Electrochemical Removal of Microorganisms in Drinking Water

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It is known that silver, even in small concentrations (hundred parts of milligrams per liter), has the ability to destroy microorganisms, i.e. it has strong bactericidal abilities. Cleansing vast amount of water using bactericidal ability of silver is usually performed in electrochemical way. The advantages of electrochemical disinfection process like: (a) environmental compatibility, (b) versatility to kill a wide variety of microorganisms under mild conditions, (c) no need for adding chemical medicines and (d) the benefits of in-situ generation greatly lower problems and dangers of usage gas chlorine in water disinfection, which is greatest during transport and storing of this disinfectant. Appliances for electrochemical disinfection of drinking water eliminate these faults of conventional disinfection methods. Medical researches show that excess of chlorine in water reacts with organic matter, leading to mutations and cancer formation in digestion organs and bladder. This paper represents research of succesful microbiological disinfection of natural water that contains *Acinetobacter*, *Pseudomonas aeruginisa*, Sulfate-reducing *clostridium*, *Streptococcus* (F), *Aeromonas*, *Citrobacter* (F), *Esherichia coli*, *Enterobacter* (F) and *Bacillus* by water-disinfection appliance. This appliance can be used in water systems like water sorces, traps, reservoires, pools etc. (certificate of Clinical Center of Serbia).

1. INTRODUCTION

Pollution of natural water, which is primary resource for survival of mankind, is evidently gaining concerning scale. Vulnerability of open springs, waterfowls, natural lakes, artificial accumulations as well as natural wells (open and underground waters) is direct consequence of ever increasing pollution of environment. Besides unacceptably increased concentrations of physico-chemical constituents in raw water, new emerging problem is bacterial, i.e. microbiological water pollution. Within water treatment, process of disinfection has highly important role [1-5].

For several decades in developed countries, the emphasis is on improvement of technology for purification of drinking water. This is primarily due to new findings on the effects of various harmful and dangerous substances that are found in natural waters or are formed in the water treatment process, especially with the use of oxidizing agents, primarily chlorine [6-12].

Danger of, nowadays most widely, use of chlorine, both gaseous and liquid, as well as other oxidative species, in disinfection of drinking water is especially expressed in its transport and storage. Medical researches confirm that increased amount of chlorine in drinking water leads to increased probability for tumor development in digestive organs, and bladder and colon cancers and mutations. This fact lead large producers of relevant technology equipment to put effort in finding and applying alternative ways of water disinfection, i.e. water that is used in different industries, primarily food [3-5, 13-16].

Given all mentioned above our goal was to define different methodology of drinking water disinfection, where use of oxidative disinfection compounds is completely omitted. This mainly relates to chlorine, thus eliminating all of its bad consequences to human health [15].

Water treatment is dominated, wherever it is possible, by biological and physical processes. Hence the concept of disinfection of drinking water has, for all previously mentioned reasons concerning oxidative means, tendency to change and improve. Search for flawlessly microbiologically clean drinking water and for water used in food and drink industry etc., without risks that commercially available disinfectants bring, becomes the imperative. The device that represents combination of ultrasound and silver hence becomes important segment of drastically new approach in area of water disinfection. This device, due to its advantages, is integral part of wider ecological progress trends [4, 17-19].

Conventional methods of water disinfection usually include the use of oxidant, active chlorine, as mean of final disinfection of water, as well as for preservation of bacteriological stability of water in the water distribution network. In practice, depending on case, other means can be used (reactive oxygen species, etc.). However, this practice has previously mentioned disadvantages. Potentially adverse processes and phenomena for human health are taking place and they are undoubtedly present besides their basic, necessary, bactericidal role. Therefore it is not rare that, taking these reasons in consideration, there is no introduction of chlorine in water supply system at the end of water treatment process after final disinfection of the water by UV light as prevention of subsequent bacterial contamination in the water distribution network [15-19]. Those who opted for absence of chlorine at the beginning of the water supply network must have weighed the risks brought by the application of chlorine in the water supply distribution system (with relevant quality of original water) in relation to consequences and possibilities of secondary pollution considering the lack of positive alternative solutions for now. Thus the presence of a partial vacuum in permanent, safe preservation of microbiologically clean water without adverse collateral consequences is quite evident, not only in flowing water systems, but in other cases. For example when, at the beginning microbiologically safe, water experiences negative change in its quality, because of the additional bacteriological contamination or from endangering its organoleptic characteristics, due to prolonged standing (very long pipelines, water reservoirs with pronounced seasonal fluctuations in consumption, etc.) [6-8]. In these cases parts of the water supply system intended for water transport or, for short time (usually one

