KAPITEL 4 / *CHAPTER 4* [4]

CORROSION OF CONCRETE SEWAGE COLLECTOR ON THE EXAMPLE OF LVIV CITY

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Introduction

The main part of existing sewage networks in Ukraine was built more than 50 years ago. The total length of sewage networks was 28.603 thou. km in 2021, including failures – 9.9 thou. km or 34.6%. 0.133 thou. km or 1.4% of the need were replaced during 2021 (Fig. 1) [1].

The part of the emergency C networks in the regions of Ukraine ranges from 22.8% (Kyiv region) to 54.4% (Volyn region) (Fig. 2). The part of the replaced sewage networks (% of those that needed replacement) by region of Ukraine ranges from 0.04% (Zhytomyr Region) to 9.1% (Kyiv Region). Networks in Kirovohrad and Poltava regions were not replaced during 2012 (Fig. 3) [1].

Diameter of pipes of networks are mainly (60%) up to 500 mm made of ceramics, cast iron, asbestos cement and steel (Table 1). Pipelines of larger diameters are mainly concrete and reinforced concrete. More than 65% of sewage pipelines use more than service life. The frequency of failures in the operation of sewage networks - violations of their tightness or throughput is different for each material and decreases with an increase in the diameter of the pipes (Table 2) [2].

Table 1 – Distribution of pipes by diameters of the sewage networks of a city [2]

Diameter, mm	Average value, %
150 … 500	60,0
600 … 1000	27,0
1200 … 2400	12,0
>2400	1,0

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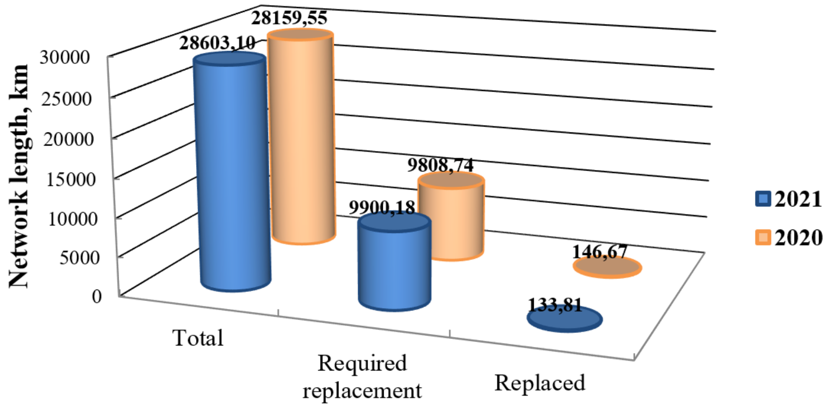

Figure 1 - Technical condition of the sewage networks in Ukraine

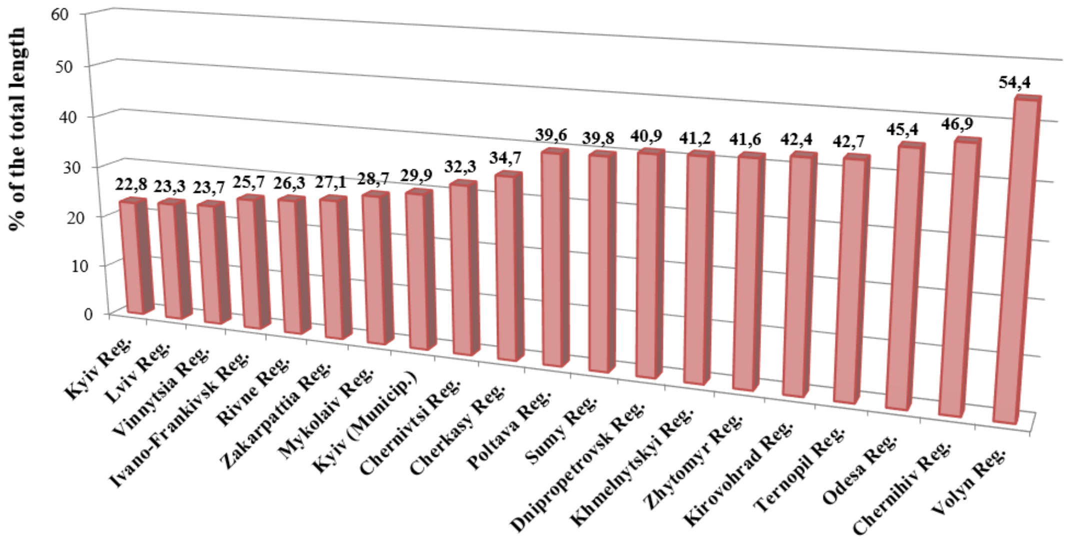

Figure 2 - Part of emergency sewage networks (for 2021 p.) by % of the total length

