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Control of Hydrogen Sulfide Concentrations in Pressure Sewers in the System of Emission-Free Sewage Transport

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1. Introduction

Organic substances in raw sewage in sewage systems are the primary source of hydrogen sulfide, characterized by the highest odour nuisance and dominance. It is a product of anaerobic biological wastewater transformation and appears along with ammonia or sulfur organic compounds, such as thiophene, dimethyl sulphide, dimethyl disulfide or mercaptans. Hydrogen sulfide is a potential threat to human health and life, and also causes problems during the operation of sewage systems and equipment because it causes corrosion of concrete and other materials used in sewage transport systems (Dębowski et al. 2008, Podraza 2014, Pochwat et al. 2019, Smyk et al. 2019).

Hydrogen sulfide is readily absorbed through the lungs, attacking the central nervous system and lungs. The smell of hydrogen sulfide becomes noticeable at low concentrations (0.0005 ppm). But 2-15 minutes of exposure to 100 ppm causes a loss of smell. Therefore, high concentration (> 500 ppm), no longer noticeable by humans, can cause unconsciousness and fatal respiratory paralysis. Hydrogen sulfide concentrations in the range 50-100 ppm cause such ailments as conjunctivitis, nose and throat irritation, and severe lung complications. (Schneider et al. 1998, Wasch et al. 1989, Malone Rubright et al. 2017).

Hydrogen sulfide is most often released from an expansion well or pumping station in the pressure sewage system. As a gas denser than air, it stays in the pipes until pumping sewage stage, which usually takes place cyclically when a certain level in the well is reached. The nuisance for sewerage system workers and, above all, the surrounding inhabitants induces more and more operators to search for efficient solutions for hydrogen sulfide emission control.

Currently, two main lines of action are used: prevention and elimination. The first one uses the chemical methods (e.g., magnesium peroxide (MgO_2) and calcium oxide (CaO)) and physical processes (aeration or oxidation) to maintain oxygen conditions in the sewage system. Operators may also apply methods that prevent the development and activity of sulfide-reducing bacteria (cleaning pipelines from sludge, increasing sewage pH, or controversial use of bactericides). The elimination of odours includes physicochemical methods, such as adsorption on activated carbon or chemical precipitation and oxidation with nitrate salts ($NaNO_3$, $Ca(NO_3)_2$), strong oxidants (H_2O_2; Cl_2; $NaClO$; $KMnO_4$; $NaMnO_4$) or iron compounds ($FeCl_3$, $FeCl_2$; $Fe(NO_3)_3$; $Fe_2(SO_4)_3$). Biological methods (biofilters or bio scrubbers) can also be applied, depending on hydrogen sulfide concentration (Brandt et al. 2017, Talaiekhozani et al. 2016, Piekarski & Dąbrowski 2009). The essential condition for the application of a given method is not only its efficiency but also the anticipated secondary effects, such as the impact on subsequent wastewater treatment processes.

The introduction of new methods solving above mentioned problems requires verification in real conditions, which is often not an easy task to do. Appropriate selection of an object, consent of an operator, adjustment to measurements, and unexpected circumstances that do not occur in stable conditions of laboratory tests constitute a difficulty, but also the value of the obtained results. This paper presents a part of field research of new technology for aeration and flushing of the pressure pipelines with compressed air called Emission-free Sewage Transport EST (BST in Polish), which regards the scope of control of hydrogen sulfide emission in the pressure sewage system.

2. Materials and methods

2.1. Objects under consideration

Two sections of different pressure sewage systems collecting wastewater from independent catchments were selected to verify the effectiveness of the EST system under real conditions. Both objects differed in volume flow, sewage characteristics, and pipeline diameter. In both cases, the tests were carried out on the sections *Pump station – Expansion well* of similar length. The essential features of both objects are given in Table 1.

Object-1 was a fragment of the system servicing a rural locality with a low inflow of sewage (Giezkowo, West Pomeranian Voivodeship, Poland). Measurements of wastewater inflow to the pumping station showed that they were not deep decay and the average redox potential was 35 mV (from -106 mV to 195 mV); it was positive in most of the measured samples. The average retention time of sewage in the tested pipeline section was 14.4 hours.

