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ULTRAVIOLET LIGHT POTENTIAL FOR WASTEWATER DISINFECTION

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Abstract
Water and wastewater require disinfection to meet the regulated limit conditions for the microbial load. The main objective of disinfection is to reduce the concentration of pathogens (bacteria, viruses and protozoa) in the water at levels below the limits of infections. Disinfection can be carried out by thermal (heat pasteurisation, solar pasteurisation), physical (filtration, ultrasounds, high pressure, electron beam, gamma irradiation, ultraviolet irradiation) or chemical means (chlorination, acidification, alkaline addition, ozone, enzymes, carbon-based materials). Ultraviolet (UV) light is a form of electromagnetic radiation having wavelengths between 10 and 400 nm. Experimental UV wavelength ranges from 200 nm to 400 nm and is subdivided in UV-A (315–400 nm), UV-B (280–315 nm) and UV-C (200–280 nm). The last one is called the germicidal range because it effectively inactivates bacteria and viruses. UV light is able to inactivate microorganisms, reducing the microbial load in thin film of drinking water and wastewaters. The germicidal effect consists of damaging the nucleic acid, thus preventing the replication of microorganisms. UV light inactivates water-borne pathogens in the following order: protozoa, bacteria, bacterial spores, viruses and bacteriophages. While UV light irradiation has not been largely used in drinking because it leaves no residual to provide protection against further contamination, it is well suited for wastewater treatment, the absence of any residual in treated water being an advantage for the aquatic life.

Keywords: ultraviolet light, electromagnetic radiation, disinfection, inactivation, water-borne pathogen, protozoa, bacteria, spores, viruses, bacteriophages, wastewater.

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1. INTRODUCTION

Water used for irrigation, water for fish farming, surface water, recreational water, water used in food production facilities, drinking water and wastewater have been recognised for years as responsible for millions of deaths and billions of illnesses annually (Burch & Thomas, 1998; Sommer et al., 2000). Water is a vector for many water-borne pathogens (bacteria, viruses, protozoa, worms) able to produce different kind of diseases: diarrhoea, cholera, enteric and typhoid fever, dysentery, hepatitis, polio, meningitis, lung diseases, giardiasis, schistosomiasis etc. (Burch & Thomas, 1998; Gleick, 2002). As a consequence of the above-mentioned and following the same line of thought, water disinfection became a compulsory intervention that can improve public health and it has to meet the regulated limit conditions for the microbial load. The main objective of disinfection is to reduce the concentration of pathogen in the water at levels below the limits of infection. To achieve this purpose / In order to achieve this, disinfection must inactivate a wide range of bacteria, viruses and protozoa in different types of water and wastewater. Disinfection can be carried out by thermal, physical or chemical means.

Thermal disinfection involves the use of thermal energy (Stuckey & McCarty, 1984; Li & Noike, 1992; Baier, 1997) and is performed as heat pasteurisation (Islam & Johnston, 2006) or solar thermal pasteurisation (Burch & Thomas, 1998; Ericsson et al., 2002; Duff & Hodgson, 2005).

Physical means include treatments such as mechanical disintegration (Baier & Schmidheiny, 1997; Kopp et al., 1997), low sand filtration, membrane filtration (Kim et al., 2002), ultrasounds (Muller & Schwedes, 1996; Tiehm et al., 1997; Chu et al., 2001), high pressure (Dollerer & Wilderer, 1993), electron beam (Farooq et al., 1993), gamma (γ) irradiation (Thompson & Blatchley, 2000;

Taghipour, 2004) and ultraviolet (UV) irradiation (Whitby & Palmateer 1993; Hassen et al., 2000; Taghipour, 2004; Koutchma et al., 2009).

Chemical means comprise chlorination (Burch & Thomas, 1998; Kim et al., 2002), acidification (Gaudy et al., 1971; Woodard & Wukasch, 1994), alkaline addition (Mukherjee & Levine, 1992; Lin et al., 1989; Haug et al., 1978), mixture of chemicals such as peracetic acid (PAA), hydrogen peroxide (H_2O_2) and sodium hypochlorite (NaOCl) (Koivunen & Heinonen-Tanski, 2005), ozone (Burleson et al., 1975; Yasui & Shibata, 1994; Khadre et al., 2001), titanium dioxide photocatalysis (Watts et al., 1995), enzymes (Knapp & Howell, 1978) and carbon-based nanomaterials (Kang et al., 2009).

