Liquid and gas flow in the sewer network in the city of Perm

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Abstract. The article describes the reasons for the formation of odors near the drainage system. The data on monitoring the section of the main unloading sewer in the city of Perm are presented. During the monitoring period, the samples of wastewater, atmospheric air quality have been taken, directly at the very point and at the border of the established sanitary protection zone (hereinafter referred to as the SPZ) or at the border of the nearest residential development (more than 30 m from the research point); in some points, the volume of the gas-air medium and the speed of gas movement in the sewer have been measured. Based on the studies carried out, the network parameters influencing the direction of gas movement have been determined. The calculation of the gaseous medium in the gravity reservoir under the influence of the entraining ability of the liquid and natural draft has been carried out. A gravity section has been taken for the calculation, located after the pressure head with the greatest length. Based on the results of the calculations, proposals are presented to change the direction of the gas-air medium, along with the direction of the wastewater flow.

1. Introduction

The provision of social and welfare services is one of the important conditions for the life support of the population. The sewerage system plays a special role in it, which transports wastewater from the population to the treatment plant. The sewerage system consists of house risers, intra-yard networks, intra-quarter networks and the main sewer collector of the city, transporting liquid to pumping stations and further for cleaning.

With an increase in the population and the volume of new houses being commissioned, the load on the sewer network increases, which affects the technical condition of the pipelines, the reliability of the system and the composition of the transported wastewater.

The transportation of wastewater is accompanied by biochemical processes that negatively affect the material of the pipelines and contribute to their destruction. The cause of the destruction of sewers is biocorrosion, which contributes to the formation of odors near the drainage networks and structures, which leads to frequent accidents and negative consequences, both for the environment and for urban residents.

Biocorrosion occurs under the influence of microorganisms with the formation of by-products. The main causative agents of biocorrosion in sewers are sulfate-reducing bacteria (SRB), through which sulfates (H2SO4) and sulfites (H2SO3) are reduced to hydrogen sulfide (H2S) and sulfides (sulfur compounds of metals and semimetals. Chemically, these are salts of hydrogen sulfide acid H2S). One part of the hydrogen sulfide is released into the atmospheric air; the other part is used by sulfur-
oxidizing bacteria to produce concentrated sulfuric acid, which directly affects the destruction of pipelines and the quality of atmospheric air near the sewer networks [1-10].

The highest release of hydrogen sulfide into the atmospheric air is observed in places where wastewater from pressure pipelines is poured into gravity sections, differential wells, and drainage points with a high temperature and a low pH value (high acidity), as well as wastewater with a high content of organic substances [11], which is due to the violation of a phase equilibrium between the gases dissolved in the waste liquid and the gaseous medium in these areas.

Large cities are more likely to face the problem of emissions of foul-smelling substances into the atmospheric air near sewer networks. To study the gas removal from the atmospheric air near the sewer networks, the main urban sewer collector in the city of Perm is considered. The route under consideration includes pressure and non-pressure sections with a total length of 10575 m. Gas exchange in the sewer collector, i.e. network ventilation, is of a practical interest.

The aim of the research is to determine the volume of the gas-air medium in the sewage system, taking into account the design features of the network laying, the hydraulic parameters of the pipelines and climatic characteristics.

2. Materials and methods

A section of the main discharge sewer collector of the city of Perm has been selected for the analysis from the RNS-1 "Yazovaya", then the SPS "Sadovaya" (sewage pumping station) and the final point - Mine No. 6 of the main discharge sewer collector. In total, 9 points have been identified on the route under analysis, at which the samples of wastewater and atmospheric air quality have been taken, directly at the very point and on the border of the established sanitary protection zone (hereinafter referred to as SPZ) or at the border of the nearest residential development (no more than 30 m from the point of analysis); at some points the volume of the gas-air medium and the speed of the gas flow in the sewer have been measured.

The studies have been carried out monthly for one day from 8:00 to 17:00 in the period from May 2019 to April 2020. An accredited laboratory of OOO Ecological Laboratory is involved to determine the qualitative composition of the gas-air environment in the sewer and atmospheric air (accreditation certificate No. ROSS RU 0001.518743); the Centre for Hygiene and Epidemiology in the Perm Region (accreditation certificate No. RA.RU.510375), OOO "NOVOGOR Priamye" (operating organization), and Perm State University have been chosen to determine the quality of transported wastewaters. The samples have been selected by the employees of NOVOGOR Priamye and the representatives of the Perm National Research Polytechnic University.

Equations 2.26-2.29 of the thesis by A.V. Malkov are taken as the basis for calculating the gaseous medium moving in a gravity sewer collector. [12].

A gravity collector after the longest pressure section with a length of 6015 m, which is characterized by an increased release of foul-smelling substances into the atmospheric air, is taken as a calculated section of the route of the main discharge sewer collector. For the calculation, the gravity section under consideration is divided into 35 sections, the end point of which is a sewer well. Each section of the gravity reservoir has excellent hydraulic parameters, due to the depth of placement and design parameters (slope, length).