Table 1. Essential features of examined sections of delivery pipelines

Selected parameters	Unit	Object-1	Object-2
Length of the section: *Pump station – Expansion well*	m	3925	3406
Inner diameter of pipeline	mm	79.2	147.6
Sewage inflow to the *Pump station*, $Q_{śrd}$	m^3/d	32.1	745.5

Object-2 was a part of a branched pressure sewer system servicing the big catchment area (Konikowo, West Pomeranian Voivodeship, Poland). Object-2 has a high flow and short residence time of sewage in the delivery pipeline (2.1 h on the average). Wastewater inflowing to the pumping station, however, had negative redox potential (from -185 mV to -360 mV), causing a high odour nuisance.

The course of tested pipelines varies in height between individual wells. Object-1 has eight wells on the tested section, while Object-2 has 12. The tests were carried out in the spring and summer, at the air temperature in the measurement well of 15-21°C.

2.2. Emission-free Sewage Transport (EST)

EST technology has been developed and tested in a wide range, on a laboratory scale, by the Polish company EkoWodrol. It is a system for aeration and flushing of the delivery pipeline using compressed air. The system is based on an innovative work algorithm developed in numerous simulations. The algorithm models the flow and aeration of sewage in the pipeline and optimizes the operation of the pumping station. The device which contains, among others, a properly selected compressor is housed in an individual container body, which is located close to the pumping station.

During tests, the air was introduced into pipelines directly behind the pumping station of both objects, in a point and a time manner. The operating parameters of the EST system are given in Table 2. During the purge of the delivery pipeline, the pumping station is stopped, existing vent valves were closed, which is also a characteristic feature of this technology.

Table 2. Input data for field tests

Selected parameters	Unit	Object-1	Object-2
The air pumping time	min	60	30-40
The volume of introduced air	m^3	97	91-121
Purge frequency	d^{-1}	1-2	1-2

2.3. Measurements of hydrogen sulfide concentration

The concentration of hydrogen sulfide was measured in the expansion well of a selected section of the pressure sewage system, both during standard system operation (as a reference level) and the EST system operation. The measurements were carried out automatically using a *H_2S BE* sensor (with a basic range of 0-2000 ppm and a peak value of 3900 ppm) and a *BLE Gateway 300640* sensor. Results were sent online and archived on the internet platform with a frequency of 1 min.

3. Results and discussion

3.1. The level of hydrogen sulfide concentration before application of the EST system

Analysis of the variability of hydrogen sulfide concentration in the expansion well of both objects was carried out at different periods. The obtained data shows a significant variation in the value of the measured parameter, from close to one up to 700 ppm. In the case of Object-1, despite the inflow of fresh sewage to the pumping station, low flows and long retention time promoted anaerobic transformations in wastewater, as well as the creation of a biological film and sludge, causing conditions for rapid deoxidation of flowing sewage. The effect was a significant production of hydrogen sulfide (Fig. 1) with significantly higher concentrations than those measured in Object-2. The wastewater inflowing to the pumping station at Object-2 was characterized by a high degree of decomposition and thus lower gas-generating potential. Analysis of measurements showed, in both cases, the occurrence of sudden increases in the concentration of hydrogen sulfide in the expansion wells, mainly during the pumping of wastewater.

Figure 2 presents an example of the daily distribution of hydrogen sulfide concentration during several selected cycles of pumping station operation. Hydrogen sulfide accumulates in the delivery pipeline between each subsequent pumping of wastewater. During the pumping of sewage, it is transported to the expansion well, where it may be released to the atmosphere. The dynamic increase in gas concentration does not always end directly after the stopping of sewage pumps. It is the resultant amount of hydrogen sulfide in the pipeline and the time of pump operation. In some cycles, a slight decrease in gas concentration occurs during the work of the pumping station. Therefore, the analyzes focused mainly on the results of hydrogen sulfide measurements obtained only during the wastewater pumping cycle.