day) water retention, acquire the roles of biological reactors which can only worsen the sanitary properties of water, which is undesirable.

On the other hand it is well known that silver has strong bactericidal properties. Even the hundredth parts of the milligram of silver per liter of water successfully destroy microorganisms. Some bacteria die in presence of 10 ppb of silver in water. Such large toxic effects of silver can be explained by high sensitivity of cell microorganism plasma to silver ions. It was shown that silver ions are included within the microbial cell together with the protoplasm where they destroy it. It is also proved that silver ions adsorbed on the microbial cell play catalytic role in plasma oxidation process by air oxygen. Experiments have shown that silver's bactericidal effect is achieved at relatively short contact, which leads to the extinction of microorganisms and thus water disinfection. The lower limit of bactericidal effect of silver is estimated to 2×10^{-11} g/dm^3. Otherwise, the silver concentration that is leathal for different types of bacteria that are likely to be present in raw water is within (and mostly, for many species, far below) range that is harmless to human body [1-3].

Incensement in concentration of silver ions in the water is quicker when the area of metal in contact with water is larger. To make the system more efficient more contact area was sought with the least expenditure of metal. For this purpose, mesh type electrode was developed.

It should be emphasized that the presence of ammonia, which is otherwise often found in water (referring to the allowable concentration, either in the original or treated raw water), has catalytic effect on the bactericidal effect of silver [3]. On the other hand, studies have shown general advantages of silver in relation to the chlorine referring to sensitivity of the bacterial spectrum. For example, olygodynamic effect of silver on 17 microorganisms, including gram-positive and gram-negative bacteria, showed maximal sensitivity of gram-positive and gram-negative sporeless bacteria in the presence of silver [20].

Conservation role of silver in maintaining the quality of drinking water (which was already mentioned above) in respect to bacteriological quality of drinking water as well as preservation of good organoleptic properties of water should be emphasized. This property implies a distinct advantage of silver in relation to application of known oxidizing agents, both with instant and those with prolonged action (with known health implications). Hereby, the silver concentration in treated water is at absolutely reasonable, and for human body, desirable range. The role of silver (in combination with ultrasound) is especially suitable in those cases where drinking water, for any reason, is retaining in different parts of the water supply system for number of days, months to approximately year. Conservation role of silver in the preservation of primary, special quality of drinking water (spring packed water) allows, for example, packing of larger volumes of water without fear of losing the quality due to prolonged use of an open vessel.

Otherwise, it is known that silver has a positive synergistic effect with various bactericidal oxidants (where the basis of disinfection is oxidant) and with ultraviolet disinfection method (immediate effect). However, this combination is significantly inferior to the combination of ultrasound-silver, including the tangible loss of ultraviolet bactericidal effect in terms of turbid and colored water, where the role of disinfection depends largely or entirely on the ultraviolet lamp, which is for many reasons a serious handicap [10, 21]. There is no conservative nor preventive role of disinfectant (it is not alternative to usually used chlorine) and it is completely obvious to see

advantages of ultrasound-silver modality. Ultrasound shows no problem with turbid and colored water to approximately 50 mg/dm^3 and it has substantial advantage in terms of conservation compared to eg. chlorine [21].

In order to increase the efficiency of the device, due to the fact that the bactericidal effect of silver and some silver is harmless to humans, but represents very strong toxin for microorganisms an electrochemical device was developed. It constitutes of a system of electrodes made of different materials with strong and proven bactericidal properties.

In the first phase, the study was aimed to determine microbiological correctness of drinking water in a pilot plant obtained after the application of the microbiological water disinfection device. The percentage of reduction of individual contamination indicators of treated water was also examined. In the second phase, additional tests were carried out, related to the testing of "live" water supply systems (wells).

