Modeling of water and air operation mode of sewer pipelines

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Abstract. An approach to complex accounting of hydraulic and aerodynamic parameters of a gravity sewage pipeline for the purpose of solution of its designing and effective operation problems has been presented herein. Consideration has been made of the variants which provide the subsurface space ventilation of a gravity pipeline in presence of aggressive and fetidly smelling gases by a mechanical air exchange system. Taking into account the complexity of manual processing of mathematical dependencies that describe the operation of a gravity pipeline and the processes that take place in it, the implementation of the problem has been achieved by developing and applying a special automated calculation program. At the corresponding values of air exchange, the dynamics of harmful gaseous substances released into the subsurface space of the gravity pipeline per unit of time, as well as the duration of their removal to the maximum permissible concentrations in the surrounding air space of populated areas, have been revealed.

1. Introduction
The effectiveness of the waste liquid flow process in gravity drainage pipelines, including their high transporting capacity, shall be achieved by selecting the optimal operation parameters, among which the most important role is played by the self-cleaning rate and the filling [1, 2]. These parameters can be disrupted by negative phenomena such as blockages in the pipeline sewer system. As a rule, any violation of the hydraulic operational mode of a gravity pipeline provokes active chemical and biological processes on the walls of the pipeline. This is followed by the appearance of an unpleasant smell (for example, rotten eggs in the presence of hydrogen sulfide) that exits through the manholes of wells on the ground surface [3, 4]. Thus, gravity sewage pipelines are a source of bad-smelling odors that are formed due to various reasons [5, 6].

The transportation efficiency of two-phase flows (waste water with sand in it) can also be positively affected by such indicators of the pipeline material as its hydrophobicity, the presence of an appropriate texture of the inner surface, and other aspects [7]. The pipeline system operators are interested in reducing the number of regular pipe cleaning operations and their duration, as well as rapid localization of the pipe damage using trenchless methods [8, 9]. The defective places on the inner surface of the pipelines also serve as a source of an active manifestation of anaerobic biological processes [10].

A detailed analysis of the water and air mode of the sewage pipeline operation can contribute to the solution of some of the above problems [11, 12].

The application of an automated program to simulate the water flow in a pipeline, taking into account the ventilation of the subsurface space, enables the modeling of complex processes followed...
by the appropriate technical measures that shall be taken to provide the required hydraulic indicators of the water flow in the pipeline and recommend the air exchange parameters.

The application of a multivariate computer simulation when working with the arrays of input values (diameters, length, the pipe slope and filling with water, the material it is made of etc), as well as the account of actual hydrodynamic and other processes enable the modeling of the pipeline different states in the presence of harmful gas impurities in the space under the pipe shell[13].

It should be mentioned that the problem of fighting the gas formation in sewage pipelines has been given a great attention for a number of years, but despite many existing methods of cleaning or removing fetidly smelling gases, none of them is considered sufficient [14]. In this context, certain and very significant attention is also paid to improving the ventilation systems of gravity sewage pipelines [15].

The data, which have been obtained as a result of the automated complex operation, their analysis and systematization can contribute to efficient and timely decisions to be made for the maintenance of sewer pipelines in a proper condition. At the same time, a detailed consideration of the ongoing hydro- and aerodynamic processes, as well as their clarification, gives a wide range of opportunities to a specialist for modification of the design solutions concerning the sanitary safety of a pipeline under designing, in particular, in places of mass stay of people.

Thus, a comprehensive study of the water and air mode of a gravity pipeline operation is a valid task that contributes to improving the efficiency of operation and service works of sewage pipelines, as well as their timely reconstruction and renovation if any negative circumstances are identified.

The aim of this work is to provide a complex study of the dynamics of changes in hydraulic and aerodynamic parameters of a gravity sewage pipeline to solve the problems of its safe and efficient use from the point of view of ecology, including an ensured sanitary safety of people in urban areas near the public event places.

