Egypt. J. Chem. Vol. 64, No. 9, pp. 5337 - 5344 (2021)

Egyptian Journal of Chemistry

http://ejchem.journals.ekb.eg/

Efficient Water Treatment of Swimming Pools Using Ozone

Mona A. Abdel-Fatah*, H. Alabd, Marwa M. Elsayed

Chemical Engineering & Pilot Plant Department, Engineering Research Division,

National Research Center, 33 El-Bohouth St., Dokki, Cairo, Egypt, Post Code 12622

Abstract

Swimming pools are common source of pollution especially public one. Recycled water should be chemically treated and microbial decontaminated. Water to be free of destructive substances, microscopic organisms, infections, green growth, pathogens, and reasonable for utilize by swimmers. This means that expansive particles are reduced to smaller volumes, which led to decay more efficiently through a channel. Since the natural matters produced a bacterial substitute, it will cause an increase in bacterial growth within the system. The regrowth of microscopic species in a conveyance framework is a negative effect. By injecting ozone into a sand channel, this will be converted into a positive effect. According to this research, ionization can improve channel performance. Ozone increases material biodegradability and microbial growth while also increasing oxygen concentration in the channel. When ozone is applied to natural carbon as total organic carbon (TOC) expulsion in a sand channel, it can be increased by up to 35%.

Keywords: Ozone, swimming pools, biodegradation, water treatment

1. Introduction

Swimming pools are used for recreational activities, and it is necessary to disinfect swimming pool water in order to protect against infection by microbiological pathogens. Swimming pool water pollution is dynamic pollution because it is caused by swimmers. The quality of water used in swimming pools has become suspected, especially in public swimming pools. Water used in such pools must be not only free of taste and smell, pleasant to see and contact but, it must also be free of organic substances and germs. It is necessary to purify this water to a quality equal to that of drinking water (Cheema, 2017).

It is intended to treat the water pretty rigorously to a high degree, at the disinfection and elimination of germs from contamination by faeces, saliva, urine, blood, and residues of skin and hair, in order to prevent the various illnesses and infections that may affect swimming pool users (Kim, 2019). Swimming pool water may include a variety of microorganisms, including fungi and mycobacteria, that are resistant to chlorination and cause opportunistic illnesses, particularly in youngsters and the elderly, as well as in those with weakened immune systems (Laat, 2010).

Treatment of swimming pool water undergoes to remain it free from harmful substances such as bacteria, viruses, algae and pathogens in order to be clean and clear (Mona et.al 2016, 2021). Purification of swimming pool water proceeded in about five steps: first step is filtration by a hair removal filter to get rid of raw pollutants, then flocculation to convert colloidal materials to visible flocks and oxidation of organic pollutants by potassium permanganate and finally floated materials were discarded by using sand filter.

The most common disinfectant used in public swimming pools is chlorine. Chlorine, therefore, interacts in the filling water with natural organic matter and contaminants introduced into pool water by bathers who form disinfection by-products (DBPs1). Mixed chlorine species (organic and

*Corresponding author e-mail: monaamin46@gmail.com ; (Mona A. Abdel-Fatah).
Receive Date: 21 June 2021, Revise Date: 12 July 2021, Accept Date: 13 July 2021
DOI: 10.21608/EJCHEM.2021.81763.4041

inorganic chloramines), haloacetic acids (HAAs), and trihalomethanes (THMs) are the most common DBPs found in pool water (Hansen, 2016).

Some investigators proved that nanosilver solution can be applied successfully for the disinfection of swimming pools (Joanna 2017). Treatment of swimming pool water by magnetic technology is a salt free technology which promotes clearer, cleaner water, easy installation with no tools, does need any plumber, prolongs pumps life and no electricity needed (Mona et,al 2019).

Ozone is a powerful oxidizer with a wide range of response times depending on the properties of the contaminants. Because both ozone and chlorine are selective oxidants that prefer to react with the same portions of organic molecules, ozone can oxidise a dissolved contaminant (i.e. dissolved organic carbon, DOC) in swimming pool water, reducing its reactivity with chlorine.

Following ozone oxidation in pool water, the production of DBPs is expected to decrease as DOC chlorine reactivity diminishes. Well-established technology for the treatment of drinking water has become increasingly important, but its application in swimming pools is still very limited (Firuzi, 2020).

There are many reasons why ozone is not commonly used in swimming pool therapy. The high capital and maintenance expense is the most cited cause. The misunderstanding concerning its usage is a second explanation. The use of Ozone is, preferred over other methods for a number of reasons, among them, iron and manganese removal, Organic removal, viral inactivation, and micro flocculation as well as for disinfection. Thus costs of ozonation and other methods cannot be compared legitimately.

Many harmful elements are conveyed by the atmosphere especially in open pools as debris from vegetation, animals, pollens, dust, insects; these will carry along with them bacteria, Viruses, Fungi, and amoeba to the water. Swimmers are generally the principal cause of deteriorating water quality through the introduction of suspension.

The soluble contribution could be in the form of sweat and urine. Colloidal contribution take numerous forms e.g. secretions (rhino pharyngeal, cutaneous), beauty products, a microbial contribution could be bacteria, Virus, and Parasites.