2. EXPERIMENTAL PART

Testing was conducted in a pilot plant. The plant consisted of a tank with capacity of 1000 dm^3 and a barrel with volume 200 dm^3, as well as devices for water disinfection.

Tank and barrel were filled with borehole water, which, in addition to its natural bacteriological status, was additionally contaminated with bacteria cultures, as follows: fecal streptococci bacteria, proteus species, and pseudomonas aeroginosa. The water in the tank was used for experimental purposes, and the water in the barrel was the control group. Samples of water from both vessels were taken for microbiological analysis at intervals of 2 hours.

Samples were taken in accordance with the principles of sanitary hygiene sampling and as such they were shipped refrigerated to the laboratory. Samples were analyzed for the laboratory parameters of microbiological quality of drinking water, in accordance with the Regulations on Hygienic Quality of Drinking Water as follows:

- Coliform bacteria of fecal origin (Escherichia coli)
- Total coliform bacteria
- Proteus species
- Total number of aerobic bacteria
- Streptococci of fecal origin
- Sulfate-reducing clostridia
- Pseudomonas aeroginosa

The genus *Acinetobacter* comprises a heterogeneous group of non-fermentative Gram-negative bacteria. According to the most recent taxonomic studies, the genus *Acinetobacter* belongs to subclass *γ-Proteobacteria*, family *Moraxellaceae*, and comprises Gram-negative, non-motile, oxidase-negative, glucose non-fermenting, strictly aerobic, catalase-positive bacteria with a G + C content of 39–47% [22]. The cells are 1.5 μm in length, with a shape varying from coccoid to coccobacillary depending on

the growth phase. The temperature range is typical of mesophylic bacteria; clinically relevant species grow optimally at 37 °C, while environmental species may prefer lower temperatures [23].

Acinetobacter species are receiving increasing attention as significant opportunistic pathogens, usually in the context of serious underlying disease [24]. Community-acquired infections (wound infection, urinary tract infection, otitis media, eye infections, meningitis and endocarditis) have been reported mainly from south-east Asia and tropical Australia. In the hospital setting, *Acinetobacter* species have been implicated in a wide range of infections, particularly in critically-ill patients with impaired host defenses. These infections include pneumonia, skin and soft-tissue infections, wound infections, urinary tract infections, meningitis, and bloodstream infections [25].

Imipenem and meropenem, which usually are the agents most active against *Acinetobacter* species, are considered the antibiotics of choice when they are used in combination with aminoglycosides for treatment [26]. Ampicillin-sulbactam (Amp-Sulb) is one of the few treatments that may retain activity against imipenem resistant *Acinetobacter* organisms [27].

Pseudomonas aeruginosa is a common environmental Gram-negative, aerobic, coccobacillus [20] which acts as an opportunistic pathogen under several circumstances. The ubiquitous occurrence of *P. aeruginosa* in the environment [28, 29] is due to several factors, including its abilities to colonize multiple environmental niches and to utilize many environmental compounds as energy sources [30].

This microorganism has the ability to express a variety of virulence determinants, and it is not surprising that it can cause experimental infections in plants, nematodes, insects, and animals [31]. It is responsible for one of the most serious opportunistic infections in humans. In recent years nosocomial infections caused by *P. aeruginosa* has been recognized as an acute problem in hospitals due to its antibiotic multi-resistance. *P. aeruginosa* is one of the main causes of nosocomial respiratory tract (chronic lung infections in cystic fibrosis (CF) patients), urinary tract and surgical site of infection [32]. Compared with other pathogens, *P. aeruginosa* is very difficult to eradicate as it displays high intrinsic resistance to a wide variety of antibiotics. Considering the multiple ways in which *P. aeruginosa* can become resistant, it is not surprising that resistance can be observed for all currently available anti-pseudomonal antibiotics. Although antibiotics are available and usable for most *P. aeruginosa* infections, resistance rates are on the rise and the high intrinsic resistance of *P. aeruginosa* makes it very challenging to find new drugs [33].

