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ENGLISH VERSION:
Odor Nuisances in the Wastewater Network of the Sewage Treatment Plant “Rübeland”

Geruchsbelästigungen im Entsorgungsnetzbereich der Kläranlage Rübeland

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1. Introduction

The ”Oberharz“ water and wastewater group operates an extensive sewage system with open channels und pressure pipe lines for collecting wastewater which is then mechanically and biologically cleaned at the sewage treatment plant “Rübeland”, based on the latest technology. This relatively large wastewater network comprises both self-aerating open channels and a number of very long pressure pipe lines that hold wastewater for a long time (> 2 hours) without any oxygen supply. Shortly after the pressure pipe lines were used for the first time, there were unpleasant odor nuisances, especially when the wastewater’s temperature increased. This led to heavy complaints by people living in the area and by tourists staying at the Tanne climatic health resort.

Several attempts were undertaken to remedy the situation; for example, the apportioning of chemicals that release oxygen (Nutriox) and of chemicals that bind sulfur (iron-III-chloride). A very promising attempt, using the DRAUSY System, was initiated on September 16, 2002: A specially perforated hose that evenly disperses air through micro holes across its entire length supplies the wastewater with oxygen. With sufficient air supply, it should be possible to keep the wastewater fresh and free of odors.

2. Problems With Odors in Drain Channels and Pressure Pipe Lines

2.1 Overview

As soon as organic components of fecal matters, food leftovers, or similar substances enter the sewage system microorganisms begin decomposing them. The processes involved in this decay are highly complex, with numerous new substances being created: new living matter and metabolites of these new forms of life. Hence, wastewater is subject to decomposition processes right from the start; intensity and the way this process takes place depend on the kind of wastewater and the prevailing conditions surrounding it.

In contrast to all superior forms of life, many microorganisms can get the oxygen they need from oxygenic compounds of nitrogen (nitrite, nitrate), sulfur (sulfite, sulfate), and even arsenic (arsenite, arsenate), which are found in the water. The microorganisms precipitate the oxygen-free compounds ammonia, hydrogen sulfide, and arsine or the elements nitrogen, sulfur, and arsenic and also the oxygen compounds carbon dioxide and water as respiration products. In an aerobic environment only the oxygen from the air is used, and carbon dioxide and water are the only respiration products.

$$\text{organic substance [C, H]} + O_2 \longrightarrow CO_2 + H_2O + \text{oxidized intermediate products}$$

In both aerobic and anaerobic environments the organic substrate breaks into cleavage products that can be highly diverse, depending on the prevailing conditions – types of microorganisms, temperature, pH-value, oxygen content, etc.

2.2 Sulfur, Nitrogen, and Arsenic Compounds

Wastewater is always rich of sulfur compounds – even drinking water and groundwater already contain sulfur (sometimes up to 250 mg/l). Detergents, urine, and fecal matter add further sulfur compounds. Food leftovers, such as meat, also contain sulfurous proteins, and fecal sludge contains sulfides.

In the absence of dissolved oxygen (anaerobic) the inorganic oxygen sulfide compounds are bacterially reduced to sulfide (desulfurization, dissimilatory sulfate reduction, sulfate respiration):

$$\text{organic substance [C, H]} + SO_4^{2-} \longrightarrow H_2S + H_2O + 2\,OH^-$$

Desulfurizers are special bacteria that exist in almost every environment; they have a high salt tolerance and are widely adaptable:

- desulfovibrio (spirillum)
- desulfomonas
- desulfotomaculum (clostridium)
- desulfococcus
- desulfosarcina
- desulfonema

They operate in temperatures between 5° and 75 °C and within a pH-value from 5 to 9.5. These bacteria are obligate anaerobic; instead of being killed in an environment with a low oxygen content, they only become inactivated. They tolerate hydrogen sulfide up to 2 g/l.

