Problems of environmental safety of water disposal as a factor of sustainable urban development

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Abstract. This paper examines the environmental safety of water disposal systems – one of the life support systems for a population – as a condition for sustainable urban development. Gaseous emissions from such systems contain a number of highly hazardous substances. The concentration of formaldehyde – a hazard category 2 substance – in sewer network emissions (using direct measurement) and in the underroof space of sewer collectors (by a calculation) was experimentally investigated. The calculations were carried out based on the measurements of the concentration of formaldehyde in the emissions and the data collected during special laboratory experiments with polymer coatings, which accumulated organic gaseous compounds from being in the sewers. It has been proved that the concentration of formaldehyde in the underroof space and in sewer network emissions significantly exceeds the corresponding maximum permissible concentration. Cooling and installation of degassers in shafts were suggested as reasonable methods for protecting the city’s atmospheric air against the emissions from sewer systems.

1. Introduction

The study of the problems of sustainable development of settlements, especially cities, nowadays is the key area of scientific substantiation of the main paradigm of the 21st century - sustainable economic, social and environmental development. Cities play a special role in achieving sustainable development, since the problems and opportunities of modern civilization are the most significant and noticeable there [1]. What is understood under the term “constant urban development” is a set of socially, economically and ecologically balanced changes in the socio-territorial system of the city, aimed at the fullest possible realization of all its potential’s components and preventing the tendencies for the population’s quality of life to deteriorate [2], which includes environmental safety as one of its elements. The stability of the city affects the ability to implement the principles of sustainable development of higher-level systems and depends on the sustainability of all the constituent elements included in the socio-economic system of the city.

The concept of sustainable development systematically connected the three main components of the development of society: economic, social and environmental. From an environmental point of view, sustainable development should ensure the integrity of biological and physical natural systems and their viability. Within the city, the viability of natural systems – first and foremost, people (the population of the city) – depends on the environmental safety of the living conditions. It is important, during the practical implementation of the principles of sustainable development of a city, not only to determine its resource provision (resources, their structure, cost, potential), but also to analyse the situation from the perspective of various types of activities, economic areas and their interaction [2, 3].
A big city changes all the environmental components - the atmosphere, the vegetation, the soil, the topography, the hydrographic network, the groundwaters and even the climate. This leads to great environmental problems caused by its high population concentration, industrial facilities, and urban infrastructure. The growth of the urban population, especially in recent decades, the rapid concentration and intensification of production and non-production activities have led to the fact that the environment in many cities around the world cannot satisfy all the biological and social requirements of modern man, including ensuring complete environmental safety.

In the context of the foregoing, the reliability and environmental safety of the functioning of city population’s life support systems is of particular importance for the sustainable development of cities. One of the links of this system is wastewater disposal, which ensures the environmental safety of water usage and, in general, performs an extremely large-scale environmental function - protecting the natural environment from pollution by liquid anthropogenic wastes.

However, sanitation facilities are large-scale technical facilities. They exert an intense technogenic load on the environment and often create dangers for urban regions, mainly as a source of ingredient pollution of the urban atmosphere. Even when sewer networks operate in the trouble-free mode, their operation poses an environmental problem caused by the formation of toxic gaseous compounds (hydrogen sulphide, mercaptan, sulphur dioxide, carbon dioxide, methane, etc.) that pollute the atmosphere of urban regions through shafts and wells (Table 1) [4, 5].

| Substance                  | Concentration in Australian sewers, µg/m³ |
|---------------------------|------------------------------------------|
| Benzene                   | 8.85                                      |
| Decane                    | 141.88                                    |
| Dimethyl disulphide       | 8.72                                      |
| Dimethyl supplied         | 65.4                                      |
| Diethyl sulphid           | 1.12                                      |
| Diethyl disulphide        | 0.15                                      |
| Ethyl mercaptan           | 3.81                                      |
| Hydrogen sulphid          | 1880                                      |
| Methyl mercaptan          | 293                                       |
| Sulphur dioxide           | 870–2600                                  |
| Toluene                   | 61.15                                     |
| Threechloromethane        | 654.25                                    |
| Xylene                    | 183.7                                     |

A particular environmental hazard in terms of the excess of maximum permissible concentration (MPC) in gaseous emissions from sewer networks is hydrogen sulfide (substance hazard category 2) [6, 7]. In addition, it initiates the development of biogenic sulfuric acid corrosion on the arched part of concrete sewer pipelines, which drastically reduces the operational life of these objects [8]. In general, all sulfur compounds (including organic) found in emissions from sewer networks are environmentally hazardous. However, their concentration, except H₂S and SO₂, is very low [4, 5].