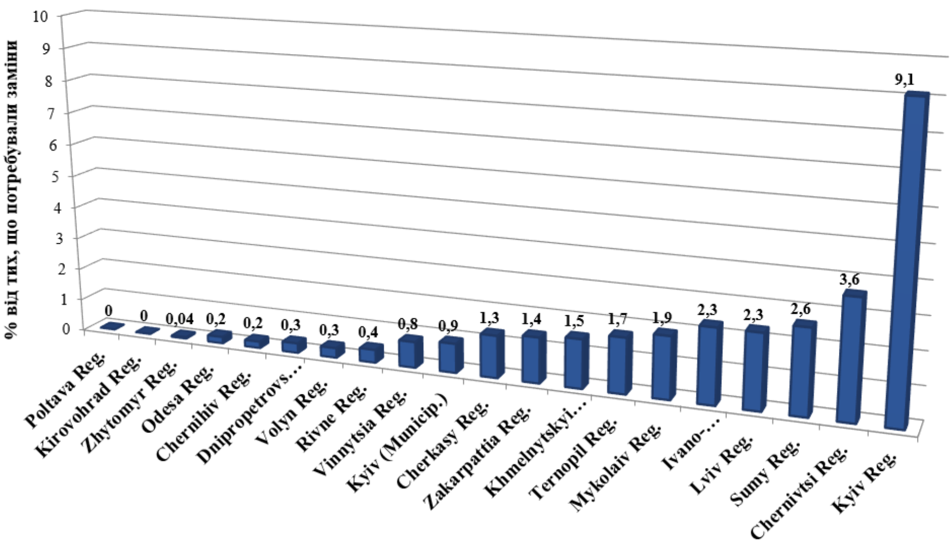

Figure 3 - Part of sewage networks that have been replaced (for 2021 p.) by % of that need to be replaced

Table 2 – The frequency of failures in the operation of sewage networks [2]

The material of the pipes	Diameter, mm	The frequency of failures λ, 1/(km·year)
Steel	200 … 1000	3,05 … 0,03
Cast iron	150 … 800	3,90 … 0,06
Asbestos cement	150 … 500	1,87 … 1,08
Ceramics	200 … 600	1,00 … 0,05
Concrete	400 … 1000	0,15 … 0,02
Ferroconcrete	600 … 3600	0,10 … 0,005

4.1. Causes of failure sewerage networks

The following factors influence the intensity of failures of external sewage networks: service life; hydraulic mode of operation of the drainage network; wastewater quality indicators; pipeline material; diameter and wall thickness of pipes; violation of the tightness of pipelines; pipe deformation; presence (absence) of underground water; laying depth; dynamic loads on the pipeline; clogging of pipelines.

The main reason for changing the hydraulic of pipelines is to reduce water consumption, and therefore waste water. In general, this positive global trend has some negative consequences. In external systems, a decrease in the flow of wastewater leads to a decrease in the speed of fluid movement (less than self-cleaning). This acts leads to a deterioration in the quality of wastewater (its decay), an increase sediment in the pipes and, accordingly, the number of blockages.

The main types of destruction caused by the mode of movement and the chemical composition of wastewater include abrasion of the tray and corrosion of the collector vault. Abrasion of the tray is mainly observed in pressure pipelines. This is due to the hydraulic mode of movement of mainly sand, which settles in the pipe tray during pumping. Corrosion of the collector vault is mainly observed in gravity sewer collectors.

Accidents on pipelines with a diameter of up to 500 mm occur as a result of physical and mechanical influences. Pipelines with a diameter of more than 500 mm are characterized mainly by corrosion damage (about 75%).

