not meet contemporary environmental requirements.

2. Methods

Modern conditions for the development of urban planning, as well as changes in environmental requirements, determine the feasibility of increasing throughput and optimizing technological regimes in the existing sewer network, namely:

- reduction of the amplitude of fluctuations in the flow of wastewater in conditions of daily irregularity;
- optimization of operating modes and improving the reliability of the SPS;
- prevention of emergency discharge of wastewater from facilities of the WD system.

It is obvious that in order to perform the tasks presented, it is necessary to re-equip individual sections of sewage networks, as well as to apply new technical solutions in sewage systems implemented in the design of pumping stations, such as:

- availability of a reservoir for receiving a regulated or emergency volume of wastewater from the sewer network or structure in gravity mode without the use of pumping equipment;
- the ability of the tank to empty the contents into the network or object in gravity mode with preservation of the conditions ensuring the prevention of bottom sediments without the use of pumping equipment;
- design of the tank should ensure its application within the boundaries of roads for various purposes with minimal restrictions of location in the plan;
- the functioning of the reservoir in the composition of the system should include hardware control in automatic mode, fully or partially limiting the presence of a person.

In order to improve the environmental safety and efficiency of the WD system, OJSC Mosvodokanal developed technical requirements for the use of emergency control tanks (ECT), which reduce the irregularity coefficient by regulating wastewater in the WD pool, and also accumulate them in an accident [17-21].

Today, on the basis of the department of engineering communications and life support systems of Irkutsk National Research Technical University, the device called “Automated damper tank of sewage pumping stations” (ADT) has been developed (Figure 1) [22].

The device is designed to dampen fluctuations in the flow of wastewater and accumulate it when an emergency stops pumps. It provides:

- automation of the process of distribution of excessive and emergency volumes of wastewater;
- the possibility of placing a damper collector within the boundaries of the road; with the binding of its geometric parameters to the terrain [22].
Figure 1. The longitudinal profile of the automated damper tank of sewage pumping stations:  
Θ - electric shut-off valves; LS - water level sensor; 1 - separation chamber; 2 - bypass gravity pipeline; 3 - lattices; 4 - gravity bypass pipeline; 5 - manhole; 6 - damping collector; 7 - receiving chamber of damping collector; 8 - waste gravity pipeline; 9 - flow meter; 10 - pressure pipe.

The principle of operation of the device is based on the action of gravity forces and the laws of fluid motion, and therefore, its functionality must be determined by mathematical modeling and analytical method of research. The operating parameters of the device should provide the reverse movement of the required volume of liquid due to its own kinetic energy without additional costs. The integration of ADTs into the existing WD system is based on a detailed study of the actual and expected conditions forming the environment for its operation.

Given that the exact time of the accident, and, consequently, the flow of waste transported in the hydraulic line cannot be foreseen, an estimate of the volume of emergency inflow can be represented as the standard deviation $\sigma$, defined as the square root of the random value variance:

$$\sigma = \sqrt{\frac{1}{n-1} \sum_{i=1}^{n} (x_i - \mu)^2},$$

(1)

In this case, the normal distribution of the standard deviation as a measure of the dispersion of a random variable relative to its expectation [23] is:

$$\mu = \frac{1}{n} \sum_{i=1}^{n} x_i,$$

(2)

where $\mu$ – estimation of expected value; $x_i$ – $i$-th selection element; $n$ – sample size.

3. Results
The inflow of domestic wastewater to the SPS during the period of the accident at the pressure section of the sewer network was modeled on the basis of the actual data of the WD basin of Berezovoy district in the city of Irkutsk [10] (Table 1).
Table 1. Estimated values based on actual performance.

| Hours of the day | Daily inequality % | Flow, Q_{hour} m³/hour | Inflow at a 6-hour accident, V₆ m³ | Inflow at a permissible 30% reduction in supply, V_{reg} m³ | Dispersion of squared deviations |
|------------------|---------------------|------------------------|----------------------------------|------------------------------------------------|-----------------------------|
| 00-01            | 1.6                 | 24.0                   | 157.5                            | 110.25                                      | 23170.9                    |
| 01-02            | 1.3                 | 19.5                   | 216.0                            | 151.20                                      | 12381.0                    |
| 02-03            | 1.3                 | 19.5                   | 298.5                            | 208.95                                      | 2864.4                     |
| 03-04            | 1.3                 | 19.5                   | 384.0                            | 268.80                                      | 40.1                       |
| 04-05            | 1.5                 | 22.5                   | 459.0                            | 321.30                                      | 3461.0                     |
| 05-06            | 3.5                 | 52.5                   | 513.0                            | 359.10                                      | 9337.4                     |
| 06-07            | 5.5                 | 82.5                   | 523.0                            | 366.10                                      | 10739.2                    |
| 07-08            | 6.8                 | 102.0                  | 493.0                            | 345.10                                      | 6827.7                     |
| 08-09            | 7.0                 | 105.0                  | 436.5                            | 305.55                                      | 1855.9                     |
| 09-10            | 6.3                 | 94.5                   | 379.5                            | 265.65                                      | 10.1                       |
| 10-11            | 5.1                 | 76.5                   | 337.5                            | 236.25                                      | 687.5                      |
| 11-12            | 4.2                 | 63.0                   | 325.5                            | 227.85                                      | 1198.5                     |
| 12-13            | 3.5                 | 52.5                   | 345.0                            | 241.50                                      | 439.7                      |
| 13-14            | 3.0                 | 45.0                   | 388.5                            | 271.95                                      | 89.9                       |
| 14-15            | 3.2                 | 48.0                   | 448.5                            | 313.95                                      | 2650.2                     |
| 15-16            | 3.5                 | 52.5                   | 513.0                            | 359.10                                      | 9337.4                     |
| 16-17            | 4.3                 | 64.5                   | 544.5                            | 381.15                                      | 14084.9                    |
| 17-18            | 5.5                 | 82.5                   | 532.5                            | 372.75                                      | 12161.7                    |
| 18-19            | 6.4                 | 96.0                   | 474.0                            | 331.80                                      | 4806.6                     |
| 19-20            | 7.0                 | 105.0                  | 402.0                            | 281.40                                      | 358.3                      |
| 20-21            | 7.5                 | 112.5                  | 316.5                            | 221.55                                      | 1674.4                     |
| 21-22            | 5.6                 | 84.0                   | 223.5                            | 156.45                                      | 11240.2                    |
| 22-23            | 3.5                 | 52.5                   | 159.0                            | 111.30                                      | 22852.4                    |
| 23-24            | 1.6                 | 24.0                   | 129.0                            | 90.30                                       | 29642.5                    |
| **Total**        | **100**             | **1500.0**             | **8999.0**                       | **6299.30**                                  | **181912.0**               |

