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METHODS USED IN DISINFECTIONS OF WASTEWATER AND SEWAGE SLUDGE – SHORT REVIEW

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Abstract
Wastewater and sewage sludge are a place of occurrence of many microorganisms, including viruses, pathogenic and relatively pathogenic bacteria. They can leak into other environments, i.e. receiver waters or soil, thus creating a biological hazard. Increasing the sanitary level of safety of municipal wastewater treatment plants requires the introduction of disinfection of sewage and sewage sludge.
The purpose of this article is a short review of the literature on methods used in disinfection of wastewater and sewage sludge. The work discusses the sanitary characteristics of wastewater and sewage sludge, primarily paying attention to the physical and chemical methods used to disinfect them. In addition, attention was also paid to the aspect of practical use of disinfection in municipal wastewater treatment plants around the world.

Keywords: **Disinfection; Microorganisms; Sanitary properties; Sewage sludge; Wastewater.**

1. INTRODUCTION

The problem of a proper water management is not only the decreasing water resources in the world, the consumption of which exceeds possibilities of their renewal, but also deteriorating water quality to the extent preventing from natural self-cleaning processes. Due tothe above, it is extremely important to protect water resources, that are treated wastewater receivers. Removal of microorganisms found in sewage and sewage sludge is a significant problem of the 21st century.

In Poland, on an annual basis (according to data for 2018), 2.3 km^3 of sewage is required for treatment, and 583 070 t of sewage sludge is generated [1, 2]. The vast majority of wastewater intended for treatment is municipal wastewater discharged mainly to the surface waters. Despite of the significant development of wastewater treatment technology, it should be remembered that treated wastewater may pose a significant microbiological threat to the quality of receiver waters, and sewage sludge contains more than 50% of raw sewage contaminants. When using highly efficient biological methods of treatment, reduction in the initial number of indicator bacteria is over 99%, however, taking into account their high number in raw sewage, their elimination is definitely insufficient [3, 4, 5].

2. WASTEWATER AND SEWAGE SLUDGE – CHARACTERISTICS AND SANITARY PROPERTIES

Wastewater is defined as water used for domestic or economic purposes entering into water or into the ground. [6]. The type and amount of sewage generated depends both on the population and negative effects of human activities: domestic, recreational and industrial. Their composition depends on a number of factors, among which the most important are: place of origin, type of sewage system, amount of sewage delivered from non-sewage areas, amount and type of industrial, raw or partially pre-treated wastewater, as well as the amount of infiltration or exfiltration caused by leaks in the sewage network [4, 7]. All these factors affect the patterns of discharge as well as chemical and biological state of raw wastewater that will be treated.

Wastewater, as it is commonly known, is a place of many microorganisms occurrence, including viruses and pathogenic bacteria. Their number is subject to significant changes over time, and depends primarily on the composition of raw sewage flowing into the treatment plant [8]. Household sewage is a large percentage in raw municipal sewage – their microbiological composition is therefore determined by human intestinal microbiome populations. The number of pathogenic bacteria in sewage, which is a minority of the total number of bacteria, depends on the number of patients in a given population and the amount of sewage they produce. However, the vast majority of sewage microflora are viruses. The number of viral particles can be up to five times greater than the number of bacterial cells [9]. Among the microflora of sewage, protozoa are the least numerous [10].

Hospital wastewater is a special type of wastewater. Their composition depends on two the most important factors: size of the hospital unit (number of beds, number and type of departments operating within its structure) and the number and type of general services provided by a given unit (kitchen, laundry, diagnostic, microbiological laboratories, etc.) [11, 12]. Physicochemical characteristics of hospital wastewater, in terms of basic parameters, is similar to that of municipal wastewater. In addition to basic parameters, they are characterized by the content of a number of various chemical substances potentially harmful to the environment, among others, disinfectants, detergents, substances from analytical and radiological laboratories and, above all, pharmaceutical products [13]. In hospital wastewater, there is an increased, compared to typical municipal wastewater, number of clinically important microbes, i.e. drug-resistant and pathogenic bacteria. In addition to bacterial strains, they can also contain parasite eggs and numerous viruses, including HIV and hepatotropic viruses that cause hepatitis [14].