The genus *Clostridium* is a heterogeneous group of bacteria which currently consists of 181 described species. Clostridia are anaerobic, endospore-forming, Gram-positive bacteria that are widely distributed in the environment as well as in the intestinal tract of humans and many animals [34]. Members of the genus *Clostridium* are ubiquitous chemo-organotrophic micro-organisms. Most of them use carbohydrates and/or proteinaceous compounds as energy sources. They are not known to dissimilate sulfate [35]. However, some exceptional cases have also been reported, such as as porogenous mutants that may appear and proliferate, different degrees of aerotolerance known for several species and mesophilic clostridia that show a transient ability to reduce sulfate [36].

Several *Clostridium* species are pathogenic to humans, domestic animals, or wildlife and are responsible for well-known clostridial diseases such as tetanus, gas gangrene, botulism, pseudomembranous colitis, and food-borne illness. In addition, clostridia can be involved in a variety

of human infections, such as cholecystitis, pneumonia, bacteremia, empyema, and abscesses, and can thus be isolated from various clinical specimens. [34].

Clostridium perfringensis is sensitive to various antibiotics, but especially to Penicillin G, which is the antibiotic of first choice for treating cellulitis, sepsis, and myonecrosis caused by this bacteria [37].

Streptococci is the general term for a diverse collection (that includes nearly 40 species) of Gram-positive cocci that typically grow as chains or pairs. Virtually all streptococci that are important in human medicine and dentistry fall into the genera *Streptococcus* and *Enterococcus*. Streptococci are generally strong fermenters of carbohydrates, resulting in the production of lactic acid, a property used in the dairy industry. Most are facultative anaerobes, but peptostreptococci (other genera of streptococci) are obligate anaerobes. Streptococci do not produce spores and are non-motile. They are catalase-negative.

The genus *Streptococcus* includes important pathogens and commensals of mucosal membranes of the upper respiratory tract and, for some species, the intestines. Genus *Enterococcus*, which is also an intestinal commensal, is related to the other streptococci, but is classified separately.

With few exceptions, individual species are exclusively associated, either as pathogens or commensals, within man or a particular animal. Human bacterial pathogens that are associated with this genus include a wide range of suppurative infections in the respiratory tract and skin, life-threatening soft tissue infections, and certain types of toxin-associated reactions.

Streptococci are naturally susceptible to penicillin and to a wide range of other antibiotics. However, acquired resistance to other agents has become an increasing problem. Although streptococci are intrinsically resistant to aminoglycosides, these agents interact synergically with penicillins and the combination is often used in the treatment of streptococcal and enterococcal endocarditis [38].

Aeromonas spp. are primarily aquatic organisms that may be readily isolated from lakes, rivers, estuarine environments, sewage effluents, ground water, drinking waters and a wide range of raw foods [39]. Species of *Aeromonas* are Gram-negative, non-spore-forming, rod-shaped, facultatively anaerobic bacteria which measure 1-3.5 μm across [40]. The aeromonads share many biochemical characteristics with members of the Enterobacteriaceae, from which they are primarily differentiated by being oxidase-positive.

The genus *Aeromonas* comprises important human pathogens causing primary and secondary septicemia in immuno-compromised persons, serious wound infections in healthy individuals and in patients undergoing medicinal leech therapy, and a number of less well described illnesses such as peritonitis, meningitis, infections of the eye, joints, and bones, and even less frequently observed conditions involving the respiratory and urogenital tracts [41].

The use of fluoroquinolones such as ciprofloxacin and cefotaxime are in the main the most successful treatment for *Aeromonas* infection. Studies have indicated their activity both *in vivo* in infected patients and *in vitro* with clinical isolates, in addition to this the identification of fluoroquinolone-resistant strains is still rare [40].

Citrobacter species are straight, facultative anaerobic, Gram-negative bacilli, typically motile by means of peritrichous flagellae and are commonly found in water, soil, food, and the intestinal tracts of animals and humans [42].

