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Ways to ensure environmental standards when harmful gaseous substances are released into the atmosphere from drainage networks based on modeling their operation

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Abstract. The issues of physical and mathematical modeling of the operation of a pressure-free drainage pipeline made of polymer material and ceramics are studied in order to prevent negative environmental consequences when harmful and toxic gases are released into the atmosphere of cities from the drainage network. Studies of the dynamics of changes in hydraulic and aerodynamic parameters during the flow of liquid and gas in the subsurface space of a ceramic pipeline are presented. An algorithm for solving the problem based on the calculation of hydrodynamic similarity criteria describing the phenomena of mass transfer as a result of forced air convection by using a mechanical ventilation system of aggressive airborne droplet mass over a water surface is compiled. Based on the results of the operation of a special automated calculation program, the total mass of harmful gases released from the water into the subsurface space of the pipeline, the time of removal of hydrogen sulfide entering the subsurface space in concentrations significantly exceeding their maximum permissible values in the city atmosphere, as well as the time of removal of gaseous substances depending on the filling of water in the gravity pipeline are determined.

1 Introduction

The subsurface airspace of general floating sewer networks is replete with harmful volatile substances. 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 [1]. In some situations, gases may be present simultaneously. They can be in different concentrations, depending on the qualitative composition of wastewater 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, for example, for hydrogen sulfide they are 0.008, ammonia 0.04 and formaldehyde 0.003 mg/m3.

Foul-smelling gases accumulate in the subsurface space of the drainage network or leave it through sewer manholes, which causes a threat to the life of the urban population, possible

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collapse of structures as a result of a gas explosion in collectors, and also make a significant contribution to the formation of the greenhouse effect.

Effective elimination of odors is carried out by physico-chemical, biological, catalytic, thermal, electric discharge, construction and other methods, which, for the most part, act selectively with respect to a particular gas. Ventilation of the sewer network can be attributed to the most universal method of removing harmful odorous volatile impurities, since when it is implemented, it is possible to remove all gaseous substances simultaneously [2].

When selecting a ventilation unit, which is installed in one of the sewer manholes, it is necessary to be guided by the calculated flow rate of the supplied air (i.e., the amount of air exchange), taking into account pressure losses (depression) in the subsurface space of the pipeline. When designing, it is necessary to focus on the minimum filling value. This will guarantee the removal of the entire mass of the released volatile substances from the subsurface space of the pipeline to the maximum permissible concentrations in the surrounding airspace. Under operating conditions, it is possible to control the process of gas removal using modern automation tools, as well as periodic full-scale monitoring of changes in the concentration of harmful volatile substances in the subsurface space [3, 4].

Among a large number of methods to combat the appearance, accumulation and neutralization of aggressive foul-smelling gases in the subsurface space of gravity drainage networks, one of the ways to eliminate them are construction methods, which include ventilation of airborne droplet mass over the water mirror with its release into the city atmosphere with concentrations below the maximum permissible values in the ambient air [5-7].

2 Study methods

The research methodology is the theoretical justification of technical measures and indicators that provide the required sanitary and hygienic conditions for humans and the surrounding urban environment by neutralizing (removing) harmful foul-smelling gases and water vapor from the subsurface space of gravity pipelines [8, 9].

The object (material) of the study is a model of a gravity drainage pipeline installed in the laboratory of the Water Supply and Sanitation Department of the NRU MGSU, and the research method is the analysis of the results of an automated calculation to find the optimal mode of operation of the drainage network for the removal of gases.

The main direction of the work was the search for the value of the assigned air exchange, i.e. the selection of the amount of air required to remove foul-smelling gases and excess moisture, taking into account the heat and mass exchange between liquid and air in the drainage pipe, as well as the real time of neutralization of gaseous substances in the subsurface space.

Figure 1 shows a simplified physical model of a drainage network with a limited computational domain, and Figure 2 shows an experimental installation.