Sewage sludge is an inseparable product resulting from the wastewater treatment process. It is estimated that the volume of generated sludge accounts for about 2% of treated wastewater, and they also contain more than half of the total load of pollutants entering the wastewater treatment plant [15, 16]. Sanitary properties of sewage sludge are recognized less than their chemical properties. Sewage sludge is undoubtedly an environment conducive to the development of microorganisms. This is home to bacteria, fungi, viruses, protozoa and parasitic worms. Bacteria are the most common group of microbial sewage sludge contaminants, and the most frequently marked include: *Escherichia coli, Salmonella sp., Shigiella sp., Pseudomonas aeruginosa, Bacillus anthriacis, Clostridium perfingens, Vibro cholera, Listeria monocytogenes, Proteus vulgaris, Streptococcus faecialis.* However, the highest significance is attached to the occurrence of Salmonella, which is the basic indicator of sewage sludge quality [17]. Table 1 shows the number of microorganisms in 1 g wet mass of raw sewage sludge.

Table 1.
Number of microorganisms in 1 g of wet mass of raw sewage sludge [18]

Organism	Type/Genus	Number in 1 g wet mass of sediment
Bacteria	*E. coli*	10^6
	Salmonella	$10^2 - 10^3$
Viruses	*Enteroviruses*	$10^2 - 10^4$
Protozoa	*Giardia*	$10^2 - 10^3$
Helminths	*Ascaris*	$10^2 - 10^3$
	Toxocara	$10 - 10^2$
	Taenia	5

Sewage and sewage sludge allow microbes to enter other environments – soil or receiver waters, causing biological hazards of varying degrees of severity [15, 19].

According to the United States Environmental Protection Agency (US EPA), the average bacterial survival in soil, or on plant surfaces, ranges from a month to two months, and their maximum life is 1 year [20]. Therefore, increasing the level of sanitary safety of municipal sewage treatment plants requires widespread disinfection of sewage and sewage sludge.

3. METHODS USED IN DISINFECTION OF WASTEWATER AND SEWAGE SLUDGE

Disinfection of wastewater or sewage sludge hygienization, is any intentional process of destroying microorganisms, in particular pathogenic, by physical and chemical or biological methods. Unlike sterilization, disinfection does not ensure complete inactivation of all live forms of microorganisms. In mechanical-biological sewage treatment plants, the following are of basic importance in the removal of microorganisms: sorption on suspended particles, predation by higher organisms and dying caused by competition for food or adverse environmental conditions [21]. At the stage of mechanical wastewater treatment, sorption is the dominant factor. Microorganisms adsorbed on the surface of the suspension particles are removed in the sedimentation process in the primary settling tank, where the effectiveness of this process ranges from 25 to 75%. Bacterial spores, protozoan cysts/oocysts and coliform bacteria are removed to the smallest degree [22, 23]. Table 2 presents the percentage reduction in the number of bacteria contained in wastewater after sedimentation process in the primary settling tank.

Table 2.
Bacteria removal from wastewater in sedimentation process in the primary settling tank [21, 24]

Type/Genius	Reduction [%]	Source
Coliforms	10	Bitton [2011]
Faecal coliforms	35	Bitton [2011]
Escherichia coli	15	Olańczuk-Neyman and Quant [2015]
Mycobacterium tuberculosis	50	Olańczuk-Neyman and Quant [2015]
Salmonella spp.	15	Olańczuk-Neyman and Quant [2015]
Shigella spp.	15	Olańczuk-Neyman and Quant [2015]
Clostridium perfingens	60	Bitton [2011]

In the biological stage of the wastewater treatment process, protozoa and higher organisms found in activated sludge play an important role in regulating the number of bacteria. As a result of predation, the number of slow-flowing bacteria present in the stream of treated wastewater decreases, which results in the elimination of faecal bacteria. In addition to predation, sorption on activated sludge flocs also plays an important role. Two basic mechanisms are responsible for the elimination of viruses: phage sorption on activated sludge flocs and viral erosion by activated sludge microorganisms. Generally, in biological wastewater treatment processes, the efficiency of removing the microorganisms is higher than at the mechanical stage, ranging from 90 to 98%. At the same time, it should be remembered that traditional methods of wastewater treatment do not significantly reduce the number and viability of protozoan cysts and oocysts [25, 26].

Currently, in water and rather wastewater technology, disinfection is one of the basic barriers preventing and limiting the spread of microorganisms causing diseases of aquatic origin, which aims at protecting a public health and reduce the risk of illness among people. Currently available methods of disinfection of sewage and sewage sludge differ in terms of effectiveness and reliability, investment and operating costs as well as undesirable effects of the application of disinfectants, therefore, when performing the method selection, a thorough analysis is necessary [21]. It should also not be forgotten that the effective reduction of the microorganisms number in sewage and sewage sludge subjected to various disinfection methods depends to a large extent on the quality of the sewage subjected to the process.

Table 3 presents the division of the methods described in this paper, including the application for disinfection of sewage and sewage sludge.