There are three species in the genus Citrobacter which are known to be pathogenic in humans, as follows: *C. amalonaticus*, *C. diversus*, and *C. freundii*. Recently, *C. diversus* has been renamed *Citrobacter koseri*. These species cause various infections in humans involving the urinary, gastrointestinal, and respiratory tracts. Infections are commonly reported in neonates, the elderly, and immuno-compromised or debilitated hosts. A few cases of infective endocarditis, mostly on the right side, have previously been reported [43].

Citrobacter species are less susceptible to antibiotics, with high resistance to penicillin (70–90%) and cephalosporins, moderate resistance to aminoglycosides (10–40%), and variable resistance to quinolones [44].

Escherichia coli is Gram-negative, facultative anaerobic rod-shaped bacteria that ferments lactose to produce acid and gas within 48 h at 35°C. *E. coli* is a member of the family *Enterobacteriaceae*. It is widely distributed in the intestine of humans and warm-blooded animals and is the predominant facultative anaerobe in the bowel and part of the essential intestinal flora that maintains the physiology of the healthy host. Since *E. coli* is abundant in human and animal feces and not usually found in other niches, its presence in food or water became accepted as indicative of recent fecal contamination and the possible presence of frank pathogens [45].

E. coli is today subdivided into several pathogenic strains causing different intestinal, urinary tract or internal infections and pathologies, in all animal species and in humans. Pathogenic *E. coli* serotypes were therefore named by the clinical syndrome they can cause: diarrhoeagenic *E. coli*, uropathogenic *E. coli*, septicaemic *E. coli*, neonatal meningitis-associated *E. coli*, enterohaemorrhagic *E. coli* etc [46].

Escherichia coli is susceptible to a wide range of antibiotics such as amikacin, nitrofurantoin, gentamicin, cefpodoxime, cefixime etc [47].

Enterobacter a member of *Enterobacteriaceae*, are motile, rod-shaped, Gram-negative bacteria that are classified as facultative anaerobes. They are found in the natural environment in habitats such as water, sewage, vegetables, and soil. Before the widespread use of antibiotics, *Enterobacter* species were rarely found as pathogens, but these organisms are increasingly encountered, causing nosocomial infections such as urinary tract infections, meningitis, pneumonia and bacteremia. In addition, they occasionally cause community-acquired infections.

Cephalosporins are most active antibiotics against different strains of *Enterobacter* species. Newer approaches to *Enterobacter* infections have adopted combination-therapy regimens employing multiple antibiotics with different core structures, such as an aminoglycoside or a fluoroquinolone in combination with a beta-lactam agent [48, 49].

Bacillus is one of the best characterized bacterial genera. It is defined as a Gram-positive, rod-shaped bacterium that can be aerobic or facultative anaerobic and produces highly resistant dormant endospores in response to nutritional or environmental stresses. *Bacilli* are ubiquitous bacteria that exploit a wide variety of organic and inorganic substrates as nutrient sources [50].

Several Bacilli may be linked to opportunistic infections, e.g. in post-surgical wounds, cancer patients, or immune-compromised individuals. Pathogenicity among *Bacillus* spp. is however mainly a feature of organisms belonging to the *B. cereus* group, a subgroup of the *B. subtilis* group within the *Bacillus* genus and which are commonly found in the environment [51].

Antibiotics which appear especially useful in the treatment of Bacillus infections are clindamycin and vancomycin, to which the vast majority of strains are susceptible in vitro [52].

Analyses were performed according to the parameters using the following methods: * *Coliform bacteria of fecal origin (Escherichia coli).* Determination of the most probable number (MPN) was determined on Mc Conkey substrate, with the identification of coliform bacteria. Incubation of primary substrates was performed at 37 ^{0}C during 24-48^h.

* *Total coliform bacteria.* Determination of the most probable number (MPN) was performed in 100 cm^3 on LAP or Mc Conkey substrate. Affirmative and final experiments with the identification of coliform bacteria were done.

* *Proteus species.* The culture was sifted on agar substrate containing lactose from the tube for determination of the most probable number (MPN) for coliform bacteria. Identification of suspected colonies was performed by biochemical tests and phenyl-alanine test. Incubation at was carried out at 37 ^{0}C.