2. Methods

The goal of the intended target has been considered as creation of an automated program of the gravity pipeline hydrodynamical calculations and the analysis of the got results by the method of theoretical justification. These results should to be used for finding of the optimal operation mode of the object under investigation for provision of the appropriate ventilation measures in the pipeline subspace under its shell.

The software program has been developed on the basis of Microsoft Visual Fox Pro and enables registration, storage, editing and data processing according to the input initial items. The calculation results for the program are generated as a Microsoft Word document that includes both input and output information.

The content of this document is presented below.

Initial data:
1. Length of the pipeline section
2. Diameter of the pipeline section
3. Pipeline slope
4. Filling
5. The Chézy coefficient
6. The assigned air exchange in the pipeline system
7. The drag coefficient
8. Concentration of harmful gases in the subsurface space
9. Maximum permissible concentration of harmful substances in the city's atmosphere
10. Name of the gaseous substance
Output form:
1. Area of the pipe living section
2. Hydraulic radius
3. Water flow rate in the pipe
4. Area of the flow living section
5. Water consumption
6. Chord length of the living section
7. Area of the mirror of water in the pipeline
8. Area of subsurface air space
9. Perimeter of the subsurface air space
10. The volume of the pipeline
11. Volume of water in the pipeline
12. Volume of air in the pipe's subsurface space
13. Air depression in the subsurface space of the pipeline
14. The amount of gaseous substances released into the subsurface space, guaranteed to reduce them to the maximum permissible concentration according to the adopted air exchange
15. Total mass of gaseous substances entering the subsurface space
16. Duration of removal of gaseous substances from the subsurface space of the pipeline at the adopted air exchange

Below is a digital representation of one of the options for modeling the situation on a city gravity sewerage pipeline under the following conditions (i.e. input information initial data): the length of the design section is 200 m, the diameter of the ceramic pipeline is 0.14 m, the slope is 0.007. The air exchange in the pipeline is assumed to be equal to 0.0277 cu.m / s, the concentration of harmful gases (hydrogen sulfide) in the subsurface space of the pipeline is 4.2 mg / m³ (according to full-scale measurements), the maximum permissible concentration of harmful volatile substances (hydrogen sulfide) in the city's atmosphere is 0.008 mg/m³.

The hydraulic operation mode of gravity pipelines is considered as an unstable one and depends on the hours of the day, days of the week, season of the year, etc. This is accompanied by changes in the filling in the pipeline network, waste water rates and sewage consumption.

3. Results and discussions (interpretation of the results)

Table 1 shows the results of automated calculations of a number of hydraulic, aerodynamic and other parameters when the filling in the pipeline is changed step by step in the range from 0.3 to 0.7 and the design amount (0.0002216 mg/s) of hydrogen sulfide released into the subsurface space, when its concentration is reduced to the maximum permissible concentration at the accepted air exchange values.

| The pipeline operation parameters | Filling value |
|----------------------------------|--------------|
|                                  | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 |
| 1. Water flow rate on the design section of the pipeline, m/s | 0.67 | 0.73 | 0.77 | 0.81 | 0.84 |
| 2. Volume of air in the subsurface space of the pipeline, m³ | 2.247 | 1.903 | 1.559 | 1.215 | 0.871 |
| 3. Air medium depression in the subsurface space of the pipeline, MPa | 0.01922 | 0.03011 | 0.05186 | 0.09896 | 0.2381 |
| 4. Total mass of the gaseous substance entering the subsurface space, mg | 9.43 | 7.99 | 6.54 | 5.11 | 3.66 |
5. Duration of removal of the gaseous substance from the subsurface space of the pipeline, h

|          | 11.8 | 10.1 | 8.2 | 6.4 | 4.6 |
|----------|------|------|-----|-----|-----|

The Table 2 presents comparative calculated values for a similar case of water and air mode modeling, where the ammonia and dimethyl sulfide have been considered instead of the hydrogen sulfide with other unchanged parameters included in the initial information for the calculated section. The maximum permissible concentrations of ammonia in the city’s atmosphere are 0.04, and dimethylsulfide is 0.8 mg / m³. The printout was made for a gravity pipeline with a diameter of 0.14 m with a design filling of 0.6.