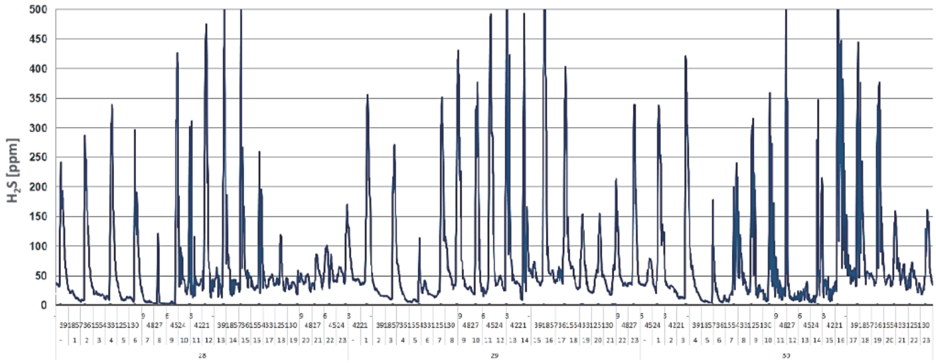

Fig. 1. Daily distribution of hydrogen sulfide concentration in the expansion well for an exemplary period of operation of pressure pipeline of Object-1 without EST purge (28-30 July 2019)

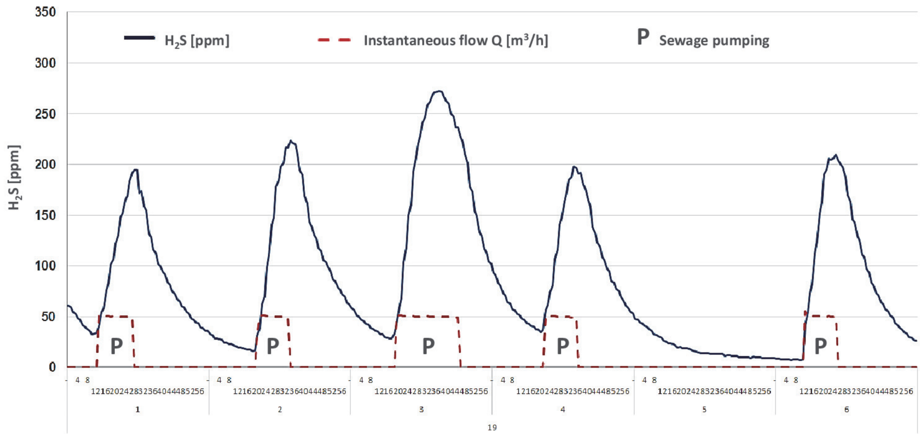

Fig. 2. Hydrogen sulfide released in an expansion well during sewage pumping (5 pumping station cycles, 19.08.2019) at Object -2 before application of EST

The average value of hydrogen sulfide concentration released in the expansion well at Object-1 was 310 ppm (ranging from 58 to 691 ppm), while at Object-2 it was 163 ppm (range from 44 to 338 ppm). Table 3 provides an analysis of the frequency of occurrence of specific H_2S concentration ranges for both objects and only during the sewage pumping. This analysis includes values of hydrogen sulfide concentration as the highest value of measurements taken within the time range of the sewage pumping cycle and a few minutes after its completion.

Since the value of hydrogen sulfide concentration alone does not fully reflect the actual nuisance of the objects, a simplifying assumption was made; all hydrogen sulfide is pushed out of the pipeline up to the maximum concentration during a given pumping. Then it is released to the atmosphere.

Table 3. Analysis of the frequency of H_2S concentration in the expansion well only during sewage pumping (Object-1 – 48 pump cycles, Object-2 – 54 cycles)

Concentration range, ppm	% share	
	Object-1	Object-2
0-50	0.00	3.70
50-100	6.25	24.07
100-200	22.92	35.19
200-300	16.66	31.48
300-400	25.00	5.56
400-500	16.67	
500-700	12.50	

This way, it is possible to determine the instantaneous hydrogen sulfide load for a given pumping cycle, calculated multiplying maximum gas concentration, and the amount of sewage pumped. The results of such analysis are presented in Table 4.