However, a number of specialists found not only sulfur-containing compounds of a high hazard category in emissions from sewer networks. Unfortunately, among the carbon-containing gaseous compounds in the emissions from sewer networks there are also many potentially very hazardous substances (Table 1). When it comes to environmental safety of carbon-containing compounds in emissions from sewer networks, formaldehyde, which was discovered by a number of specialists, attracts great attention [4,9,10]. In terms of its effect on the human body, formaldehyde, like hydrogen sulfide, is a highly hazardous substance (substance hazard category 2) [11]. These substances have a pungent and unpleasant odour. Moreover, the MPC of all types of rationing for formaldehyde is significantly lower than the MPC for hydrogen sulfide. Formaldehyde is classified as a probable
carcinogen for humans with a minimum single inhalation dose of $1.3 \times 10^{-5}$ mg/m$^3$. According to foreign scientists, its concentration in emissions from sewer networks is 0.370 mg/m$^3$ [9].

The presence of this gas in emissions from sewer networks causes such concern because of the steady excess of its concentrations in the cities of Ukraine. [12, 13]. Moreover, such excesses are usually associated with the work of certain industrial enterprises, or vehicles. However, detailed studies in cities with a small number of industrial enterprises also found that the concentration of formaldehyde in atmospheric air was higher than the MPC. Upon conducting detailed studies and calculations, it was found that the contribution of vehicles to formaldehyde emissions was also very small (up to 5%) [13]. Potentially, air pollution is the most serious environmental problem for human health in the short and in the long run. It is more difficult to avoid exposure to air pollution than to water pollution [13].

The solution to the problem of protecting the urban environment from pollution by gaseous emissions from sewer networks is carried out in various areas of the project: standardization of industrial enterprises’ discharges, operational solutions for the transportation of wastewater, the usage of degassing installations on sewer networks. However, the issue of effective removal of formaldehyde from sewer network emissions to ensure an appropriate level of environmental safety in the urban air hasn’t been studied.

2. Objects and research methods

The object of this research is to assess the level of health hazard posed by the presence of gaseous compounds of the 2nd hazard class – H$_2$S and formaldehyde – in sewer network emissions and some environmentally friendly means of solving this problem.

The studies were carried out in real conditions in May 2019 together with the employees of the operational service of PU “Kharkovvodokanal”. The section of measurements on the sewer network of Kharkov is shown in figure 1.

![Figure 1. Section of the drainage channel (Stroyhydraulika) of Kharkov where the examined shaft is located (No. 52)](image)

The measurements of the concentrations of H$_2$S, SO$_2$, CO, CO$_2$ and CH$_4$ were performed with universal portable gas analyser UG-2 and mine interferometer ShI-11 in the underroof space of the collector, where the device for sampling the air-gas mixture was lowered through the entire height of the shaft. The concentration of these substances is periodically measured by the analytical laboratory of PU “Kharkovvodokanal”. The concentrations of formaldehyde and volatile organic compounds were determined at the outlet of the sewer shaft by using a digital formaldehyde detector, the WP6910 air quality analyser.

3. Results and discussion

The concentration of these substances in Kharkov sewer shafts was measured for the first time. The results of measuring the concentration of gaseous compounds in the underroof space of shaft No 52 are given in Table. 2.