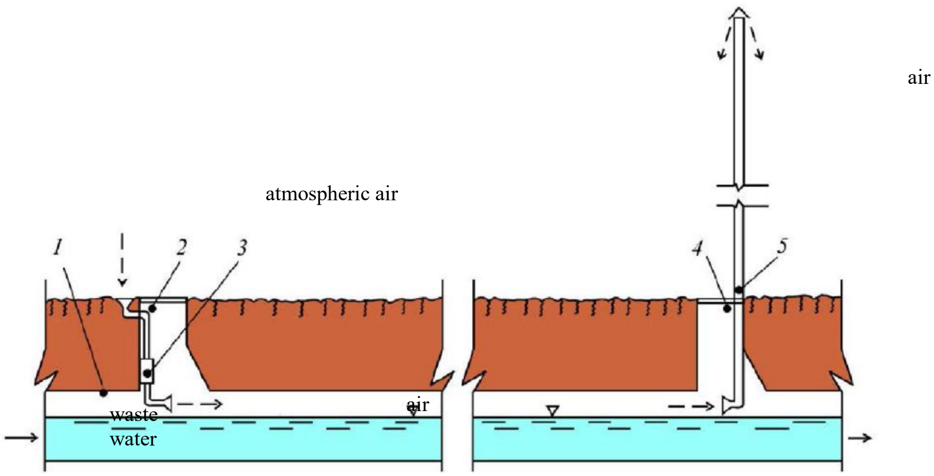

Fig. 1. General view of the model illustrating the water-air mode of operation of the drainage network: 1- a gravity pipeline laid with an appropriate slope; 2- an initial sewer well; 3- an autonomous ventilation unit with a diffuser in the direction of water flow; 4- a final sewer well; 5-a vent stack.

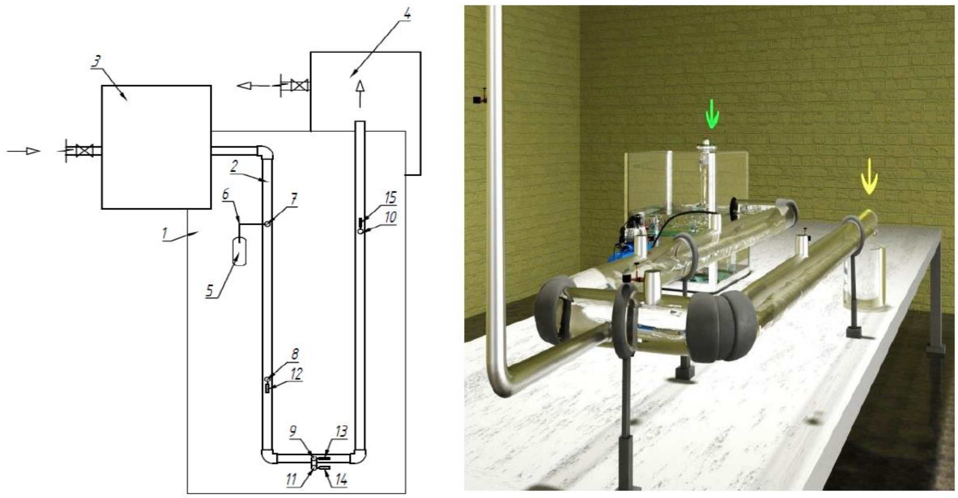

Fig. 2. Diagram of a laboratory stand for the study of the water-air mode of operation of a gravity pipeline made of polyethylene (left) and its sketch in axonometry (right): 1-table top, 2- transparent gravity pipeline with a diameter of 0.05 m, 3- storage tank, 4- receiving tank, 5- compressor, 6- air duct, 7- inspection well hatch simulator, 8-10 – technological manhole simulators, 11- stack simulator, 12-15 - stationary anemometers.

To solve the problem of modeling the water-air mode of operation of a gravity pipeline network, it is necessary to take into account the phenomena of mass transfer (gas-liquid reactions). It is very difficult to fully cover these phenomena when drawing up a model, therefore, in the course of solving the task at this stage of research, certain assumptions and simplifications were made, namely: equilibrium is observed in the system at the interface of phases (air-water). By this it can be understood that the gas released from the surface of the water mirror does not react with the transported wastewater (there is no diffusion of gases, their adsorption and chemical reactions). At the same time, the amount of air exchange should be determined to remove foul-smelling odors, as well as excess moisture entering the subsurface space of the pipeline as a result of evaporation of wastewater. The exclusion of these negative phenomena is one of the most demanded tasks in the field of wastewater transportation via gravity networks, since foul-smelling gases coming through the hatches of inspection wells reduce the comfort of people's living and harm their health, and moisture on the inner surface of pipelines, coupled with gas emissions, contributes to corrosion of pipe walls [10]. Heat and mass transfer can be carried out in two ways, due to specific conditions of heat transfer, i.e. natural or forced convection.

3 Results and discussions

The analysis of the results of work on the experimental installation and automated calculation was carried out taking into account the most significant hydraulic and aerodynamic parameters, according to which the sufficiency of the accepted air exchange was assessed for the removal of harmful gases from the subsurface space of the ceramic pipeline and the removal of excess moisture. The initial data on the modeling object in the abbreviated version are presented in the following numerical indicators: the length of the network section 500 m, the diameter of the pipeline 0.4 m, the slope of the route 0.0025, the assigned air exchange in the pipeline system 0.00277 m3/s, the concentration of harmful gaseous substances (for example, hydrogen sulfide), respectively, in the subsurface space 4.2 mg/m3 (according to field measurements by gas analyzers) and the maximum permissible concentration in the atmosphere of the city is 0.008 mg /m3.