The calculated data obtained have been compared with the actually measured ones and are used to justify measures to reduce the negative impact on the environment.

3. Results and negotiations

The flow of a gaseous medium in a gravity reservoir, in the under-roof space, occurs under the influence of the entrainment of the liquid and natural draft.

The flow of the gas-air medium under the force of the entraining ability of the liquid can be described by the Navier-Stokes equation [13-15]. The gas flow diagram is hyperbolic. The maximum flow rate of the gaseous medium is achieved on the pipe axis and decreases when approaching the
pipeline wall, which is due to the fluid velocity, which decreases parabolic from the longitudinal axis of the pipeline to its walls.

The movement of a gaseous medium due to natural draft occurs when there is a pressure difference between the two ends of the sewer section. The pressure difference arises due to the temperature difference between the outside air and the gas-air environment of the sewer collector and the depth of the wells (mines) at the ends of the design sections [13-19].

The gas flow rate in the underwater space of the sewer collector also depends on the filling of the pipeline, the length and slope of the section under consideration, and the dynamic viscosity of the gas.

The considered calculated gravity section of the mining complex of the city of Perm from the pressure damping chamber on the Sibirskaya street to the Mine No. 6, located on the territory of the central collective farm market, has a length of 1598 m. The depth of the collector is 2.09 - 21.89 m. The slope of the pipeline at each calculated section varies from 0.001 to 0.071.

The wastewater flow rate during the observation period varies from 551.39 l/sec. to 829.17 l/sec. on the day of sampling. June, July, January, February are the months with the lowest wastewater consumption. August, October, November, March are the months with the highest wastewater consumption.

The main parameters to choose the differential equation [12] for calculating the flow rate of the gas-air medium in the sewer collector is the filling of the pipeline and the pressure difference at the ends of the calculated segments.

When determining the pressure difference at the ends of the calculated sections of the considered gravity section of the main discharge sewer collector, it has been found that the depression of natural draft has a negative value, which is due to the terrain and the depth of the wells (Figure 1, Figure 2). The natural draft depression value ranges from 0.77 Pa to -33.3 Pa. The positive value of the natural draft depression is recorded in one area with a minimum slope in each month.

![Figure 1. Profile of the section of the main discharge sewer collector under consideration. Section 1-19.](image)
The calculation of the amount of gaseous medium in the main discharge sewer collector is carried out in the MAPL 17 software package.

According to the calculation results, the value of the amount of gas in the sewer pipeline is obtained with a minus sign, which indicates the movement of the gas-air medium against the flow of the waste liquid. An exception is 5 sections per month with a wastewater flow rate of more than 745 l/sec., a filling of more than 0.5 and a slope in the range from 0.001 to 0.003. In areas with the flow of a gaseous medium along with the waste liquid, the gas consumption under the action of the forces of entrainment is greater than the gas consumption under the influence of natural draft. In areas with the flow of a gaseous medium against the flow of wastewater, an inverse relationship is observed.

The natural draft depression in areas with the reverse return movement of the gaseous medium to the wastewater flow does not exceed 0.77 Pa and does not fall below -2.09 Pa.

It should also be noted that the most problematic points in the considered section of the main discharge sewer collector, in terms of atmospheric air pollution by foul-smelling substances, are wells with a minimum depth of 2.09 m to 2.26 m. At these points, an increased content of hydrogen sulfide is noted, which is noticeable for the city residents and causes discomfort.

4. Conclusion

Significant overpressure is created in the considered section of the main discharge sewer collector, which is due to a number of factors:

- the height of the top of the well installed on the considered section of the network. The route with wells repeats the terrain, depending on the slope of the earth's surface the slope of the sewer pipeline is adopted, which provides a counterflow of the gas medium due to an increase in pressure in each subsequent well;
- the change in the hydraulic parameters in terms of filling the sewer and changing the speed;
- a filter for air purification at the end point of the section under consideration, the resistance of which exceeds the depression created by the entraining ability of the waste fluid flow on the inflow into the mine [18, 20].

The largest amount of gas accumulates in mine 6, which is the end point in the area under consideration, which is due not only to the installation of a filter on the ventilation pipe of the cabin,
but also to the form of this mine as a drop well that collects wastewater from two directions, the total depth of which is 21.89 m. The depth of the well in front of the mine is 2.26 m and 5.6 m.

The amount of gaseous medium moving in the gravity sewer collector is in the range from 0.44 to -11.3 m$^3$/sec. The maximum values of the backflow of the gas-air medium are observed in the places where the gentle slope changes from 0.013 to 0.071, the speed increases from 2 m/sec. to 4 m/sec., and the filling of the pipeline decreases by 0.1-0.2. The value of the amount of gaseous medium moving under the action of the entraining ability of the liquid is much less than the amount of gaseous medium moving under the action of the natural draft.