Table 3.
Selected methods used in disinfection of wastewater and sewage sludge

Methods used in disinfection	Disinfection of wastewater	Disinfection of sewage sludge
Chlorination	+	+
Ozonation	+	+
Performic acid (PFA)	+	-
Peracetic acid (PAA)	+	+
Pasteurization	+	+
UV radiation	+	+
Membrane methods	+	-
Ultrasounds	+	+

3.1. Chemical disinfection methods

Chlorination

The use of chlorine is the cheapest and the most common disinfection method. The effect mainly depends on the composition of sewage, chlorine dose, pH, temperature, contact time, type and number of microorganisms. As the reaction progresses, the pH increases, the sewage temperature decreases, the dose and contact time decrease, the disinfection effects decrease [27]. At pH values below 5.0, chlorine compounds remain in the dissociated form, and they dissociate when the pH increases significantly. The ions formed are a much weaker disinfectant than undissociated forms [21].

For disinfection of sewage and sewage sludge, the most commonly used are: chlorinated lime, calcium hypochlorite ($Ca(ClO)_2 \times 4H_2O$), sodium hypochlorite ($NaClO \times 5H_2O$), chlorine (as chlorinated water) and chlorine dioxide. All forms of chlorine are very corrosive and toxic and, if not handled properly, can be very dangerous [21, 27].

Typical concentrations of chlorine gas used to disinfect the outflow from a municipal sewage treatment plant range from 5 to 20 mg/dm^3 at 30–60 min. contact time (the condition is low suspension content) [21].

Chlorinated lime and calcium hypochlorite are usually used in small sewage treatment plants and for disinfection of screenings, sand from sludge, in particular raw sludge [28]. The most effective chlorine inactivates bacteria. Viruses, bacterial spores, cysts and protozoa oocysts (*Cryptosporidium parvum, Giardia lamblia, Entameba histolytica*) and helmint eggs are more resistant to chlorine than bacteria [29]. Chlorination of sewage and sewage sludge requires prior treatment and knowledge of their detailed characteristics. As indicated by Ji et al. [30], free chlorine effectively inactivates gastroenteritis viruses.

Chlorine doses intended for disinfection of municipal sewage are usually not they destroy spore forms of bacteria and parasitic worm eggs. The stimulating effect of chlorine on egg development up to the invasive stage is sometimes observed. Chlorine disinfection is currently the most commonly used disinfection method emergency. Due to the formation of organochlorine compounds, continuous disinfection of municipal wastewater with chlorine compounds should not be used [27].

Ozonation

Ozone with 2.07 V oxidizing potential (at pH 7) is one of the strongest oxidants used in wastewater treatment. Ozone destroys bacteria much more effectively than chlorine [21]. It is an effective microbicide that destroys all microorganisms potentially found in wastewater, including viruses as well as protozoan cysts and oocysts. The process of microorganisms inactivation occurs rapidly even at low ozone concentrations (e.g. 13 mg/dm^3), at residual concentrations (1 mg/dm^3) of chlorination-resistant microorganisms, e.g. protozoan cysts *Cryptosporidium* and *Giardia* [31]. The effectiveness of the ozonation process depends on the susceptibility of organisms, contact time and ozone concentration [32]. The ozonation process is short (10–30 minutes), and ozone doses for biologically treated sewage are in the range from 15 to 30 mg/dm^3 [33]. Although ozonation is a recommended method for technological reasons, it is associated with high economic costs, which limits its use. Ozone treatment is a unique method of disintegration of sewage sludge, due to the lack of formation of by-products.

Performic acid and peracetic acid

<u>Performic acid (PFA)</u> is the strongest oxidant used for disinfection with an oxidizing potential of 2.70 V. Its effectiveness has been confirmed in the inactivation of pathogenic microorganisms, including viruses and bacterial spores. The highest PFA activity is shown at the pH close to 7.0 (at higher pH values, the PFA activity decreases), also a decrease in temperature decreases its activity [34]. PFA does not generate by-products and does not increase the biological or chemical oxygen demand, disinfects quickly and then decomposes into carbon dioxide and water [35]. Despite the low durability of performic acid, PFA is used in wastewater disinfection. Disinfection of outflows after the first treatment stage with PFA at a dose of 6 mg/dm^3 at 45 min. contact causes complete removal of faecal coliforms [21, 35, 36, 37].

<u>Peracetic acid (PAA)</u> is considered an effective disinfectant to fight bacteria, viruses, fungi and spores, which has a stronger oxidizing potential than chlorine and chlorine dioxide. Apart from high efficiency of bacterial and virus neutralization as well as low level of by-product formation, the advantages of PAA include the lack of influence of the pH value on the process efficiency and short contact time required. The use of PAA at a concentration not exceeding 1 mg/dm^3 does not contribute to the formation of mutagenic products in wastewater. The product of peracetic acid decomposition is acetic acid, which is an easily biodegradable compound. This feature causes danger of secondary microbial growth in wastewater without residual peracetic acid. PAA can be used to disinfect all types of wastewater, also in the presence of organic matter, but the disinfection efficiency is clearly weaker in the case of outflows after the first treatment stage [21, 38, 39]. A serious limitation of the use of PAA in wastewater disinfection is its high cost.