Of these, the most widely used methods of water disinfection include chlorination, slow sand filtration, pasteurisation and UV radiation. In order to reduce turbidity, pre-treatment of water with a coarse roughing filtration is generally used with the first three methods. This also contributes to a severe reduction of cysts and worm eggs and to the maintenance of a high efficiency of the disinfection treatment.

Among chemical methods using disinfectants (chlorine, bromine, iodine, chlorine dioxide, chloramines etc.) for the disinfection of drinking water, chlorination is the most popular (Kim et al., 2002). Chlorine is inexpensive, corrosiveness and has long-term effectiveness. However, chlorination requires continuous supply of disinfectant (Burch & Thomas, 1998). There are also concerns related to the presence of chlorination by-products (i.e., chlorinated organics) in domestic drinking water, which have adverse health effects, notably the carcinogenity of trihalomethanes.

Slow sand filtration is easy to achieve, has the lowest cost but requires large investments in labour (Huisman & Wood, 1974; Burch & Thomas, 1998).

Pasteurisation of water for disinfection has been widely used as many pathogenic bacteria are easily destroyed at high temperatures. An example is heat pasteurisation of water for boiler water system where *Legionella* was found to be almost instantly inactivated at temperatures higher than 70°C (Lin et al., 1998). Boiling of water does not require initial costs, but fuel and labour are very high. Solar pasteurisation disinfects drinking water but does not remove other contaminants without additional filtration or treatment. Solar pasteurisation devices, batch and flow-through, are effective and relatively maintenance-free, and have a depreciation period of about 5 years. However, some are expensive (i.e., solar panels, reflectors) and the existing products yield high treatment cost.

UV radiation can inactivate microorganisms, reducing the microbial load in air, on hard surfaces and in thin layer of liquid food. It can also eliminate pathogens from potable water and fruit juices (Koutchma et al., 2009). UV light has been used for years for water sterilization, showing effectiveness against a wide variety of microorganisms (Yip & Konasewich, 1972). Since then, the disinfection of drinking water and wastewater by UV light was investigated in several studies (Qualls et al., 1983; Chang et al., 1985; Shama, 1992; Whitby & Palmateer, 1993; Liltved & Cripps, 1999; Sommer et al., 2000; Sutton et al., 2000). Batch treatment with solar UV light is very easy to perform but efficiency in practice is uncertain since temperatures above 50°C should be reached (Burch & Thomas, 1998). Equipments provided with UV lamps are inexpensive, easy to use and can be designed in various ways. However, they require power and access to maintenance infrastructure (Burch & Thomas, 1998).

An increasing awareness of the disadvantages of chemical disinfectant has lead to the selection of UV radiation as a promising alternative for water disinfection (Taghipour, 2004). The comparison of UV radiation effects to those of chlorination evinces the fact that UV light treatment does not produce disinfection by-products or chemical residuals as in the case of chlorine disinfection. While both treatments seem to be noncorrosive, the community safety risks are much higher when

chlorination is applied. Moreover, UV radiation devices are well-suited for changing regulations.
The aim of this work is to evaluate available literature data concerning UV disinfection of water and wastewater and to discuss the efficiency of this treatment compared to other disinfection methods such as chlorination.