Summary data on the results of operation of the experimental installation are shown in Figure 3, and the results of automated calculation according to a specially developed program are shown in Table 1 [11, 12].

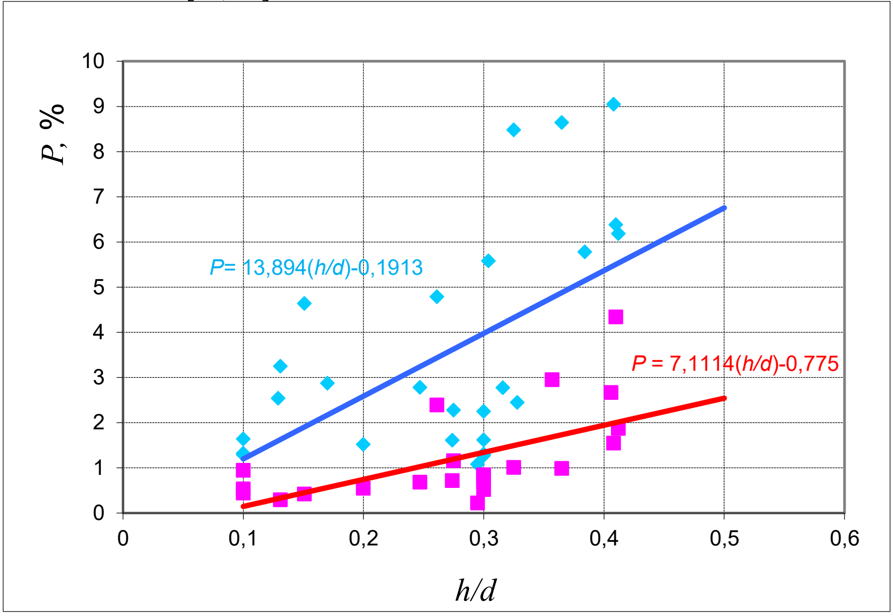

Fig. 3. Summary graph of changes in the percentage p, % of air output (with trend line) from filling h/d for well simulators (p=13.894(h/d)-0.1913) and stack (p=7.1114(h/d)-0.775) with moving fluid with and without the organization of the injection ventilation system of the subsurface space.

The basic conclusion from experimental bench studies of the water-air mode of operation of a gravity pipeline (in the range of 0.1-0.5 water fillings) is that the percentage P of a foul-smelling odor removed from the subsurface space through stacks and wells not equipped with special structural elements in the form of directional partitions can be 0.1-2.5% and 1.5-5.7%, respectively, which, despite their insignificant absolute values, can negatively affect the health of people directly located in the area of the release of aggressive gases, i.e. disrupt the ecological situation in the atmosphere of the city. In this regard, when designing, it is recommended to install directional baffles at the end of the design section in the corresponding wells, which will allow removing foul-smelling emissions into the atmosphere with a concentration below the MPC for each of the gases under consideration.

Table 1. Summary results of automated calculation for various fillings h/d and the assigned air exchange of 0.00277 m3/s.

Name of the calculated indicator	***h/d=0.3***	***h/d=0.5***	***h/d=0.7***
The flow rate of waste water in the pipeline, m/s	0.678	0.786	0.849
Air velocity in the subsurface space of the pipeline in standing water conditions, m/s	0.0302	0.0436	0.0781
The air velocity in the subsurface space of the pipeline, taking into account its entrainment by the flow of water, m/s	0.679	0.787	0.853
The volume of air in the subsurface space of the pipe, m^3	45.82	31.78	17.74
The total mass of gaseous substances from the water surface entering the subsurface space of the pipeline, mg	192.45	133.48	74.52
Duration of removal of gaseous substances from the subsurface space of the pipeline with accepted air exchange in standing water conditions, s (h)	16542.2 (4.6)	11473.6 (3.2)	6405.0 (1.8)
The real time of moisture removal when the air flow velocity changes, taking into account its entrainment by the flow of water, s (h)	736.4 (0.204)	635.1 (0.181)	586.1 (0.163)
Total depression of the air environment, taking into account the overcoming of atmospheric pressure, MPa (mt)	0.09801 (10.001)	0.09802 (10.002)	0.09804 (10.004)

Analysis of the data in Table 1 shows that when the filling changes from 0.3 to 0.7, there is an increase in air velocity from 0.679 to 0.853 m/s (25.6%). At the same time, there is a sharp decrease in the total mass of gaseous substances entering the subsurface space of the pipeline (from 192.45 to 74.52 mg) due to a decrease in its volume from 45.82 to 17.74 m3, which for both indicators is 30.72%.

For the same values of the filling range and the virtual condition of standing water in the pipeline (i.e. without taking into account the flow velocity) and air velocities in the range 0.0302-0.853 m/s, the duration of removal of gaseous substances from the supply space of the pipeline by ventilation will decrease from 4.6 to 1.8 hours, i.e. by 39.1%.