2. Materials and Methods

2.1 Materials

All chemicals and reagents were bought from Sigma-Aldrich (Germany) and used exactly as directed. The ozonation set-up was based on a 20 g/h ozone generator from O3-Technology AB (Vellinge, Sweden) that was fed with dry oxygen gas. The generated ozone was disseminated by a diffuser in an ultra-pure water collecting container that was submerged in an ice bath to enhance ozone solubility.

A manometer and valve were inserted after the collecting bottle to improve ozone solubility even more, and a pressure of 1.4-gauge bar was applied. The concentration of ozone obtained in the stock solution was between 80 and 100 mg/L under these testing conditions.

2.1.1 Ozone Treatment for Pool Water Contaminants

When people use swimming pools, several different sorts of contaminants are introduced into the water. Animal and vegetal waste, pollen, and airborne microorganisms, as well as items wiped off and expelled from human bodies, pollute outdoor pools. Organic, microbiological, and inorganic pollutants are the three types of additional contaminants.

Perspiration, urine, secretions (nasal, pharyngic), body lotions and ointments, and cosmetic items are all examples of organic pollutants. Urea and amino acids are two chemical components that are challenging to handle (such as creatinine Bacteria, viruses, fungus, yeasts, amoebae, and cysts are microbiological pollutants; inorganic contaminants include ammonia, chlorine (free and mixed), and bromine (free, combined, and bromide ion). When the raw water comes from a well, pollutants such as soluble iron, manganese, and sulphide ions may be present.

2.1.2 Organic Compounds and Ozone Reactions

Although a few organic compounds are rapidly oxidized to destruction by ozone (e.g., formic acid, phenol), the vast majority of organic compounds are only partially oxidized in aqueous solutions, even by a powerful oxidising agent like ozone, especially under the conditions found in swimming pool and spa water.

Most organic compounds, especially those that are naturally refractory, (i.e.,organo–nitrogen compounds -urea, creatinine; organochlorine compounds -chloroisocyanurates, trihalomethanes), are very weakly reactive with ozone and are not killed by it, unless very long reaction periods (up to hours) are required, which is not practicable in pool and spa water treatment.

2.2 Methodology

2.2.1 Swimming Pool Water Analysis

Samples analysis show that overage swimmer discharges (30-50 ml) of urine and introduces (3 gm) of organic substances, (0.8 - 1 gm) of which is organic carbon. The major harmful effects of the contaminated swimming pool can come from chemical and microbiological substances that can penetrate orally or cutaneous. Risks due to this undesirable substance range from simple irritation of the mucous membranes to diseases that could cause death, as shown in Table (1).

Table (1) Risks due to this undesirable substance and its sequences

Germs	Agents	Consequences
Amoeba bacteria	Entamaeba Naegleris Staphylococcus	Meningitis Rhino pharyngitis, Conjunctivitis Otitis
Microscopic Fungus Virus	Papillomavirus	Cutaneous Mycosis Warts.

Treated water enters the bottom of the pool basin and flows upward, overflowing to the balance tank (this hydraulic configuration allows the lighter pollutants to wash out of the pool continuously with clean water) and the pump discharge water passes through a rapid sand filter. Ozone was incorporated into the pool water using a gas liquid contactor. Side stream water (about 30 % of the total volume) was recirculated continuously and all ozone-containing air gas streams is aspirated into the water by means of an injector, to be mixed with all circulating water in a contact tank specially designed. The exit ozone gas is catalytically destroyed.

2.2.2 Secondary Additional Treatment Ozone

In swimming pools, ozone, a gaseous molecule, is employed as a secondary treatment.

According to reports, ozone is both a high-potential oxidant and an efficient disinfectant for killing microorganisms (Lee et al., 2010). Because ozone is a strong preoxidant, disinfection by-products can be minimised (Kleiser, & Frimmel, 2000). Ozone is a dangerous gas that is harmful to people. Ozone has a higher density than air. Because ozone has a poor solubility, it can collect just above the water's surface, putting swimmers at risk. The risk is minimal, however, because most ozone is consumed before entering the pool, and a deozonator should be present to remove any residual ozone before the water is chlorinated. (National Swimming Pool Foundation, 2012).

3. Results and Discussion

A corona discharge Ozonator (maximum ozone production: 60 g/h, ozone concentration 20 g/m' gas, maximum gas flow 3 m'/h) generated ozone from dry air (dewpoint -60 to -70 ‘C). The ozone generator, contact tank, injector, and control system were all provided by the Cuban Ozone Research Center. Astral S.A. provided the pumps, sand filter, and PVC pipe systems (Spain). From October through March, this ozone dosage was sufficient to maintain satisfactory water quality (stage I).

However, under summer circumstances (high temperature, increased solar irradiation, rainy season), the ozone dose has to be raised even further, to 3 g/m' from April to September (stage 11). Furthermore, throughout the period of greater bathing loads, weekly flocculation was required (July-August). Table 2 shows the results of physicochemical studies and organoleptic evaluations done on the water at both phases.