In this case, the density function of the normal distribution [23] is:

\[
f(x) = \frac{1}{\sigma \sqrt{2\pi}} \exp \left[ -\frac{(x-\mu)^2}{2\sigma^2} \right];
\]  

(3)

Thus, on the basis of the 3-sigmas rule, the volume of wastewater, m³ from the object under study, lies in the range of values \( \mu = 262.5 \) m³ and \( 1\sigma = 87.1 \) m³ in the 6-hour time interval during an accident at the pressure section of the sewer line [22] taking into account the permissible 30% reduction in water supply to consumers for household needs. Where the value of the signs of the general population fluctuates from the arithmetic mean ± 3 \( \sigma \).

Therefore, the determination of the capacity of the damper tank – \( V_p \) m³, is:

\[
V_p = \frac{1}{2}(V_e + V_{\text{rim}}) - V_{\text{sc}},
\]

(4)

where \( V_e \) – emergency volume of wastewater (the maximum value is taken \( \mu + 1\sigma \)), m³; \( V_{\text{rim}} \) – the volume of rainwater, m³, entering a separate household sewage system through manholes during the period of precipitation intensity, while excluding the flow from storm water inlets, is defined as:
\[ V_{\text{atm}} = \frac{N_s \cdot t_{20} \cdot Q_{\text{inf}}}{P}, \]

where \( N_s \) – number of sewer wells within the basin of WD; \( t_{20} \) – rain time at maximum intensity 20 min; \( Q_{\text{inf}} \) – water consumption, m³/s, formed exclusively by infiltration through the gap between the blind cover and the sewer manhole case, is determined according to [24]:

\[ Q_{\text{inf}} = \frac{2\mu b}{3g} \left( H_2^{3/2} - H_1^{3/2} \right) \]

where \( \mu \) – for most cases, the outflow of water from round and other forms of holes is taken 0.6; \( b \) – horizontal cross-section hole; \( H_2 \) – the pressure in the lower part of the holes, m, is defined as follows:

\[ H_2 = \frac{q_{20} \cdot 1200}{10000}, \]

where \( q_{20} \) – rain intensity for a given area, m³/s on 1 hectare; \( H_1 \) – the pressure in the upper part of the holes, m, is defined as follows:

\[ H_1 = H_2 - h_s, \]

where \( h_s \) – vertical section of a rectangular hole [33]; \( P \) – intense rainfall probability coefficient, is defined as:

\[ P = \frac{m_i}{\sum_{i=1}^{M_i}}, \]

where \( m_i \) – average amount of rain per year; \( M \) – number of days in a month.

\( V_{fr} \) – the accumulating volume of the gravity sewer network, m³, the calculation of which is determined from the free volume of the working part of the manholes, has the following form:

\[ V_{fr} = \sum N_{sw} \cdot (D_{sw} \cdot H_{sw}), \]

where \( N_{sw} \) – number of sewer wells within the basin of WD; \( D_{sw} \) – sewer diameter, m; \( H_{sw} \) – the height of the sewer well, m, is defined as:

\[ H_{sw} = h_0 + h_{des}, \]

where \( h_0 \) – mark of the tray of the sewer well, m, taken from the conditions of:

\[ h_0 < \left( h_{\text{des.min}} - 0.5 - 1.8 \right), \]

where \( h_{\text{des.min}} \) – minimum design mark of the ground, m, of the manhole of the gravity sewer network; \( h_{\text{des}} \) – design elevation of the ground, m, of the manhole of the gravity sewer network (the maximum level for the estimated filling of the free network capacity is taken below 0.5 m from the edge of the manhole of the viewing sewer well located within the smallest horizontal marks).

The algorithm for calculating the emergency volume of domestic wastewater and the influence of precipitation on it is based on the results of the research [10,25,26].

4. Conclusion
As a result of the studies carried out with regard to accidents at sewage pumping stations, problems of the operation of objects of the WD system were considered. The technical equipment of the existing sewage pumping stations on the territory of the Russian Federation was analyzed and evaluated. The conditions of the impact of external factors on the work of the sewer system were considered. An innovative solution was presented: “Automated damping tank of sewage pumping stations”, as an additional construction of a pumping station. An algorithm was compiled in the system for calculating the emergency volume of domestic wastewater and the influence of precipitation on the basis of a structural plan for determining the conditions for introducing ADTs. The dependence of the reservoir calculation on the basis of the probabilistic approach (the 3-sigmas rule) has been determined; a graph of the square deviation distribution on the results of the research has been built, which allows to determine the main operating parameter of the environmental protection facility.

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