Table 4. Results of hydrogen sulfide measurements from the period including only pump cycles – EST system not applied (reference)

Parameters	Object-1			Object-2		
	min	average	max	min	average	max
H_2S [ppm]	58	310	691	44	163	338
Sewage volume in the cycle [m^3]	0.241	1.772	2.053	4.0	19.0	67.0
H_2S, [mg/l][*)]	82	439	976	63	230	479
H_2S load in the cycle [mgH_2S/pump cycle]	145	758	1 956	1 153	3 914	12 317

[*)] calculations for 20.6°C according to formula: concentration [mg H_2S/l] = concentration of H_2S [ppm] 414.96/273+temp. °C

The average value of the instantaneous hydrogen sulfide load for Object-1 was 758 mg H_2S/pump cycle, while for Object-2, it was 3 914 mg H_2S per cycle. The values indicate a much more significant nuisance of the Object-2. It generates much more significant hydrogen sulfide load during the pump cycle (more sewage, longer pump operation time, and larger pipeline diameter), despite the lower concentrations of hydrogen sulfide released in the expansion well. At the same time, the pump cycle frequency at the Object-2 was about 30 starts daily, increasing the effect of the nuisance. At the Object-1, the pump cycle frequency was two times lower (15 cycles/day).

3.2. Hydrogen sulfide concentration after application of the EST system

Application of EST system that purges the delivery pipeline of Object-1 with compressed air once a day caused significant change of hydrogen sulfide concentration in the expansion well. 89% from 78 measurements taken during pump cycles were below 25 ppm. For two purges per day (morning and evening), 93% of measurements (from 57) were below 25 ppm. The remaining 7% of the results were within the range of 25-50 ppm. High concentrations of hydrogen sulfide were observed only during the purge when it was removed from the pipeline to the atmosphere, i.e., 1-2 times a day (Fig. 3). Without the EST system, the number of such outbursts per day was higher (over a dozen), along with each pumping cycle. Also, an increase in the number of purges and the improvement of conditions in the sewage system may cause a gradual decrease in the amount of hydrogen sulfide released.

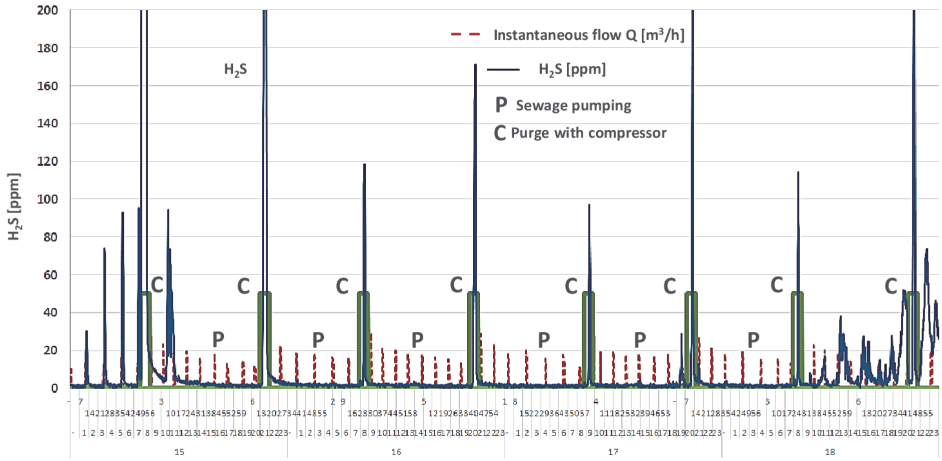

Fig. 3. Daily distribution of hydrogen sulfide concentration for an exemplary period of EST application (15-18.07.2019) at Object-1 (two purges per day)

During tests, sporadic situations (Fig. 3, day 18) of a slight increase in the concentration of hydrogen sulfide between purges also occurred. It was probably caused by an inflow of hydrogen sulfide to the expansion well from a further section of the sewage system, due to incomplete filling of the pipeline with sewage. This example shows that in the real conditions of pipeline operation, various difficulties are resulting from the specificity of a given sewage system. Therefore, it is essential to optimize the work of the EST system individually, flexibly adapting it to the existing, but also changing conditions.