2. UV LIGHT ELECTROMAGNETIC SPECTRUM

UV light is a form of electromagnetic radiation having wavelengths shorter than that of visible light, but longer than X-rays. This spectrum consists of electromagnetic waves having frequencies invisible to humans, but visible to some insects and birds. These frequencies are higher than those that human eye identifies as the violet colour; therefore, they are called „ultraviolet".
UV light is found in sunlight and is emitted by electric arcs and specialized lights such as black lights and mercury lamp. It can cause chemical reactions and causes many substances to glow or become fluorescent.
Commonly, the wavelength of UV light ranges from 10 to 400 nm. The range of experimental UV wavelength is between 200 nm and 400 nm. According to ISO 21348-2007, standard on determining solar irradiances, this range is subdivided in three parts (Table 1). UV-A (315–400 nm) contains long UV waves and is normally responsible for changes in human skin called tanning. UV-B (280–315 nm) or medium UV waves can cause skin burning and possibly lead to skin cancer. A smaller fraction of this region (295–297 nm) is responsible for the formation of vitamin D in all organisms that make this vitamin, including humans. Finally, UV-C (200–280 nm) contains short UV waves and is called the germicidal range because it effectively inactivates bacteria and viruses (Koutchma *et al*., 2009, p. 2).
Short UV-C is almost completely absorbed in air within a few hundred meters. In addition to that, around 97% of UV-B is absorbed by the ozone layer; otherwise, the atmosphere if penetrated, it will cause much damage to living organisms. Consequently, the atmosphere acts as a filter media of UV light and after that, only about 3% of the total energy of sunlight at the zenith is UV, this fraction decreasing at other sun angles.

3. MICROBIAL INACTIVATION BY UV LIGHT

UV light is lethal to most types of microorganisms found in air, water or on hard surfaces. It inactivates cells by damaging nucleic acid, thus preventing the replication of microorganisms. The nucleic acid is either deoxyribonucleic acid (DNA) or ribonucleic acid (RNA). Most cells have the nucleus composed of double stranded DNA. DNA contains the information necessary for the synthesis of ribosomal, transfer and messenger RNA involved in the metabolic processes of synthesis within the cell.

Table 1. Division of electromagnetic spectrum of experimental UV light (from ISO 21348-2007)

Name	Abbreviation	Wavelength range, in nm	Energy, in eV/ photon	Alternative names
Ultraviolet (exp.)	UV	200 – 400	3.10 – 12.40	
Middle ultraviolet	M-UV	200 – 300	4.13 – 6.20	
Near ultraviolet	N-UV	300 – 400	3.10 – 4.13	Visible to birds, insects and fish
Ultraviolet C	UV-C	200 – 280	4.42 – 12.40	Short wave, germicidal
Ultraviolet B	UV-B	280 – 315	3.94 – 4.43	Medium wave
Ultraviolet A	UV-A	315 – 400	3.10 – 3.94	Long wave, black light

The genetic material of viruses and bacteriophages is DNA or RNA, either single or double stranded (Koutchma *et al*., 2009, p. 69).

However, the damage of nucleic acid does not prevent the cell from experiencing metabolism and other cell functions. Some of the damage of nucleic acid can be repaired by enzyme mechanisms within the cell; therefore, microorganisms can repair themselves and become infectious again after a certain time from the UV light treatment. Consequently, the UV treatment has to provide enough dosage of UV light to ensure that nucleic acid is damaged beyond the stage where it can be repaired.

As Koutchma *et al*. (2009) showed, this behaviour is different from killing microorganisms which happens when chemical disinfectants are used. Indeed, chemical disinfectants, such as chlorine, chlorine dioxide, iodine, peroxide, destroy and damage cellular structures that interferes with metabolism, biosynthesis and growth.

The germicidal effect consists of producing pyrimidine dimmers in microbial DNA or RNA, which hampers nucleic acid replication (Kim *et al*., 2002; Koutchma *et al*., 2009, p. 71), thus preventing the replication of microorganisms, which become inactive an unable to cause infection. Maximum killing effect is produced by short-wavelength UV (UV-C) at 254 nm.

4. UV DISINFECTION OF WASTEWATER

UV light irradiation has not been largely used in drinking water disinfection because it leaves no residual to provide protection against further contamination. This could be a disadvantage for protection of public drinking water supply (Kim *et al*., 2002). On the contrary, the absence of any residual in treated water is an advantage for the aquatic life. Therefore, UV disinfection is well suited for wastewater disinfection and this is of growing interest in the water treatment industry since it was demonstrated that UV radiation is very effective against pathogenic microorganisms (Hijnen *et al*., 2006; Koutchma *et al*., 2009).