Hydrogen sulfide thus does not inhibit the growth of desulfurizers but it blocks the growth of the accompanying microorganisms or even poisons them. Desulfurizers can be found anywhere, including the sewage film or deposits of wastewater pipes, where they multiply excessively. Apart from the desulfurization the microbial decay of proteins also occurs in an anaerobic environment, forming hydrogen sulfide but also thiols (mercaptans), thioethers, and polysulfides. The contribution of the protein decomposition to the sulfide content is very small. However, due to their odor even in the smallest concentration, one must not fail to mention the formation of organic sulfur compounds and organic nitrogen compounds (scatol and amines, such as putrescine and cadaverine). The minimum amount of the organic sulfur compounds generally perceivable by the senses is often twice to the tenth power lower than those of hydrogen sulfide.

2.3 Conversion Rates and Oxygen Depletion

In fresh domestic wastewater the oxygen depletion is 2 to 4 mg/(l x h); in a pressure pipeline and at a temperature of 15 °C oxygen depletion rates of 10 to 18 mg/(l x h) were measured at the pump well and the mouth of the pressure pipe line. Research on old wastewater showed an oxygen depletion of 15 to 25 mg/(l x h).

The oxygen depletion rates correlate neither with the organic dry substance content nor with the concentration of the organic contamination parameters in the wastewater. The inhibiting factor is the metabolism of the bacteria and not the available substrates. Hence, the multiplication of microorganisms during the "ageing process" of the wastewater is the crucial factor for the oxygen depletion.

In addition to this oxygen depletion in the wastewater, the oxygen depletion in the sewage film, especially in pressure pipelines with a small diameter, is of significant importance. This oxygen depletion is positively dependent on the organic dry substances content in the sewage film. Especially important in this case is the relation between pipe surface and wastewater volume. The oxygen depletion in the sewage film is usually between 250 to 700 mg/(m^2 x h) at a temperature of 15 °C. Based on the diameter of the pressure pipe line the following table shows the influence of the oxygen depletion in the sewage film at 700 mg/(m^2 x h):

Oxygen Depletion in the Sewage Film

Pipe Diameter mm	Pipe Surface m^2/m	Pipe Volume m^3/m	Depletion mg/(m x h)	mg/(l x h)
80	0.25	0.005	175	35
100	0.31	0.008	220	28
200	0.63	0.03	440	14
500	1.51	0.2	1,060	5.6
1,000	3.14	0.8	2,200	2.8

At a volume of 500 mg/(m^2 x h) the oxygen depletion in the sewage film in a DN80 pipe equals 125 mg/(m x h) or 25 mg/(l x h). Together with the oxygen depletion of the wastewater, which is 15 mg/(l x h), the total depletion in this pressure pipe line is 40 mg/(l x h). If the wastewater enters the pressure pipe line with an oxygen concentration of 8 to 10 mg/l O_2, the oxygen will be depleted after approx. 12 to 15 minutes. Then the formation of sulfide slowly begins. The wastewater binds some of the sulfide (e.g. iron in the wastewater); only the additionally formed sulfide leads as hydrogen sulfide H_2S to odor nuisances.

The hydrogen sulfide formation in regular sewage films equals 0.25 to 1.1 g/(m^2 x h) during anaerobic operation of the pressure pipe line. At a formation rate of 1 g/(m^2 x h) and a pressure pipe line with a diameter of 1 m this results in a hydrogen sulfide content of approx. 4 mg/l after only one hour.

2.4 Consequences of the Putrefaction of Wastewater

Through diffusion and turbulences in the sewage installation downstream of the pressure pipe lines the volatile sulfur compounds in the wastewater escape into the atmosphere and thus get into contact with walls and other surfaces. It is here that the sulfur compounds chemically oxidize to elementary sulfur. The sulfur can then be oxidized to sulfuric acid by the different omnipresent thiobacilli. This sulfuric acid corrodes hardened cement paste, calciferous additives, and metals.

Wastewater generally contains less than 5 mg/l of hydrogen sulfide. A hydrogen sulfide content of up to 0.1 mg/l is not critical, less than 1 mg/l is tolerable, and more than 2 mg/l is harmful.

Due to their toxicity, sulfur compounds, and H_2S in particular, can be hazardous to the work force in closed buildings. The extreme toxicity of these sulfur compounds can also have negative consequences on the biological processes of the sewage plant. While there is only a small impact on the performance of biological processes below 3 mg/l sulfur, the performance slump becomes significant at 8 mg/l sulfur, and very strong beyond 24 mg/l sulfur.