A list of average values obtained from the analysis of hydrogen sulfide concentration released during the pump cycle measurements is given in Table 5. Application of EST system caused the decrease in the average hydrogen sulfide concentration measured during the pump cycle from 310 to 13.5 ppm, and the instantaneous gas load released in the expansion well during sewage pumping was reduced by 95.4% at one purge per day. An increase in the number of purges in the delivery pipeline decreased concentration of H_2S to 6.1 ppm and increased to 98% reduction of the hydrogen sulfide load.

Table 5. Analysis of the results of hydrogen sulfide measurements for a selected test period with and without the EST system (five consecutive days with one purge per day and four days with two purges per day) obtained during sewage pumping only at Object-1 (about 15 pump cycles per day)

<table>
<tr><th colspan="2" rowspan="2">Parameter</th><th rowspan="2">Unit</th><th colspan="3">Number of purges per day, d^{-1}</th></tr>
<tr><th>0</th><th>1</th><th>2</th></tr>
<tr><td colspan="2">Share of H_2S concentration within the range of 0-50 ppm</td><td>%</td><td>0.0</td><td>92.3</td><td>100</td></tr>
<tr><td colspan="2">Average H_2S concentration</td><td>ppm</td><td>310</td><td>13.5</td><td>6.1</td></tr>
<tr><td>Instantaneous load of H_2S in expansion well during the pump cycle</td><td>min-max
average</td><td>mg H_2S/pump cycle</td><td>145-1956
758</td><td>1-404
35</td><td>2-100
15</td></tr>
</table>

The use of the EST system in Object-2 required more optimization of the aeration frequency to the existing situation in the sewage system than in Object-1. The measurement period starts at the end of the purge. The measurement period ends when the purge effect fades (H_2S concentration increases above 50 ppm). The general principle was adopted – the limit concentration of the next purge is 50 ppm. Data collected during different measurement periods (2,192 measurements from 4 days of tests) show that after application of purge, 76.5% of the results of hydrogen sulfide concentration in the expansion well during sewage pumping are within the range of 0-10 ppm.

Before the application of EST, more than 96% of measurements of H_2S concentration during the pump cycle exceeded 50 ppm, with the average value of 163 ppm. Purges with air decreased an average H_2S concentration to 11.6 ppm (Table 6).

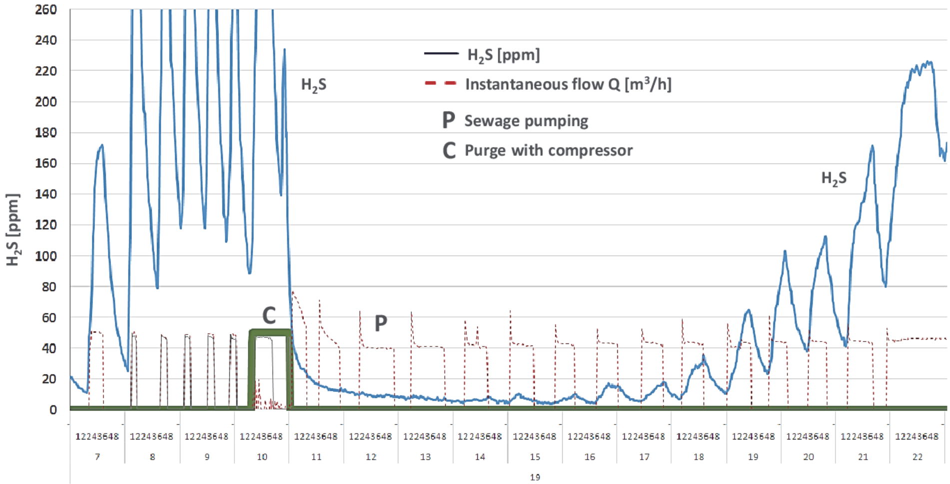

Fig. 4. Changes in hydrogen sulfide concentration for an example purge in the EST system (19.08.2019) at Object-2