Two pathogenic microorganisms of huge importance for the safety of drinking water are (oo)cysts of protozoa *Cryptosporidium* and *Giardia*. In water-disinfection practice, UV light is usually most effective at inactivating *Cryptosporidium* and *Giardia*, followed by bacteria. UV light is least effective against spores and viruses, the order of destruction with UV light being the following (Koutchma *et al*., 2009, p. 73):

Cryptosporidium and *Giardia* > Bacteria > Spores > Viruses

Clancy *et al*. (1998) showed that *Cryptosporidium parvum* oocysts were highly susceptible to UV light treatment. Their research was followed by many other researches which were demonstrated the inactivation of *Cryptosporidium parvum* (Clancy *et al*., 2000; Morita *et al*., 2002), *Giardia muris* (Craik *et al*., 2000), *Giardia lamblia* (Shin *et al*., 2005) and *Acanthamoeba* spp. (Maya *et al*., 2003) by UV radiation.

Bacteria as vegetative cells and bacterial spores are less susceptible to UV light treatment than protozoa. Among the most studied bacteria are: *Bacillus subtilis* (Hijnen *et al*., 2004), *Camphylobacter jejuni* (Wilson *et al*., 1992), *Clostridium perfringens* (Hijnen *et al*., 2004) *Escherichia coli* (Chang *et al*., 1985; Zimmer & Slawson, 2002; Oguma et al., 2004), *Escherichia coli* O157 (Sommer *et al*., 2000), *Legionella pneumophila* (Oguma et al., 2004), *Salmonella typhi* and *Shigella disenteriae* (Wilson *et al*., 1992), *Shigella sonnei* (Chang *et al*., 1985), *Streptococcus faecalis* (Harris *et al*., 1987) *Vibrio cholerae* (Wilson et al., 1992), *Yersinia enterocolitica* (Wilson *et al*., 1992). Aerobic spores of *Bacillus subtilis* (Munakata *et al*., 1996) and anaerobic spores of *Clostridium perfringens* (Lanao *et al*., 2010) are clearly less sensitive to UV than the vegetative bacterial cells. The most UV-resistant bacterium is *Deinococcus radiodurans* which needs a D_{10} doze ranging from 19.7 up to 145 mJ/cm^2 (Koutchma et al., 2009, p. 73). Fortunately, this bacterium is something of an

oddity, and highly unlikely to be found in normal food processing operations (Shama, 2007).

Viruses (adenoviruses, calciviruses, hepatitis A virus, poliovirus, Norwalk and Norwalk-type viruses etc.) and bacteriophages were intensely studied due to their resistance to UV radiation.

The most UV-resistant organisms are viruses, specifically Adenoviruses, and bacterial spores (Hijnen et al. 2006). Yates et al. (2006) provide a very good review of the effect of adenovirus resistance on UV disinfection. The high level of resistance of adenovirus to UV light were studied using low-pressure (LP) UV sources at a wavelength of 254 nm (Gerba et al., 2002; Thurston-Enriquez et al., 2003; Nwachuku et al., 2005; Baxter et al., 2007). Linden et al. (2007) compared the inactivation of enteric adenovirus type (Ad40) and respiratory adenovirus type (Ad2) using a low-pressure (LP) monochromatic UV source with the results obtained using medium pressure (MP) UV lamps with full spectrum and polychromatic UV light. It appears that other wavelengths emitted by the polychromatic UV lamps are more effective than the 254 nm emitted by LP UV. This is due to the fact that the UV transmittance of drinking water or wastewater may not allow lower wavelengths, such as those below 230 nm, to penetrate deep into a water layer. Nevertheless, even when these lower wavelengths below 230 nm were eliminated, the polychromatic MP UV system has better inactivation performances than the monochromatic LP UV system (Linden *et al.*, 2007).

Table 2 summarizes the key research performed to study the UV disinfection of wastewater.