As it is seen from the gathered data, the concentration of H$_2$S, SO$_2$, CO$_2$ and CO in the underroof space significantly exceeded MPC$\text{working area}$. Thus, carrying out any kind of work in this shaft is unacceptable without personal protective equipment.
Table 2. Concentrations of polluting substances in the underroof space of the sewerage pipeline of the surveyed shaft

| Polluting substance | Concentrations of polluting substances in the underroof space, mg/m³ | MPC working area, mg/m³ |
|---------------------|---------------------------------------------------------------------|-------------------------|
| Hydrogen sulfide, H₂S | 15*                                                                 | 10                      |
| Sulphur dioxide, SO₂ | 35*                                                                 | 10                      |
| Carbon oxide, CO    | 0*                                                                  | 20                      |
| Carbon dioxide, CO₂ | 0,83*                                                               | -                       |
| Methane, CH₄        | 0,57**                                                              | 1500-1700               |

* - concentration values obtained using direct measurement at the shaft; ** - the concentration value calculated in accordance with the dependence determined by the authors

Using the data on the concentration of gaseous substances in the underroof space (table 2), we calculated the concentration of these contaminants in the emissions from the shaft (at the outlet of the shaft). For this calculation, an empirically established dependence (1, 2, 3) of the concentration of H₂S in sewer shafts and the height of the shaft was used.

\[ N = 7,37H + 97,49, \]  

where \( N \) - relative concentration of H₂S at the output from the shaft with respect to the concentration in the underroof space, %; \( H \) - height of shaft, m (12).

\[ N = \frac{C \text{ output} \times 100}{C \text{ underroof space}}, \]  

where \( C \) output - concentration of H₂S at the output from the shaft, mg/m³; \( C \) underroof space - concentrations of H₂S in the underroof space, mg/m³; 100 – conversion factor, %.

Hence:

\[ C \text{ output} = \frac{(7,37H + 97,49)C \text{ underroof space}}{100} \]  

This dependence could be used for an approximate calculation of concentrations of gases that have the same molecular mass as hydrogen sulphide, i.e., CO. Taking into account that the concentration of SO₂, CO and CH₄ is proportional to the dynamic of H₂S in sewer networks [10], it can be used for a rough estimate of the concentration of these gases as well. Concentrations of polluting substances at the output from the surveyed shaft represented in Table 3.

Table 3. Concentrations of polluting substances at the output from the surveyed shaft

| Polluting substance | Concentrations of polluting substances in release from the shaft, mg/m³ | MPC daily average, mg/m³ | Rate of MPC excess |
|---------------------|------------------------------------------------------------------------|--------------------------|--------------------|
| Hydrogen sulphide, H₂S | 1,5**                                                                  | 0,008                    | 188                |
| Sulphur dioxide, SO₂ | 3,5**                                                                  | 0,05                     | 70                 |
| Carbon oxide, CO    | 0**                                                                    | 3                        |                    |
| Carbon dioxide, CO₂ | 0,083**                                                                | -                        |                    |
| Methane, CH₄        | 458**                                                                  | -                        |                    |
| Formaldehyde, CH₂O  | 1,99*                                                                  | 0,003                    | 663                |
| Volatile organic compounds | 4,88*                                                                 | -                        |                    |

* - concentration values obtained using direct measurement at the shaft; ** - the concentration value calculated in accordance with the dependence determined by the authors

As it is seen from table 3, formaldehyde – a hazardous gas – poses the biggest threat as its concentration in the gaseous emissions from the observed sewer shaft is much higher than the MPC.
The concentrations of H₂S and SO₂ also significantly exceed the MPC daily average. This creates a special danger for citizens living in areas adjacent to sewer shafts, since all these gases belong to hazard class 2. Given that formaldehyde is close in its molecular weight to hydrogen sulfide, the concentration of formaldehyde at the outlet of the shaft (in the emission) can be used to calculate its approximate concentration in the underroof space of the sewer collector using the determined dependence (1). The concentration of formaldehyde in the underroof space (C underroof space) could be calculated using the equation:

\[
C_{\text{underroof space}} = \frac{C_{\text{output}} \cdot 100}{(7.37H + 97.49)}
\]  

where, 100 – conversion factor, %.

According to the calculation, this concentration is 19.9 mg/m³, while the MPC of formaldehyde in the atmospheric air of the working area is 0.5 mg/m³.