Apart from the corrosion the formation of odors is the worst side effect in wastewater pipe lines with an anaerobic environment. The tolerance level with respect to odors has steadily gone down over the last few years; at the same time the demand for protection against them has grown. Aerobic wastewater only has its own peculiar odor, which is usually not unbearable. (Special cases, such as industrial wastewater are clearly an exception.) Odor nuisances only occur in sewage systems with insufficient aeration, and the primary osmogenes that are brought in by the wastewater itself are therefore usually negligible. The secondary osmogenes are the odorous matter that is formed in the wastewater. Generally, the critical osmogenic substances are only formed in an anaerobic environment.

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2.5 Odor Nuisances, Avoidance Strategies

Odors are perceptions of the senses, and different people perceive the same odor differently, both on a qualitative and quantitative level – what a person smells and how strong this smell is perceived varies from individual to individual; in other words, there is a psychological component involved in complaints about odor nuisances. It is virtually impossible to make a clear distinction between acceptable and unacceptable odors.

An investigation into how odors occur can lead to effective avoidance strategies:

- keeping wastewater fresh in order to avoid anaerobic conditions within the wastewater
- avoiding deposits of sludge, dirt and the like; frequent cleaning
- avoiding fecal sludge – including septic tank overflows – at the inlet of the pressure pipe line
- strong turbulences in the pressure pipe line minimize the thickness of the sewage film and thus the intensity of the odor

2.6 Specific Issues With Respect to Wastewater

As long as wastewater remains under mainly aerobic conditions, the formation of odors and corrosive substances will be very limited. Such aerobic conditions only exist, however, if the wastewater is sufficiently supplied with oxygen both in the drain channel prior to the pump station and in the pressure pipe lines. It is also important to regularly clean non-aerated parts of the pump station and the pipe line. The pump well and all hydraulically unfavorable locations of the wastewater transport should be completely emptied in short intervals in order to at least partly aerate the incrustations.

Biological incrustations build up easily at hydraulically unfavorable locations. All deposits, sewage films, and incrustations contain sulfate-reducing bacteria that inoculate the wastewater, which is originally free of desulfurizers. This process enhances the formation of hydrogen sulfide.

In enclosed wastewater pipes (pressure pipe lines) that are not aerated there is an intensive oxygen depletion, depending on the wastewater's transport time and the sewage film. Based on the oxygen saturation – approx. 10 mg/l O_2 – at the time of entry into the pressure pipe line, the oxygen content will be reduced by 8 to 15 mg/(l x h) due to the depletion in the wastewater and by 250 to 500 mg/(m^2 x h) due to the depletion in the sewage film. Lower depletion rates are unlikely, because due to flow paths and flow time prior to the pressure pipe line an ageing of the wastewater with correspondingly high depletion rates and an inoculation with desulfurizers is to be expected.

The minimum flow rate for maintaining sufficient turbulences is generally considered to be 0.5 m/s. If the wastewater is free of sandy deposits and other solids, flow rates of > 2 to 2.5 m/s are also possible; the larger the pressure pipe line's diameter, the faster the maximum flow rate can be without damaging the pipes.

Where aeration with air is difficult or not possible at all, pure oxygen can be used for the oxygen supply of the wastewater. Due to its better solubility, pure oxygen is much more efficient than oxygen from the air. Apart from pure oxygen and oxygen from the air, substances that release oxygen, such as hydrogen peroxide or nitrate, can also be used. The denitrification of calcium nitrate is often used to avoid the formation of sulfide.