* *The total number of mesophilic bacteria.* Test was performed by scraping 1 cm^3 of diluted water onto nutritious agar and counting formed colonies. Incubation was at 37 ^{0}C for 48^h.

* *Streptococci of fecal origin.* Determination of MPN was done in 100 cm^3 of broth with sodium azide confirmatory test on agar for Streptococci. Catalase test was performed. Identification was done afterwards.

* *Sulphate-reducing clostridia.* Determination of the number of black colonies in the sulfite agar in 100 ml of water was done. Confirmatory test included subculture of black colonies on blood agar in anaerobic conditions at 37 ^{0}C for 24^h. Identification of clostridia was performed as needed.

* *Pseudomonas aeruginosa.* The most probable number (MPN) was determined on LAP in 100 cm^3. Confirmatory test was performed on King A substrate at 42 ^{0}C for 24^h. Proof of thiocianine by chloroform was done.

Device for microbiological disinfection of water of our own production was used. It produces reverse current. The unit consists of a system of electrodes of different materials based on silver. The device itself can be connected to the AC source as well as the source of direct current, through the electronic controller, as shown in Figure 1.

Figure 2 shows the block diagram of autonomous devices (current controller), which provides a constant direct current. Electronic controller has integrated connector for connection to the city power grid of 220V/50Hz. If power from the grid can be used, it is enough to insert the plug-in connector in the power-supply plug.
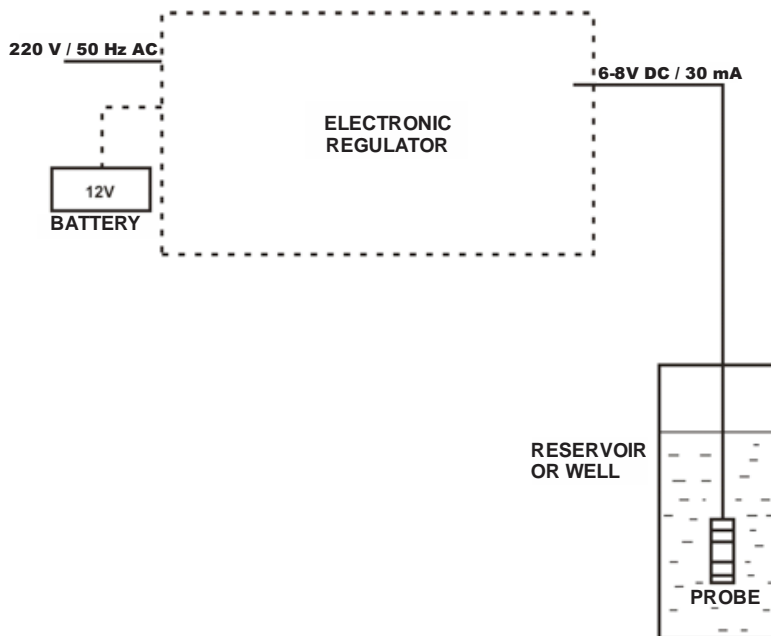
Figure 1. Block diagram of the connection of electronic current regulator with the probe for microbial disinfection
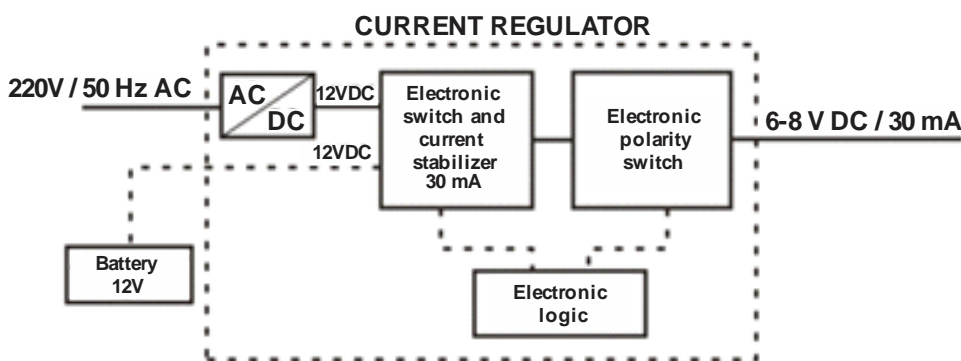
Figure 2. Block diagram of current controller