Corrosive damage to concrete and reinforced concrete pipelines is characterized by a significant speed and scale, and also has a specific type – the destruction of the pipe vault with good quality of the pipe tray.

Only non-pressure pipelines are destroyed. The emergency of pipelines depends on the chemical composition of wastewater and the availability [2]:

- pressure areas with anaerobic conditions or anaerobic zones in the wastewater flow;
- zones of increased turbulence of wastewater (overflow wells, fast currents, turns, etc.);
- connection of collectors in which the water temperature is higher or the pH is lower than in the main flow of wastewater; significant content of organic substances in wastewater (wastewater of industrial enterprises).

It should be noted that the tendency to increase the number of accidents is characteristic of sewage networks in Ukraine. Emergency leaks from sewage networks have a negative impact on the environment and, in particular, on people [3].

4.2. Mechanism of concrete corrosion of sewage collectors

Today, scientists distinguish three stages of development of microbiological corrosion of sewage collectors [4].

The first stage of development of microbiological corrosion

Abiotic neutralization of the concrete surface. The pH value on the concrete surface of the new collector ranges from 11 to 13 [5]. Under water, a biofilm with a thickness of about 1 mm is formed on the walls of the collector under normal conditions; up to 0.3 mm – at a high speed of wastewater movement; up to 3 mm – at a negligible speed of wastewater movement [6, 7]. The biofilm is inhabited by anaerobic sulfate-reducing microorganisms (SRM) (Fig. 4).

As a result of sulfate respiration and oxidation of organic substances contained in wastewater, they form hydrogen sulfide and carbon dioxide according to the equation [8, 9]:

$$Organic\ substances + SO_4^{2-} \xrightarrow{SRM} H_2S + \mathrm{CO_2}. \quad (1)$$

The formed hydrogen sulfide enters the wastewater, where it is in molecular form, as well as in the form of dissociated ions H^+ i HS^-. At a normal pH value for domestic wastewater (6.5–8), 25–35% of dissolved sulfides exist in the form of molecular H_2S [5].

Through the "liquid-gas" phase interface H_2S i is released into the space under the vault of the collector and dissolves in the condensation film on the walls of the collector. Where H_2S dissociates into ions again H^+ i HS^-. And the surface of concrete is saturated with products of oxidation of hydrogen sulfide with air oxygen – sulfur, thiosulfate, polythionates [5]. CO_2 in turn, dissolves with the formation of carbonic acid in various forms (H_2CO_3, H^++HCO^{3-}, $2\ H^++CO_3^{2-}$). Weak acids formed in the condensation film react with alkalis in concrete (for example, $Ca(OH)_2$), reducing over time the pH of the concrete surface to 9 [5].

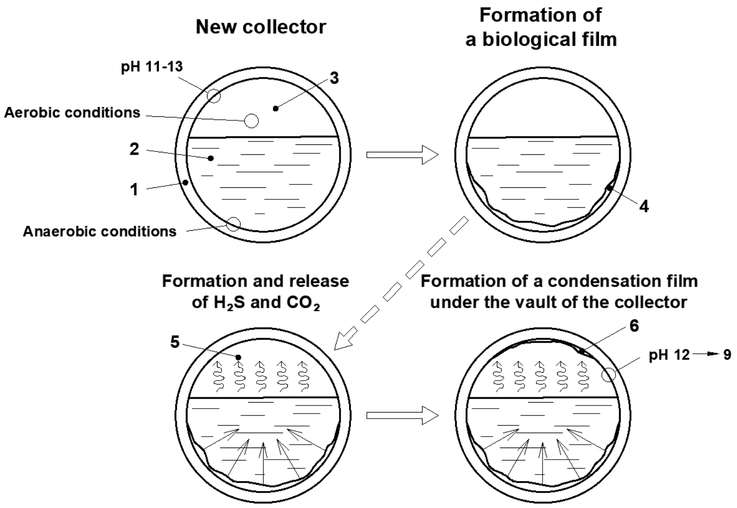

Figure 4 - The first stage of development of microbiological corrosion [4]:
1 – cross-section of the sewer collector; 2 – waste water; 3 – space under the vault of the collector (gas sphere of the collector); 4 – biofilm; 5 – released gas; 6 – condensation film

The second stage of development of microbiological corrosion

Colonization by neutrophilic bacteria. With a sufficient amount of oxygen, nutrients and humidity, neutrophilic microorganisms that oxidize sulfur begin to populate the concrete surface when the pH decreases to 9 (Fig. 5) [5, 10]. Such microorganisms include bacteria of the genus *Thiobacillus, Thiomonas, Hallothiobacillus, Starkeya, Thiospira and Paracoccus*. Bacteria oxidize H_2S to H_2SO_4, which diffuses into the condensation film [5, 10].