**Table 2. Parameters of the gravity pipeline operation at the design filling 0.6 in the presence of various harmful volatile substances**

| The pipeline operation parameters | Denomination of harmful volatile substances |
|-----------------------------------|--------------------------------------------|
|                                   | Dimethylsulfide | Ammonia | Hydrogen sulphide |
| 1The amount of gaseous substances released into the subsurface space per unit of time, guaranteed to be reduced up to the maximum permissible concentrations at the design air exchange, mg/s | 0.0221600 | 0.0011080 | 0.0002216 |
| 2. Duration of removal of the gaseous substance from the subsurface space of the pipeline, h | 0.1 | 1.3 | 6.4 |

It follows from table 1, each step which increases the filling value enables a higher rate at the design section (position 1), as well as the resistance (depression) to the air medium movement (position 3) due to the reduction of the air subsurface space volume. The values of the remaining parameters of the pipeline operation (items 2, 4 and 5) tend to decrease. In particular, the duration of removal of the gaseous substance from the subsurface space of the pipeline with the adopted air exchange (position 5) is sharply reduced due to a smaller air volume in the subsurface space of the pipe, as well as a smaller mass of the gaseous substance that entered the subsurface space (position 4).

It follows from table 2 that the higher the maximum permissible concentration of harmful volatile substances, the faster the process of removing them with the appropriate air exchange.

The subsurface air space of general discharge sewer pipelines abounds with harmful volatile substances [16, 17]. It is dominated by ammonia, hydrogen sulfide, formaldehyde, dimethyl sulfide, phenol, as well as a number of other volatile compounds in the form of mixtures of natural mercaptans, acetic, propionic and butyric acids. Moreover, in some situations, gases can be present simultaneously. They can be in different concentrations, depending on the quality of the wastewater composition and the efficiency of chemical and biochemical processes in them. The maximum permissible concentrations of these volatile pollutants in the air of populated areas vary greatly. In this regard, when designing a ventilation system, it is necessary to focus on the removal of the most dangerous component of volatile contaminants, taking as a basis the multiplicity of air exchange, which allows for its neutralization.

Ventilation of the sewer pipelines can be attributed to the most universal methods of removing harmful volatile impurities, since it enables the removal of all gaseous substances at the same time [18]. When selecting a ventilation facility to be installed in one of the sewer manholes provision shall be made of the design intake air consumption (i.e., the air exchange rate; in the case under
investigation it makes 0,0277 m³/s) taking into account the pressure losses (depression) in the pipeline subsurface space (in this case, 0,09896 MPa).

When designing, it is necessary to focus on the minimum filling value (in this case, 0.3). This will ensure that the entire mass of released volatile substances will be removed from the subsurface space of the pipeline to the maximum permissible concentrations in the environment air. The filling surges in the pipeline can be compensated by an effective management of the mechanical ventilation system of the subsurface space. The process can be controlled using modern automation tools, as well as periodic in-situ monitoring of changes in the concentration of harmful volatile substances in the subsurface space [19, 20].

4. Conclusion
1. To successfully solve the problems related to the designing of gravity pipelines, a particular attention should be paid to ensuring and improving the water and air mode of their operation.
2. One of the possible solutions to the problem of designing sewage pipelines, taking into account the effective prevention of fetid smell emissions on the terrain of the earth's surface, should be the modelling of water and air operation mode of gravity pipelines.
3. The most significant factors that ensure the optimal water and air operation mode of the pipeline are the consideration of the amount of gaseous substances released into the subsurface space per unit of time, guaranteed to reduce their concentrations to the maximum permissible values at the adopted air exchange, as well as the duration of a gaseous substance removal from the subsurface space of the pipeline. These parameters enable the choice of an effective ventilation system for removing fetidly smelling gases.

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