In areas with a sharp change in the hydraulic and design parameters of the gravity collector, there is an increased content of hydrogen sulfide in the atmospheric air at the boundary of the sanitary protection zone (SPZ). The concentration of hydrogen sulfide reaches 0.067 mg/m$^3$ (January 2020) with a normalized maximum permissible concentration of 0.008 mg/m$^3$.

To reduce the peak emissions of an aggressive gas medium from the sewer into the atmospheric air, we need gas exchange by means of ventilation units to redistribute the gas flow. The change in the design features and hydraulic parameters is impossible due to the laying of the collector in the city.

The selection of the ventilation unit and its location will be determined by calculating the rate of gas exchange in the underflow and a mine space of the sewer network, taking into account the rate of gas removal from wastewater, based on the data of measurements of the quality of the gas-air medium in the sewer collector and the atmospheric air near the drainage network based on the permissible concentrations of foul-smelling substances and the threshold of the sensibility of foul-smelling substances by a human.

Reference

[1] Chizhik K I and Belookaya N V 2017 Model of microbiological concrete corrosion in sewage systems Izvestiya vuzov. Investments. Construction. Property 7(2) 75–83
[2] Akolzin A P and Zhukov A P 1985 Oxygen-type corrosion of power engineering equipment (Moscow: Chemistry) p 240
[3] Allen E E, Tyson G W, Whitaker R J, Detter J C, Richardson P M and Banfield J F 2007 Genome dynamics in a natural archaeal population Proc. Natl. Acad. Sci. U.S.A. 104 1883–1888. DOI:10.1073/pnas.0604851104
[4] Sokolova T S and Konovalova V D 2017 Effect of thionic bacteria on steel corrosion Bulletin of Perm National Research Polytechnic University. Chemical Technology and Biotechnology 2 7–19
[5] Rozenthal N K 2011 Corrosion and protection of concrete and reinforced concrete structures of wastewater treatment plants Concrete and reinforced concrete. Equipment, materials, technology 1 96–103
[6] Lebedeva E S, Yurchenko V A and Sverguzova S V 2014 Quantitative assessment of the influence of a temperature factor on the hydrogen sulfide accumulation in the under-roof space of the sewer collector Bulletin of Kazan National Research Technological University (Kazan: KNITU publishing office) 17(24) 141–143
[7] Kofman V Ya 2012 Hydrogen sulfide and methane in sewer networks (review) Water Supply and Sanitary Engineering 11 72–78
[8] Klyushenkova M I 2012 Environmental protection from industrial gas emissions: textbook (Moscow: MSUEE) p 141
[9] Mayorov V A 2002 Odors and their elimination in industrial gas-air emissions: Textbook (Penza: PGASA publishing office) p 131
[10] Didenko E A, Khromchenko Ya L and Svetlopolianskyi V A 2002 Influence of the composition of transported wastewater on the state of sewer pipeline systems Water Supply and Sanitary Engineering 5 33–35
[11] Vasiliev V M, Pankova G A and Stolbikhin Yu V 2013 Destruction of sewer tunnels and structures because of microbiological corrosion Water Supply and Sanitary Engineering 9 55–61

[12] Vasiliev V M 1993 The necessity to ventilate sewer collectors Underground space of the world 5-6 12–18

[13] Gaifutdinov M G 1985 Mutual flow of wastewater and gases in sewers and measures to prevent gas corrosion: thesis of a Candidate of Sciences (Engineering): 05.23.04 academic advisor N.N. Lapshov; (Leningrad: Ministry of Higher and Secondary Vocational Education of RSFSR; Leningrad Civil Engineering and Construction Institute) p 23

[14] Alshul A D, Zhivotovskiy L D and Ivanov L P 1987 Hydraulics and aerodynamics: textbook (Moscow: Stroyizdat) p 414

[15] Popov D N 1982 Non-stationary hydromechanical processes (Moscow: Mechanical Engineering) p 240

[16] Zhmakov G N 2015 Drainage networks and structures World Techniques and Technology 6(74) p 48

[17] Leybovich L I and Patsurkovskiy P A 2013 Mathematical modelling of the liquid flow in a drop moving in a gas flow Bulletin of V.I. Vernadsky Taurida National University. Series: Biology, Chemistry 26 (65) No 4 288–297

[18] Grigoriev L N and Burenina T I 2013 Principles of calculation of equipment for chemical treatment and emission neutralization: textbook (Saint Petersburg: GTU RP) p 110

[19] F Bertrán De Lis, Saracevic E and Matsché N 2007 Control of sulphide problems in pressure sewers Novotech Session 4.3 965–972

[20] Klebanov F S 1995 Air in a mine: an article on the airing of coal mines Russian Academy of Natural Sciences, Skochinsky Institute of Mining, Russian Coal Mining (Moscow: Image publishing house) p 574