The formed sulfuric acid reacts with silicate and carbonate compounds in the cement component of concrete. At the same time, mechanically weak gypsum is formed by such reactions [5]:

$$H_2SO_4 + CaO\cdot SiO_2\cdot 2H_2O \rightarrow CaSO_4 + Si(OH)_2 + H_2O; \quad (2)$$

$$H_2SO_4 + CaCO_3 \rightarrow CaSO_4 + H_2CO_3; \quad (3)$$

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$$H_2SO_4 + Ca(OH)_2 \rightarrow CaSO_4 + H_2O. \quad (4)$$

The formation of gypsum leads to an increase in the volume of the solid phase by approximately 124%, which weakens the cement structure [9]. During the second stage, the pH of the concrete surface is constantly decreasing. At a pH value of 7, the concrete is inhabited by micromycete fungi, which use their filamentous cells (hyphae) to penetrate the cracks of the surface layer, and therefore destroy the concrete. The penetration of mycelium of fungi into the concrete contributes to the fixation of other microorganisms and the penetration of the products of their vital activity into the body of the concrete. At this stage, concrete still retains its mechanical strength [5].

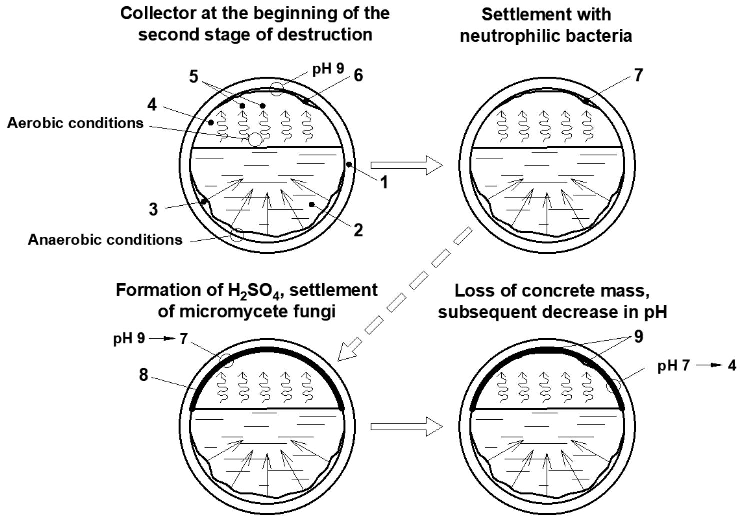

Figure 5 - The second stage of development of microbiological corrosion [4]:
1 – cross-section of the sewer collector; 2 – waste water; 3 – biofilm; 4 – space under the vault of the collector (gas sphere of the collector); 5 – released gas; 6 – condensation film; 7 – colonies of neutrophilic bacteria; 8 – sulfuric acid; 9 – a layer of corrosion products

The third stage of development of microbiological corrosion

Colonization by acidophilic bacteria. The main loss of concrete mass. This stage occurs when the pH on the concrete surface decreases to 4 [8]. Colonization by acidophilic microorganisms that oxidize sulfur begins [5, 10]. Acidophilic thione bacteria (*Acidithiobacillus thiooxidans*) are the largest producers of sulfuric acid. They also oxidize thiosulfates, polythionic acids and elemental sulfur, which is deposited on the vaults of the collector as a result of the oxidation of hydrogen sulfide by oxygen in the air under the vault of the collector [6]. The activity of acidophilic bacteria reduces the pH to 1–2.