The performance of UV disinfection of wastewater is highly influenced by wastewater quality. Many studies have been demonstrated the effectiveness of UV light treatment in disinfecting of high quality secondary and tertiary treated effluents (Blatchley et al., 1996; Braunstein et al., 1996; Oppenheimer et al., 1997). However, the presence of particle-associated microorganisms in wastewater subjected to UV disinfection may have a negative influence of the process of disinfection (Zukovs et al., 1986; Whitby & Palmateer, 1993; Sakamoto, 1997). Loge et al. (1999) showed that UV light is not able to penetrate solid materials, microorganisms associated with particles are thus not destroyed. The effect of particles, as small as they are, is to shield the cells of microorganisms (Emerick et al., 2000). Ormeci & Linden (2002) have reported that naturally occurring particle-associated coliforms survive when wastewater is treated with typical UV and chlorine disinfection doses and in this case the use of filtration is recommended to reduce the concentration of particle-associated coliforms.

Table 2. Studies on wastewater to inactivate protozoa, bacteria, spores, viruses and bacteriophages using UV light treatment

Microorganism(s)	References
Protozoa	
Acanthamoeba spp.	Maya *et al.*, 2003
Cryptosporidium parvum oocysts	Morita *et al.*, 2002 Shin *et al.*, 2001 Craik *et al.*, 2001 Clancy *et al.*, 2000 Clancy *et al.*, 1998
Cyclospora cayetanensis	Mead *et al.*, 1999
Giardia lamblia cysts	Shin *et al.*, 2005 Linden *et al.*, 2002
Giardia muris cysts	Craik *et al.*, 2000
Toxoplasma gondii	Mead *et al.*, 1999
Bacteria	
Acinetobacter baumanni ATCC 19606	Hassen *et al.*, 2000
Aeromonas hydrophila	Mead *et al.*, 1999
Bacillus cereus	Mead *et al.*, 1999
Bacillus subtilis	Hijnen *et al.*, 2004 Hassen *et al.*, 2000 Chang *et al.*, 1985
Camphylobacter jejuni	Mead *et al.*, 1999 Wilson *et al.*, 1992 Butler *et al.*, 1987
Citrobacter freundii ATCC 8090	Hassen *et al.*, 2000
Clostridium botulinum	Mead *et al.*, 1999
Clostridium perfringens	Hijnen *et al.*, 2004 Mead *et al.*, 1999
Enterobacter aerogenes ATCC 13048	Hassen *et al.*, 2000