Inside the current controller contains four functional blocks that have the following roles:

1.   AC / DC Block - Adapter that transforms 220V/50Hz from the grid into 12V DC voltage;

2.   Electronic switch and power stabilizer – It maintains fixed current through the electrodes of 30 mA and turns on/off the electrodes in the intervals of about 3 hours;

3.   Electronic polarity switch – It changes the polarity of the voltage on electrodes in a period of about 4 min;

4.   Electronic logic - Timer switch that commands all the other blocks.

If there is no possibility for usage of the power grid 220V/50Hz AC current, the terminals inside the box can be connected to 12 V car batteries, or any other (i.e. solar cells) as backup power.

The device operates on the principle of differences in electrode potentials. Different electrode materials under the influence of an electric current, produce certain kinds of cations and anions (finely dispersed ions), which have specific bactericidal properties, thus carrying out disinfection.

3. RESULTS AND DISCUSSION

Test results of treated and control (untreated) water of examined markers indicate that the microbiological quality of water from both the vessels before putting the device for disinfection was unsatisfactory due to the presence of *Escherichia coli*, total coliform bacteria, proteus, aerobic mesophilic bacteria, fecal origin streptococci and *Pseudomonas aeruginosa*. Figure 3 shows the presence of certain bacteria versus time during the operation of the device.
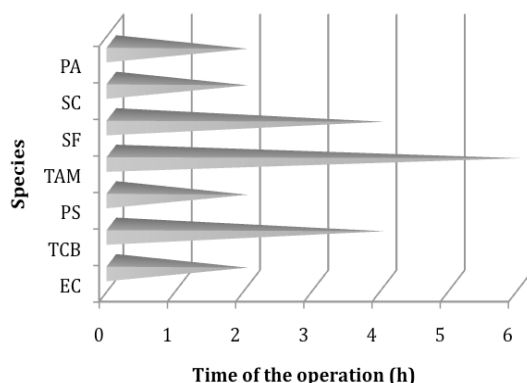
Figure 3. The presence of bacteria in the water during the device engagement. EC-E. Coli, TCB-Total coliform bacteria, PS-*Proteus* species, TAM-The total aerobic mesophilic bacteria, SF-*Streptococci of fecal origin*, SC-*Sulfate-reducing clostridia*, PA-*Pseudomonas aeruginosa*

Figure 4 gives a detailed change in concentration (extinction rate) of total coliform and aerobic mesophilic bacteria.
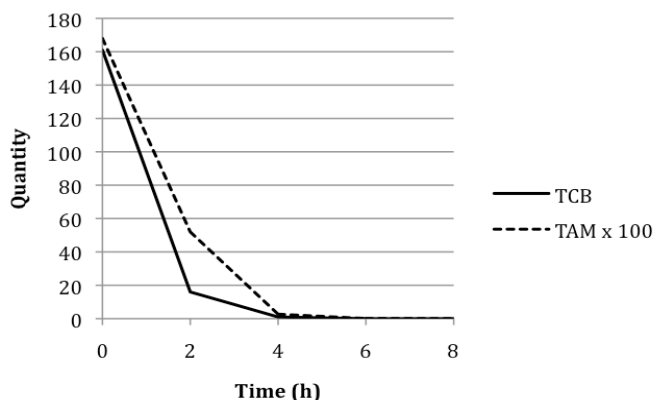
Figure 4. Change of concentration (extinction rate) of the total coliform and aerobic bacteria. TCB-Total coliform bacteria, TAM-Total aerobic mesophilic bacteria

After only 2 hours after sinking the device for water disinfection, the device starts to eliminate causes of water bacterial pollution, while after 8 hours the water was bacteriologically correct.

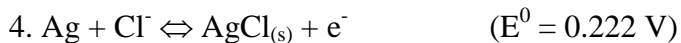Table 1 shows bacteriological testings of treated and untreated water.