The third stage of microbiological corrosion (Fig. 6) is characterized by a sharp increase in the rate of destruction of the material. Under the action of sulfuric acid, calcium oxide hydrate turns into gypsum according to reactions (2) and (3). However, the further reaction (5) between gypsum and tricalcium aluminate inside the cement matrix at the border of destroyed and not yet destroyed by corrosion concrete with the formation of the mineral ettringite [5] is more destructive:

$$CaSO_4 + 3CaO{\cdot}Al_2O_3{\cdot}6H_2O + 25H_2O \rightarrow 3CaO{\cdot}Al_2O_3{\cdot}CaSO_4{\cdot}31H_2O. \quad (5)$$

The formation of ettringite leads to a tenfold increase in the volume of destroyed concrete. A significant amount of water of crystallization is observed in the structure of ettringite. In turn, this leads to internal cracking and the formation of pores in the concrete. Consequently, the reaction surface increases, and moisture, acid and microorganisms penetrate more easily into the body of concrete. The depth of concrete softening increases rapidly [5]. Throughout the corrosion process, a soft white layer of corrosion products (mainly gypsum) is formed on the concrete surface, which gradually thickens.

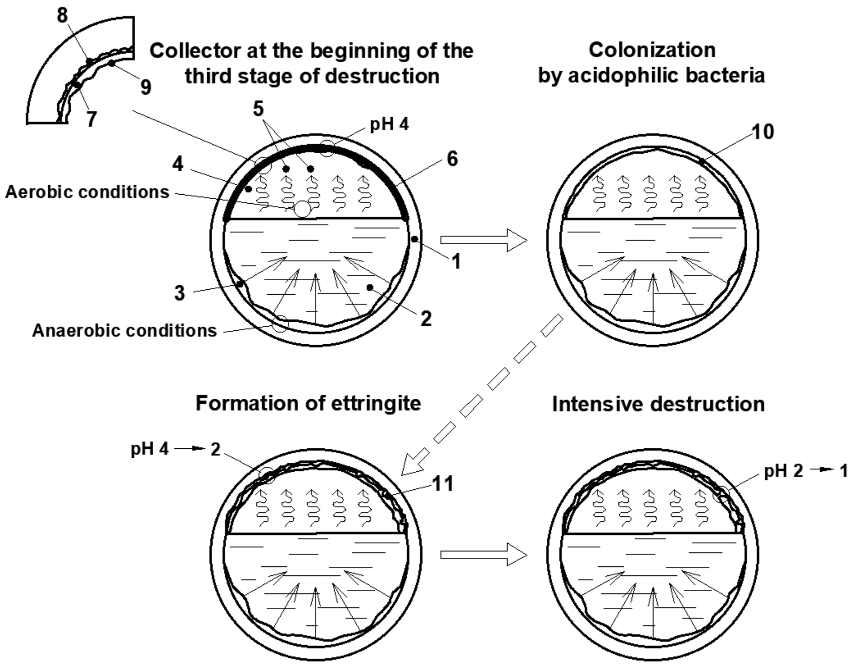

Figure 6 - The third stage of development of microbiological corrosion [4]:
1 – cross-section of the sewer collector; 2 – waste water; 3 – biofilm; 4 – space under the vault of the collector (gas sphere of the collector); 5 – released gas; 6 – condensation film; 7 – colonies of neutrophilic and acidophilic bacteria; 8 – sulfuric acid; 9 – a layer of corrosion products; 10 – bacterial colonies; 11 – ettringite

The destruction of the protective layer of concrete leads to the exposure of the reinforcement. Its surface is inhabited by aggressive thione bacilli *Acidobacillus ferroxidans*. They get energy for their vital activities by oxidizing divalent iron to trivalent, as well as sulfur compounds with the formation of sulfuric acid [8, 9].

4.3. Gravity sewage collector in the city of Lviv on Akademika Sakharova Street

A visual inspection of the collector area (photo 1) indicates the development of the second stage of microbiological corrosion of its vault (photo 2). Silting of the tray part of the collector (photo 3) leads to its destruction..

Conclusions

The presented materials describe the technical condition of sewage networks in Ukraine for 2021. The reasons for malfunctioning of sewage networks are outlined. The mechanism of concrete corrosion of sewage collectors is described. On the basis of a visual inspection of the gravity sewage collector of the city of Lviv, the development of the second stage of its microbiological corrosion was revealed.

Photo 1 – Sewage collector on Akademika Sakharova Street (Lviv)

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Photo 2 – Vault of the sewer collector

Photo 3 – Sewage collector tray

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