Enterobacter cloacae ATCC 23355	Hassen *et al*., 2000
Microorganism(s)	**References**
Enterococcus hirae ATCC 10541	Hassen *et al*., 2000
Enterococcus faecalis ATCC 19433	Hassen *et al*., 2000
Escherichia coli	Oguma *et al*., 2004 Taghipour, 2004 Otaki *et al*., 2003 Zimmer & Slawson, 2002 Oguma et al., 2002 Butler *et al*., 1987 Harris *et al*., 1987 Chang *et al*., 1985
E. coli O157	Sommer *et al*., 2000 Wilson *et al*., 1992
E. coli ATCC 11229	Hassen *et al*., 2000 Sommer *et al*., 2000
E. coli O157:H7 *E. coli* O25:K98:NM *E. coli* O78:K80:H12 *E. coli* O50:H7	Sommer *et al*., 2000
Klebsiella pneumoniae ATCC 13883	Hassen *et al*., 2000
Legionella pneumophila	Oguma et al., 2004 Wilson *et al*., 1992
Listeria monocytogenes	Mead *et al*., 1999
Proteus mirabilis	Hassen *et al*., 2000
Pseudomonas aeruginosa	Hassen *et al*., 2000
Salmonella marcensens ATCC 8100	Hassen *et al*., 2000
Salmonella typhi	Wilson *et al*., 1992 Chang *et al*., 1985
Salmonella. Typhimu-rium ATCC 14028	Hassen *et al*., 2000
Shigella disenteriae	Wilson *et al*., 1992
Shigella sonnei	Chang *et al*., 1985
Staphylococcus aureus	Mead *et al*., 1999
Streptococcus faecalis	Harris *et al*., 1987 Chang *et al*., 1985
Vibrio cholerae	Wilson et al., 1992
Yersinia enterocolitica	Mead *et al*., 1999 Wilson *et al*., 1992
Bacterial spores	
Bacillus subtilis	Munakata *et al*, 1996 Quintern *et al*., 1991 Tyrrell *et al*., 1978
Clostridium perfringens	Lanao *et al*., 2010 Gehr *et al*., 2003
Microorganism(s)	**References**
Viruses	
Adenovirus	Yates *et al*., 2006
Adenovirus 2 (respiratory)	Baxter *et al*., 2007 Gerba *et al*., 2002
Adenovirus 5	Baxter *et al*., 2007
Adenovirus 40 (enteric)	Linden *et al*., 2007
Adenovirus 41	Baxter *et al*., 2007 Malley *et al*., 2004
Adenovirus ST2	Malley *et al*., 2004
Adenovirus ST15	Thompson *et al*., 2003 Gerba *et al*., 2002 Meng & Gerba, 1996
Adenovirus ST40	Thurston-Enriquez *et al*., 2003
Calcivirus bovine	Malley *et al*., 2004
Calcivirus feline, canine	Duizer *et al*., 2004 De Roda Husman *et al*., 2003 Thurston-Enriquez *et al*., 2003
Coxsackie virus B5	Gerba *et al*., 2002 Battigelli *et al*., 1993
Enteroviruses	Gerba *et al*., 2002
Hepatitis A virus	Duizer *et al*., 2004 Gerba *et al*., 2002 Sommer *et al*., 1999 Battigelli *et al*., 1993 Wiedenmann *et al*., 1993 Wilson *et al*., 1992
Norwalk virus	Mead *et al*., 1999
Poliovirus type 1	Meng & Gerba, 1996 Maier *et al*., 1995 Wilson *et al*., 1992 Harris *et al*., 1987 Chang *et al*., 1985
Rotavirus SA-11	Malley *et al*., 2004 Battigelli *et al*., 1993
Bacteriophages	
Bacteriophages B40-8, T7 and Qβ	Clancy *et al*., 2004
MS2-phages	Mamane-Gravetz *et al*., 2005 Malley *et al*., 2004 Meng & Gerba, 1996
Bacteriophage PRD1	Meng & Gerba, 1996
Bacteriophage γX174	Sommer *et al*., 2001 Battigelli *et al*., 1993

Table 3 presents the ranges of average D_{10} doses of UV disinfection of various microorganisms. The doses for 1-log inactivation of yeast, fungi, and algae are given for inactivation in air (Shama, 2007; Koutchma *et al*., 2009, p. 73).

Table 3. D_{10} UV inactivation doses in mJ/cm^2 at λ = 253.7 nm (Shama, 2007 ; Koutchma *et al.*, 2009, p. 73)

Microbial group	D_{10} UV doses, in mJ/cm^2
Enteral bacteria	2 – 8
Cocci and micrococci	1.5 – 20
Spore formers	4 – 30
Enteric viruses	5 – 30
Yeast	2.3 – 8
Fungi	30 – 300
Protozoa	60 – 120
Algae	300 – 600

5. UV DISINFECTION EQUIPMENT

The main components of a UV disinfection system are a reactor, mercury arc lamps and a control box. The source of UV radiation is either a LP or MP mercury arc lamp with low or high intensities.

The optimum wavelength to effectively inactivate microorganisms is in the range of 250 to 270 nm. The intensity of the radiation emitted by the lamp dissipates as the distance from the lamp increases. LP UV lamps emit essentially monochromatic light at a wavelength of 253.7 nm. Standard lengths of the LP lamps are 0.75 and 1.5 meters with diameters of 1.5–2.0 cm. The ideal lamp wall temperature is between 35 and 50°C (95 and 122°F).

MP UV lamps are generally used for large facilities. They have approximately 15 to 20 times the germicidal UV intensity of low-pressure lamps. The MP UV lamp disinfects faster and has greater penetration capability due to its high intensity. However, these lamps operate at higher temperatures with higher energy consumption than LP UV lamps (EPA, 1999).

There are two types of UV disinfection reactor configurations: contact types and noncontact types. In both the contact and the noncontact types, wastewater can flow either perpendicular or parallel to the lamps. In the noncontact reactor, the UV lamps are suspended outside a transparent tube conduit, which carries the wastewater to be disinfected. This configuration is not as common as the contact reactor. In the contact reactor, a series of mercury lamps are enclosed in quartz sleeves to minimize the cooling effects of the wastewater. In both types of reactors, a control box provides a starting voltage for the lamps and maintains a continuous current.