Table 1. Bacteriological signature of contaminated and treated water

| Bacteria species	Contaminated water before treatment with the device	2 hours after treatment with the device	4 hours after treatment with the device	6 hours after treatment with the device	8 hours after treatment with the device	24 hours after treatment with the device
E. coli	Found	Found	Not found	Not found	Not found	Not found
Total coliform bacteria	161	> 16	1	0	0	0
Proteus species	Found	Found	Not found	Not found	Not found	Not found
Total aerobic mesophilic bacteria in 1 cm^3 at 37^0 C	16800	5200	267	10	3	0
Streptococci of fecal origin	Found	Found	Found	Not found	Not found	Not found
Sulfate-reducing clostridia	Found	Found	Not found	Not found	Not found	Not found
Pseudomonas aeruginosa	Found	Found	Not found	Not found	Not found	Not found

It is evident that the effect of bactericidal effect depends on the duration of electrolysis and the current intensity. Most resistant to the bactericidal action are intestinal bacilli (fecal bacteria). Therefore, silver chloride electrodes are built in the device system for water disinfection. The device provides faster and more convenient way for elimination of vegetative forms as well as sporophite bacteria [1-4]. In this way, each of the types of electrodes applied to the device is capable of destroying a particular group of bacteria and it is selective in a limited group of microorganisms. In addition, in certain types of electrode evolution of oxygen is provided, which plays a catalytic role in the oxidation of plasma [53].

Possible reactions in the system are as follows:

1. $Ag_2O + H_2O = 2Ag + 2H^+ + 2e^-$ ($E^0 = 1.398$ V)
2. $2Ag + H_2O = Ag_2O + 2H^+ + 2e^-$ ($E^0 = 1.173$ V)
3. $Ag \rightarrow Ag^+ + e^-$ ($E^0 = 0.798$ V)

4. $Ag + Cl^- \Leftrightarrow AgCl_{(s)} + e^-$　　　　　　　　$(E^0 = 0.222 \text{ V})$

In addition to the above reactions the following combination is set up in the system:

$Ag, AgCl_{(s),} Cl^-_{(aq)}$
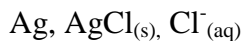
The following process takes place on the electrode:

$Ag \rightarrow Ag^+ + Cl^-$

Or, if the area is saturated with AgCl electrode, formed silver ions will precipitate very quickly from the solution in the form of AgCl, so the reaction can actually be shown by formula:

$Ag^+ + Cl^- \Leftrightarrow AgCl_{(s)} + e^-$　　　　　　　$(E^0 = 0.222 \text{ V})$

Solubility of AgCl is very small and constant, and at $25 \, ^0C$ the ionic solubility product is:

$L_{AgCl} = C_{Ag}^+ \text{ x } C_{Cl}^- = 1.8 \text{ x } 10^{-10}$

Hence, the potential of the electrode is:

$E^0 = E_{Ag} + RT/F \ln L_{AgCl} = 0.798 \pm 0.059 \log (1.8 \text{ x } 10^{-10}) = 0.222 \text{ V}$

Ag/AgCl electrode can, therefore, be regarded as chlorine electrode with reduced pressure dissolution. This means that there is always presence of certain amount of chlorine in the water.

In summary, one can say that silver, hydrogen and oxygen reduction can be displayed at the cathode, while chlorine and oxygen evolution can be displayed at the anode [4,54-57].

4. CONCLUSIONS

The device for microbiological disinfection of water eliminates risks of conventional methods. It was shown that the device started to eliminate causes of water bacterial pollution after 2 hours, while after 8 hours the water was bacteriologically correct. The device eliminated all known biological water pollutants, i.e. *Acinetobacter*, *Pseudomonas aeruginisa*, Sulfate-reducing *clostridium*, *Streptococcus* (F), *Aeromonas*, *Citrobacter* (F), *Esherichia coli*, *Enterobacter* (F) and *Bacillus*. The appliance can be used in water systems like: water sorces, traps, reservoires, pools etc. (certificate of Clinical Center of Serbia). Our product is patented in the Serbian Intellectual Property Office in Belgrade under number P51132 and the Institute for Intellectual Property Sarajevo, Bosnia and Herzegovina under number BAP112878A [58,59]

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