One can assume that such high concentrations of formaldehyde, which were found in the emissions from the observed shaft, are episodic and can rarely be observed. However, further studies performed in the shaft, where the concentration of hydrogen sulphide in the underroof space was approximately the same as this indicator in the underroof space of shaft No. 52, have proved that the presence of formaldehyde in the atmosphere of the underroof space of sewer collectors is not an accidental phenomenon. In the process of researching the effectiveness of various polymer concrete coatings in protecting concrete from corrosion processes, a special attention was paid to the intense saturation of these coatings with unpleasant odorous gases after being in the sewer networks for some time (3 months). The polymer coatings must have played the role of an adsorbent for certain types of gaseous compounds in the sewer networks.

During special laboratory experiments, quantitative indicators of formaldehyde emission from the coating surface were determined after being exposed in the sewer collector. For this, samples of concrete coated with a polyethylene coating (total coating area ~ 0.3 dm²) were placed in hermetically sealed desiccators (2 dm³) with a formaldehyde gas analyzer. The results of the measurements of the concentration of formaldehyde in the desiccator are shown in Figure 2.

![Figure 2](image)

**Figure 2.** The accumulation of formaldehyde over samples of polymer coating after exposure in a sewer collector

As it is seen from the presented data (Figure 2), the concentration of formaldehyde in the desiccator steadily increased in a linear relationship with increasing exposure time. The specific emission of formaldehyde from the coating surface calculated using this data was 0.002-0.007 mg (m² h). Assuming that formaldehyde accumulated in this coating at a similar rate, then the concentration of formaldehyde in the underroof space could be calculated using the formula (5):
The concentration of formaldehyde calculated by the formula (3) is 15.12 mg/m³. Since the experiment with a concrete sample coated with a protective coating was carried out some time after the actual exposure in the collector, formaldehyde emission from the coating may have been somewhat weakened. Therefore, it could be noted that the value of the concentration of formaldehyde in the underroof space calculated by the formula (5), corresponds to the value of the concentration of formaldehyde received using the formula (4).

The obtained data indicates a consistently high concentration of formaldehyde in the underroof space of the sewer networks. So, while carrying out repairs in sewer network collectors, employees of the maintenance and repair services of drainage networks are exposed to environmentally hazardous concentrations of formaldehyde and other hazardous gaseous substances, which negatively affects their performance and general physical condition. Measures must be taken to prevent maintenance workers from getting poisoned by sewer gases that can vary in composition.

Based on the established positive correlation between the concentration of hydrogen sulphide in sewer networks and the concentration of formaldehyde [10], it is safe to assume that the concentration of formaldehyde is very high in the emissions from the shafts with the concentration of hydrogen sulphide that is substantially higher than 1.5 mg/m³ [6-9]. This should be taken into account when calculating the dispersion of gaseous substances in emissions from sewer shafts in the atmospheric air of cities. Such calculations were performed almost exclusively for H2S, as a hazardous component of such emissions [6]. It is worth noting that the MPC\textsubscript{daily average} for formaldehyde is 2.7 times lower than the MPC\textsubscript{daily average} for hydrogen sulphide.

Among the methods for protecting the urban atmospheric air against the emissions of H2S and formaldehyde (two gaseous compounds, which are hazard category 2 substances) from water disposal systems, the most promising are cooling and the installation of degasifiers on the shafts. These methods [6, 7] have shown their effectiveness in protecting atmospheric air in Kharkov against the H2S pollution and safety for the urban environment, including the videoecological aspect. The prospects of using wastewater cooling transported by networks to reduce formaldehyde emissions are quite good, since it is a product of microbiological metabolism and microbial destruction of wastewater pollution under anaerobic conditions. It is known that the rates of microbiological reactions follow the temperature dependence of Vant-Hoff: with an increase in temperature by 10 °C, the speed increases by a factor of 2–3. Therefore, just like in the case with H2S, this effect halves the concentration of gaseous matter in the atmosphere of the underroof space, and, consequently, in the emissions from the shafts into the urban atmospheric air. The usage of a degasifier to remove formaldehyde from gaseous emissions from water disposal systems also has positive prospects, since the tests of biochemical treatment of emissions of a similar composition were able to demonstrate a high cleaning effect [14]. Moreover, the videoecological problems of such installations for cleaning gaseous emissions from sewer networks (degasifier) – visual discomfort when located among residential and historical buildings, parks, and recreational areas – have been successfully resolved as well [6]. Various design solutions can help to harmoniously blend in these technogenic elements (small architectural forms) with the urban environment.