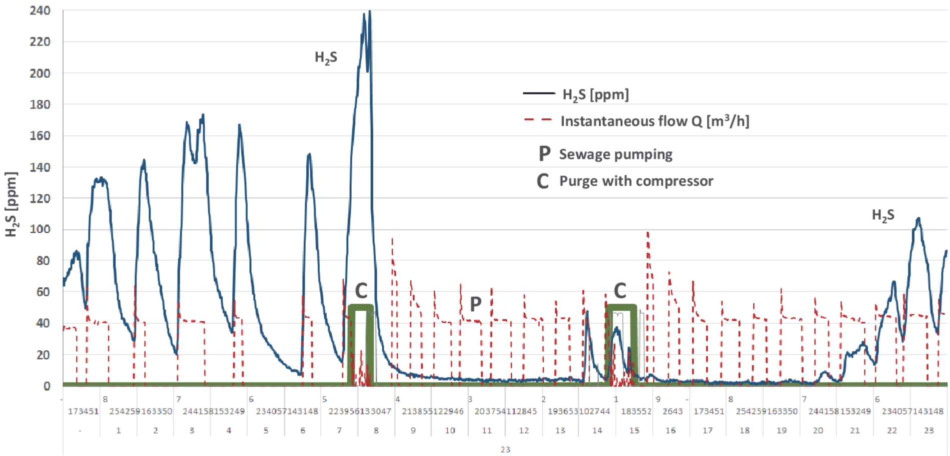

Fig. 5. Daily changes in hydrogen sulfide concentration for two exemplary purges in the EST system during the day (23.08.2019) at Object-2

Table 6. Analysis of the results of hydrogen sulfide measurements for a selected test period with and without the EST system (four consecutive days with 1-2 purges per day) obtained during sewage pumping only at Object-2 (about 30 pump cycles per day)

Parametr		Unit	Number of purges per day, d^{-1}	
			0	1-2
Share of H_2S concentration within the range of 0-50 ppm		%	3.7	100
Average H_2S concentration		ppm	163.0	11.6
Instantaneous load of H_2S in expansion well during the pump cycle	min-max average	mg H_2S/pump cycle	1 153-12 317 3 914	68-1 302 322

Studies have shown that the purge carried out at Object-2 was sufficient to maintain the concentration of hydrogen sulfide in the expansion well below 50 ppm for 8-10 pump cycles (i.e., from 8 to 12 hours). It was noted that the increase in hydrogen sulfide concentration over 50 ppm occurred only when the analyzed section of the pipeline was filled with sewage 2.5-3 times. At that moment, the next purge is required. It is visible on the charts of H_2S concentration courses in Fig. 4-5. The average hydrogen sulfide load in the expansion well released during sewage pumping decreased by 92% (Table 6).

4. Summary and conclusions

Field tests of the emission-free sewage transport system presented in this paper, were an essential supplement to previously performed a wide range of laboratory tests. Results obtained in the real conditions showed the possibility of effective control of the generation and emission of hydrogen sulfide in a pressure sewage system. So the EST system is a good alternative to the available methods of reduction of odor nuisance of a sewage system. The presented results, obtained at two different objects, allow us to draw the following conclusions:

- The highest concentration of hydrogen sulfide in the expansion well at both objects occurred abruptly during the cyclic operation of the pumping station as a result of pushing gas by pumped sewage. The range of H_2S concentration was from 44 to 691 ppm.
- The use of aeration and flushing of the pipeline in the EST system decreased hydrogen sulfide concentration in the expansion well below 50 ppm and maintained that value during subsequent wastewater pumping cycles.

- Purges of pipelines by the EST system in a cycle of one to two per day caused the decrease of instantaneous hydrogen sulfide loads released in the expansion well by 92-98%.
- During the operation of both objects without EST system, short-term increases in the concentration of hydrogen sulfide occurred, depending on the number of pumping cycles, from a dozen to nearly 30 times a day. When the EST system was applied, short-term increases in H_2S occurred only during the purge with air.
- The cyclical purge in the EST system allows to keep a delivery pipeline free of deposit, which contributes to the generation of hydrogen sulfide. EST purges also create temporary oxygen conditions as a result of the gradual washing of aeration zones formed in the upper parts of the pipeline. Both actions lead to a decrease in the frequency of EST purges in the long run.
- The EST system ensures high efficiency of reduction of hydrogen sulfide release in the expansion well and the lack of side effects. Thus no chemical compounds have to be dosed in the situation of a significant nuisance of odors generated by the sewage system.