In real conditions, the time for removing moisture from the subsurface space when the air flow velocity changes, taking into account its entrainment by the water flow, will decrease from 0.204 to 0.163 hours (21.1%). This indicates that moisture from the subsurface space will be removed from the sewer network faster than harmful gaseous substances, and in the range from 4.6/0.204 = 22.54 to 1.8/0.163 = 11.04 times, depending on the filling in the pipeline.

With regard to the air pressure (depression value) for the selection of the ventilation unit, it should be noted that the depression practically does not undergo changes due to small aerodynamic resistances in the subsurface space of the pipeline.

Thus, the air exchange value of 0.00277 m3/s adopted in the simulation ensures the removal of both hydrogen sulfide and moisture from the subsurface space of the pipeline (including the stack) to its maximum permissible value in atmospheric air of 0.008 mg/m3. However, the optimal operation of the ventilation unit will be the relative equality (proximity of values) of the times for removing moisture and hydrogen sulfide. Since the time differences in the considered example are significant, the modeling of the water-air mode of the pipeline operation was carried out with a higher value of the assigned air exchange with tracking in the automated mode of the moment of equality of the two indicators. Using an automated program, calculated data were obtained for a new air exchange value of 0.04 m3/s.

Figure 4 shows graphs describing the change in the range of time values (in minutes) for neutralizing foul-smelling odors according to the formula T=-11.446(h/d) + 11.337 and for removing moisture from the pipeline according to the formula T=-8.5214(h/d) + 8.7996 as the results of the automated calculation.

If we compare the results of calculating the times with the previous value of air exchange (0.00277 m3/s), when the results varied from 22.54 to 11.04 times, then with the new value of air exchange, the difference calculated according to the proposed formulas was from 7.9/6.24 = 1.26 (when filling 0.3) to 3.32/2.83=1.17 (when filling 0.7). At values h/d=0.8, the time values will almost coincide.

Thus, the calculated value of air exchange will successfully solve the problem of removing foul-smelling gases and moisture within a minimum period of time.

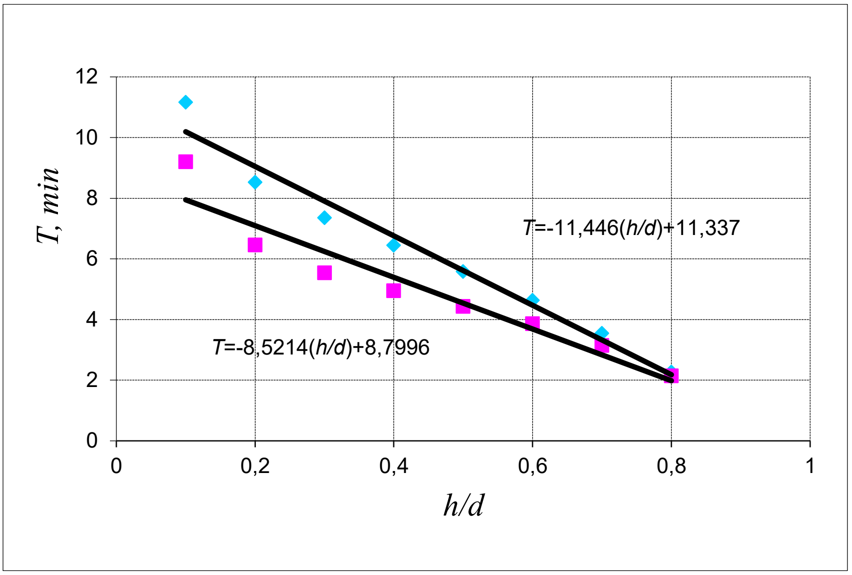

Fig. 4. Graphs of the dependence of the time t (min) of the removal of odorous substances (upper curve) and moisture (lower curve) with an accepted air exchange of 0.04 m3/s.

4 Conclusions

The development of physical and mathematical models for the study of the water-air mode of operation of pressure-free pipelines, as well as the automated calculation of a number of basic parameters, make it possible to quickly monitor the dynamics of changes in the indicators of the pipeline system in conditions of intensive release of gases harmful to human health, preventing man-made hazards and ensuring environmental requirements for the state of the atmosphere of cities.

The user-assigned air exchange, as well as the estimated duration of removal of odorous substances (for example, hydrogen sulfide) and moisture from the subsurface space of the pipeline are taken as basic parameters when modeling the water-air mode of operation of a pressure-free pipeline.

With the help of an automated complex, it is possible to adjust the amount of air exchange depending on technical circumstances and minimize the cost indicators of reconstruction and operation of pipeline networks equipped with ventilation units.

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