In addition to this, not only do the suggested technical solutions (cooling of wastewater transported by sewage networks and degasifiers on sewer networks) effectively remove H2S, but they also remove an even more environmentally hazardous gas – formaldehyde, which significantly increases their environmental and economic attractiveness.

4. Conclusions
One of the most important factors in ensuring sustainable development of cities is the security of the living environment of its inhabitants, which includes atmospheric air. One of the sources of urban air pollution by environmentally hazardous substances are water disposal facilities.
The study focused on the concentration of gaseous compounds of hazard class 2 – H₂S and formaldehyde – in emissions from sewer shafts. It was shown that the concentration of formaldehyde in emissions from sewer shafts is many times greater than the MPC_daily average for this compound.

Two technical solutions that have proven to be effective in the removal of H₂S were deemed promising for the effective extraction of this compound from emissions from sewer shafts: cooling of emissions from sewer shafts. It was shown that the concentration of formaldehyde in emissions from sewer shafts is many times greater than the MPC_daily average for this compound.

5. References
[1] Goptsiy D O 2015 Scientific approaches to understanding the concept of sustainable development and directions of its use in urban development planning URL: http://dspace.knau.kharkov.ua/jspui/bitstream/123456789/464
[2] Mozgovoi A A 2014 Sustainable urban development: preconditions and contradictions URL: http://ir.nmu.org.ua/bitstream/handle/123456789/148166/58-61.pdf?sequence=1/
[3] Kovalevskaya A V, Zelensky S V, Petrova R V 2017 Sustainable city development: the essence of the concept and prerequisites of implementation Social economics 53 (1) pp 69-75
[4] Pochwat K, Kida M, Ziembowicz S and Koszelnik P 2019 Odours in sewerage-a description of emissions and of technical abatement measures environments Electronic Materials 6 89 doi:10.3390/environments6080089
[5] Shammay A, Sivret E C, Le-Minh N, Fernandez R L, Evanison I, Stuetz R M 2016 Review of odour abatement in sewer networks Electronic Materials 4 3866–3881
[6] Iurchenko V., Lebedeva E, Brigada E 2016 Environmental Safety of the Sewage Disposal by the Sewerage Pipelines Procedia Engineering 134 pp 181-186
[7] Iurchenko V., Lebedeva E 2016 Reduction of environmental hazard of hydrogen sulfide emission from sewerage pipelines and visual pollution, formed by degassing units Environmental problems 1 (2) pp 155–158
[8] Iurchenko V, Brigada E 2014 Kinetic characteristics of microbial corrosion of concrete drainage networks Water and ecology. Problems and solutions 1 pp 51-61
[9] Hvitved-Jacobsen T, Vollertsen J and Nielsen A H 2005 Odor from sewer networks - processes and prediction 9th NORDIWA Conference on Collection and Treatment of Wastewater (Stockholm, Sweden)
[10] Yan-li Zhu, Guo-di Zheng, Ding Gao and el. 2016 Odor composition analysis and odor indicator selection during sewage sludge composting Journal of the Air & Waste Management Association pp 930-940
[11] Dorogova V B, Taranenko N A, Ryachgova O A 2010 Formaldehyde in the environment and its effect on the body (review) Bulletin of the VSSC SB RAMS 1(71) pp 32–35
[12] Zerkalov D V 2007 Ecological safety: management, monitoring, control (CST, Dakor, Osnova) p 412
[13] Survey of Formaldehyde 2014 A LOUS review project The Danish Environmental Protection Agency p 73
[14] Kulikov N I, Annan A A, Kostik V V, Beldiy M G 1995 Installation for researching the processes of biochemical purification of industrial gas emissions Chemistry and Water Technology 17 (60) pp 621-624