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Oxygen Depletion in a Pressure Pipe Line, ø = 80 mm

Depletion in the Sewage Film			Depletion in the Water	Total Depletion	Oxygen Demand at V Pressure Line 5 m^3	
mg/(m^2 x h)	mg/(m x h)	mg/(l x h)	mg/(l x h)	mg/(l x h)	kg/h	kg/d
260	65	13	4	17	0.09	2.0
300	75	15	6	21	0.11	2.5
340	85	17	8	25	0.15	3.0
400	100	20	10	30	0.17	3.6
460	115	23	12	35	0.19	4.2
500	125	25	15	40	0.23	4.8

In order to prevent the release of any potential odors that might exist in the wastewater despite all precautionary measures, any stripping from the wastewater in the transport system downstream of the pressure pipe line must be avoided; in other words, the wastewater needs to flow at a steady pace, and there should not be any steep falls or similar turbulences. The part where the pressure pipe line leads into the sewage plant is particularly vulnerable to odors and corrosion.

The maintenance work for these pipe lines includes the intermediate buffering (possibly with early oxygen supply at the pump station), the pump station, the operation and oxygen supply of the pressure pipe line, and regular cleaning intervals to remove all incrustations.

Technical means are the only reliable way to effectively avoid odor nuisances. This includes dosages of air, oxygen, hydrogen peroxide, or nitrate to influence the oxygen depletion and possibly the apportioning of iron-III-saline solution to bind sulfide.

3. Aeration of a Pressure Pipe Line Section With the DRAUSY-System

On September 16, 2002, a project was begun, using the DRAUSY System to aerate a 1,100 m long section (difference in elevation = 39.6 m) of the sewage system “Hasselfelde — Tanne” between the E3 shaft (approx. 2,450 m past the pump station Hasselfelde) and the B4 shaft (approx. 1,100 m before the test portion shaft in Trautenstein). At the entrance of the pressure pipe line the wastewater is still fresh, as indicated by the oxygen and sulfide contents in the following table:

Date	Temperature °C	O_2 Content mg/l	O_2 Depletion mg/l	Sulfide mg/l	COD mg/l
09-19-2002	14.4	3.5	3.8	0.05	371
10-01-2002	13.4	1.6	4.8	0.10	1,096
10-09-2002	12.1	5.4	3.0	0.06	435

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The following table lists the measured test results at the check point past the aerated pressure pipe line.

Date	Temperature °C	O_2 content mg/l	O_2 depletion mg/l	Sulfide mg/l	COD mg/l
08-16-2001	15.3	0.9	5.5	7.9	--
08-21-2001	16.0	0.1	5.2	4.4	--
12-13-2001	7.3	2.7	7.7	0.09	--
12-14-2001	5.4	1.9	4.0	0.14	--
06-06-2002	12.6	--	--	1.0	1,062
06-24-2002	13.2	--	--	< 0.05	181
07-15-2002	14.5	--	--	< 0.05	159
09-19-2002	14.0	8.7	1.5	< 0.05	38
10-01-2002	13.7	4.9	5.7	0.19	1,292
10-09-2002	12.0	6.5	2.1	0.06	202

The oxygen content in the wastewater below the aerated section was only higher than 2 mg/l O_2 when the wastewater temperature was relatively low; sufficient oxygen contents were only measured after the section had been aerated. With otherwise equal oxygen depletion rates the wastewater's sulfide content (primary parameter for the odor) was high (4 to 8 mg/l in August) at higher temperatures (around 15 °C) and low (< 0.2 mg/l) at lower temperatures (around 5 °C). Since the beginning of the aeration on September 16, 2002, the sulfide content is below 0.2 mg/l even at temperatures around 12 to 14 °C, while the oxygen depletion is around 6 mg/(l x h).

At the same time it becomes apparent that the oxygen depletion rates rise and fall parallel to the COD-concentration. COD test results are needed in order to interpret the processes in the drain channel, especially the reasons for the different oxygen depletion rates.

At later points in the pipe line the oxygen content of the wastewater goes down, depending on the COD concentration – shaft G4, located before the town of Tanne and approx. 4,500 m past the aerated section. The development of the hydrogen sulfide concentration in the air of shaft G4 (tests carried out by "Milieu Analytik GmbH," Magdeburg) still shows extremely high contents. In order to further investigate the situation, it is recommended to also research short-term wastewater samples over one or two days, in addition to the air samples (pH-value, COD, but also on-site: O2, oxygen depletion, and sulfides).

The small number of measurements already show that the DRAUSY System is an effective way to technically control the problems of odor nuisances from pressure pipe lines.

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