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Abstract

The EST system – emission-free sewage transport is one of many methods used to counteract and limit the formation of hydrogen sulfide in the sewage system. EST method is the environment and human friendly, and effective at the same time. This solution applies aeration and flushing of pressure pipelines using compressed air with closed vent valves. The paper presents the results of field tests of the EST system, which also verified previous laboratory tests carried out in a broader range.

The tests were carried out on two different delivery pipelines (Object-1, Object-2), consisting of several kilometers long sections *Pump Station – Expansion well* with hydrogen sulfide concentration measurement. The results show that the EST system is an effective solution for controlling hydrogen sulfide in a pressure sewage system. The application of the EST system caused an immediate decrease in H_2S concentration under 50 ppm. The measurements were taken in the expansion well, where short-term outbursts of large loads of hydrogen sulfide were observed during sewage pumping. Purges carried out 1-2 times a day, caused a decrease in instantaneous gas load (from the average level of 758 mg H_2S/pump cycle at Object-1 to 15 mg H_2S/cycle and from 3 914 to 322 mg H_2S/cycle at Object-2).

Results of field studies have also shown that individual optimization of the EST system operation for a selected section of the pressure sewage system (length of the aeration cycle and its frequency during the day), may control the concentration of H_2S. The EST system, reducing the concentration of H_2S by over 90%, ensures the safety of sewage system operation and decreases its impact on the surrounding environment.

Keywords:
pressure sewage systems, pipeline aeration, sulfate corrosion, hydrogen sulfide, elimination of odours, EST system, odour emission

Kontrola stężenia siarkowodoru w kanalizacji tłocznej w systemie bezemisyjnego transportu ścieków

Streszczenie

Wśród wielu stosowanych metod przeciwdziałania i ograniczenia powstawania siarkowodoru, jedną z bardziej przyjaznych zarówno dla środowiska, jak i człowieka, a jednocześnie skuteczną jest system BTS – bezemisyjnego transportu ścieków. Rozwiązanie to bazuje na napowietrzaniu oraz płukaniu rurociągów tłocznych sprężonym powietrzem przy zamkniętych zaworach odpowietrzających. W niniejszym artykule przedstawiono wyniki testów terenowych systemu BTS, które były jednocześnie weryfikacją przeprowadzonych wcześniej w szerszym zakresie badań laboratoryjnych. Badania przeprowadzano na dwóch różnych rurociągach tłocznych (Obiekt-1, Obiekt-2), obejmujących kilkukilometrowe odcinki *Pompownia – Studnia rozprężna* z pomiarem stężenia siarkowodoru. Uzyskane wyniki wykazały, że system BTS jest skutecznym rozwiązaniem kontroli siarkowodoru w kanalizacji ciśnieniowej. Bezpośrednio po jego zastosowaniu stężenie H_2S obniżało się do wartości <50 ppm. Pomiary wykonywane były w studni rozprężnej, w której to obserwowano chwilowe wyrzuty dużych ładunków siarkowodoru podczas pompowania ścieków. Przeprowadzone przedmuchy płuczące rurociągu w cyklu 1-2 razy na dobę pozwoliły na obniżenie chwilowego ładunku gazu z poziomu średniego 758 mg H_2S/cykl pompowy dla Obiektu-1 do 15 mg H_2S/cykl oraz z 3914 do 322 mg H_2S/cykl dla Obiektu-2. Badania terenowe wykazały, że w oparciu o indywidualną optymalizację pracy systemu BTS dla wybranego odcinka sieci kanalizacji tłocznej, w zakresie długości cyklu napowietrzania oraz jego częstotliwości w ciągu doby można uzyskać kontrolę stężenia siarkowodoru zapewniając bezpieczeństwo w zakresie eksploatacji kanalizacji oraz oddziaływania na otaczające środowisko, zmniejszając stężenie gazu o ponad 90%.

Słowa kluczowe:
kanalizacja tłoczna, napowietrzanie, korozja siarczanowa, siarkowodór, system BTS, usuwanie odorów, emisja gazów