Figure 1 shows two UV contact reactors with submerged lamps placed parallel (6) and perpendicular (8) to the direction of the wastewater flow. Flap gates or weirs are used to control the level of the wastewater.

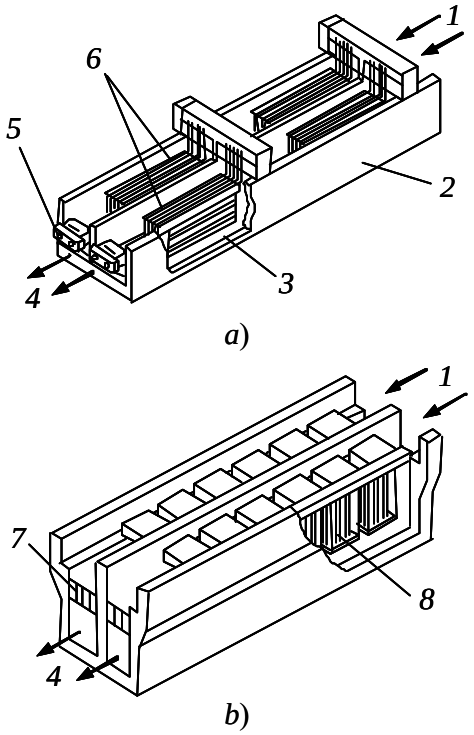

Figure 1. UV disinfection systems:
***a*) with horizontal UV lamps (adapted from http://trojanuv.com/products/wastewater);**
***b*) with vertical UV lamps (adapted from http://ozonia.com/media/pdf/uv/Aquaray)**
***1* – feeding with wastewater; *2* – UV bank 1; *3* – UV bank 2; *4* – evacuation of disinfected wastewater;**
***5* – automatic level control; *6* – UV horizontal lamp module with support racks; *7* – Flap gate level control; *8* – UV vertical lamp module with support rack.**

6. ADVANTAGES AND ISADVANTAGES

Advantages of UV disinfection are:

– It is effective at inactivating most viruses, spores, and cysts;

- It is a physical process rather than a chemical disinfectant, which eliminates the need to generate, handle, transport, or store toxic/hazardous or corrosive chemicals;
- There is no residual effect that can be harmful to humans or aquatic life;
- UV disinfection is user-friendly for operators.
- UV disinfection has a shorter contact time when compared with other disinfectants (approximately 20 to 30 seconds with low-pressure lamps);
- UV disinfection equipment requires less space than other equipments.

Disadvantages of UV disinfection are:

- Low dosage may not effectively inactivate some viruses, spores, and cysts.
- Organisms can sometimes repair and reverse the destructive effects of UV through a „repair mechanism", known as photo reactivation, or in the absence of light known as „dark repair." A preventive maintenance program is necessary to control fouling of tubes.
- Turbidity and total suspended solids (TSS) in the wastewater can render UV disinfection ineffective. UV disinfection with low-pressure lamps is not as effective for secondary effluent with TSS levels above 30 mg/L.

6. CONCLUSIONS

Disinfection is considered to be the primary mechanism for the inactivation/destruction of pathogenic organisms used to prevent the spread of waterborne diseases to downstream users and in the environment. It is important that wastewater be adequately treated prior to disinfection in order for any disinfectant to be effective.

An UV disinfection system transfers electromagnetic energy from a mercury arc lamp to an organism's genetic material, DNA and RNA. When UV radiation penetrates the cell wall of an organism, it destroys the cell's ability to reproduce. UV radiation, generated by an electrical discharge through mercury vapour, penetrates the genetic material of microorganisms and retards their ability to reproduce.

The effectiveness of a UV disinfection system depends on the characteristics of the wastewater, the intensity of UV radiation, the amount of time the microorganisms are exposed to the radiation, and the reactor configuration. For each one of the treatment plant, disinfection success is directly related to the concentration of colloidal and particulate constituents in the wastewater.

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