The use of PAA in the hygienization of sewage sludge reduces the viable fraction of all bacteria within 12 hours after application, including vegetative forms capable of forming spores [48].

3.2. Physical disinfection methods

Pasteurization

Pasteurisation is a process of thermal decontamination of wastewater or sewage sludge (digestate, less often raw) at temperatures from 65 to 90°C, for 5 to 30 minutes. During classical pasteurization, the vegetative forms of microorganisms are destroyed and the spore forms and bacterial spores die only at temperatures above 100°C. At least two separate rounds of pasteurization are needed to eliminate endospores, an expensive procedure. Pasteurization is commonly used for disinfection of treated sewage, while in the case of sewage, it is economically justified in locations where sewage sludge management allows for highly efficient use of biogas from sludge fermentation [28, 40, 48].

UV radiation

UV disinfection involves the production of radiation of an appropriate wavelength and transmission capacity to microorganisms; its effectiveness depends therefore on the properties of radiation emitting devices as well as conditions prevailing in the disinfected environment. The least resistant to UV radiation are bacteria and viruses, slightly more yeast, and most moulds. Spore forms are more resistant than vegetative forms. UV-C radiation with a wavelength of approx. 254 nm shows the highest disinfecting efficiency against microorganisms [21]. The basic mechanism of bactericidal action of UV rays is associated mainly with changes induced in nucleic acids, mainly in DNA nucleotides. Disinfection with UV radiation is the best, proven, accepted and ecological method of wastewater disinfection, giving high results in the case of well-treated sewage. The presence of solid particles and suspended solids in the wastewater reduces the effectiveness of the UV disinfection process [28, 41].

Membrane methods

Disinfection using membrane methods involves physical removal of microorganisms by means of broadly understood filtration. The membranes used constitute a physical barrier, on which particles of specific dimensions are separated from the flowing liquid. The separation takes place using pressure and specially designed porous semi-permeable membranes. Membrane filtration, especially ultrafiltration (with a pore size in the range from 0.001 to 0.1 μm) and microfiltration (with a pore size in the range of 0.2 to 10 μm) can be used to increase and improve the disinfection of water and biologically treated wastewater. The use of membrane techniques guarantees theoretically very high efficiency in relation to the number of removed microorganisms. Ultrafiltration acts as a barrier to viruses, bacteria and protozoa, microfiltration does not remove viruses [42, 43]. In addition to the diameter of membranes, process parameters, i.e. transmembrane pressure and turbidity of the feed, have significant impact on the removal of microorganisms. Membrane methods are completely non-reacting and require no additional installation, except for pumps, but high cost is their significant disadvantage [44].

Ultrasounds

Ultrasounds, i.e. vibrations with a frequency of 20–100 kHz, are sound vibrations that interrupt the continuity of cellular shields. The effectiveness of ultrasound disinfection depends on the intensity, frequency, duration of ultrasound and the type and number of microorganisms destroyed. Nowadays, research is being conducted on the use of low and high frequency ultrasound in disinfection of sewage and sewage sludge on an increasing scale. They confirm the effectiveness of ultrasonic waves in destroying microorganisms [8, 16, 17, 45, 46].

4. SUMMARY AND CONCLUSIONS

Disinfection can be carried out in many physical or chemical ways. Currently, there are also attempts to use alternative methods that are a combination of physical and chemical processes, or using advanced oxidation methods with high efficiency in neutralizing pathogens, such as PEROXONE (dosing into ozone-treated hydrogen peroxide) [47].

In operational practice, some countries have introduced partial disinfection of wastewater discharged from sewage treatment plants; in Germany – wastewater discharged into recreational areas is disinfected, in France – sewage discharges in protected areas, such as bathing areas and mollusc farming areas, and in Spain – wastewater for agricultural irrigation, fruit trees, sports fields and gardens [28]. The most stringent sewage disinfection law applies in the United States (California), where continuous disinfection is carried out. In Poland, however, disinfection of treated wastewater in properly operated municipal (mechanical-biological) sewage treatment plants, in general, is not carried out.

Disinfection of sewage and sewage sludge should be considered as a necessary element in public health control. The protection of water resources requires increasing the efficiency of the wastewater treatment process, which is associated with obligatory introduction of disinfection as a barrier against the spread of waterborne diseases.

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