Table 2. Swimming Pool Water Quality

			Stage I		*Stage II*	
Parameter	Unit	Recommended	Mean Value	Range	Mean Value	Range
Temperature	°C	25	25	20-29	31	27-34
Turbidity	NTU	<5	0.67	0.4-1.4	<5	0.8-1.7
pH		7.2-8.2	7.6	7.1-8.1	**7.5**	7.1-8.0
Total alkalinity	mg $CaCO_3$/L	80-100	148	132-262	142	115-283
Total Hardness	mg $CaCO_3$/L	200-400	514	442-585	381	211-557
Free bromine	mg/L	0.5-1	0.5	0.1-1.1	0.4	0.1-0.7
Nitrate	mg/L	<20	3.6	1.6-5.3	3	1.8-3.5
Ammonia	mg/L	<0.5	0.46	0.1-1	0.4	0.1-0.8
Daily Makeup water	%Total	5-10	4	2-8	5	3-8

N.D.: not detected

3.1 Purification of Recycled Water Swimming pool water must experience treatment, in arrange to stay clear, clean, free from destructive substances, microscopic organisms, infections, green growth, pathogens and reasonable for utilize by swimmers. Purification steps of swimming pool water are passed through different decontamination steps as shown in Figure 1. The water is transported being passed from swimming pools to a water decontamination plant #1. Within the water decontamination plant, it'll stream go through a hair expulsion channel #2, which expels crude contaminations, such as hairs, mortars, and takes off, from water. After that, a flocculants #3 is included, which causes little colloids to tie together. Colloids are unmistakable coasting particles of natural matter, such as skin tissue and material filaments. This bunch of toxins moreover concerns colloidal poisons, such as spit, cleanser remains, restorative items and skin fats. When these toxins are inexhaustible, they cause turbidity. Water to be recycled must be of quality equal to that of drinking water. Purification takes place in several steps as shown in Figure (1)

1. Removal of suspended and colloidal substances
2. Removal of dissolved substances
3. Germ processing

Flocculation is done to eliminate colloidal particles, dissolved substances, and fine suspended particles. Aluminum sulphate (1-3 g/m^3) is the most used flocculants. Iron chloride could also be used.

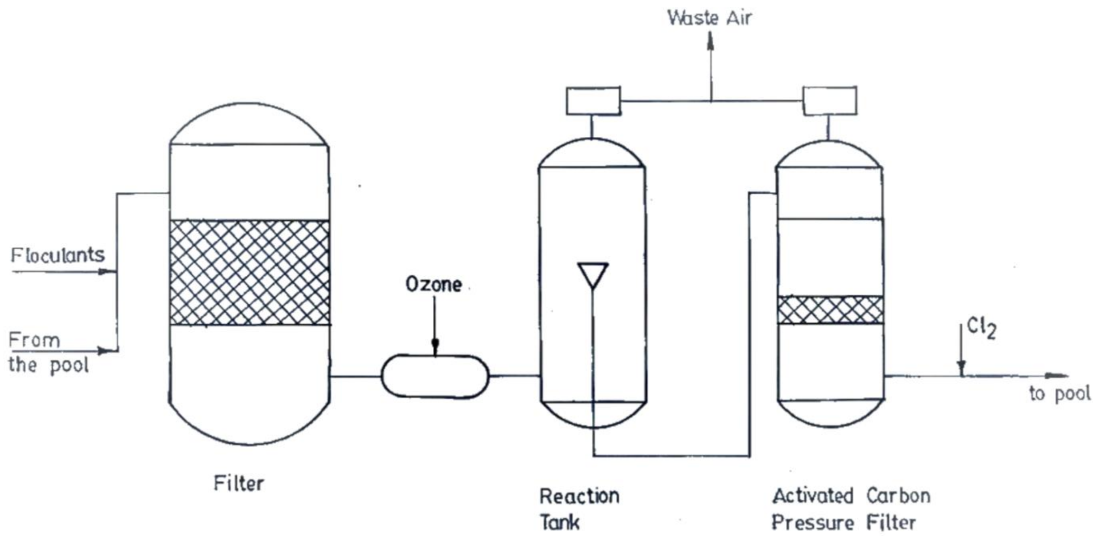

Figure (1) Purification steps of recycled water in swimming pool

Filtration process eliminates all suspended substances; this is an important step chemically and microbiologically. Ozone oxidizes and sterilizes the swimming pool water. Ozone is the most powerful oxidizer next to fluorine. In the treatment of drinking water, 0.4 g/m^3 of ozone for 4 minutes inactivate 99.9% of the most common viruses according to Polio virus echo virus, coxsachia, adenoid virus, etc.... (Mona A. et.al 2016, 2019, 2020, 2021)

Treatment of swimming pools differs in that: water is circulating and that it is treated constantly. From the great majority of research projects on virus inactivation, it is apparent that contact time of 2 minutes or even 1 minute of 0.4 g/m^3 O_3 inactivates at least 90% of the virus, as soon as the water has passed through the plant for the second time, inactivation will be virtually total. (Waqas, 2018)

From a microbiological point of view [Carlson 1-2], It was found that bactericidal and veridical activity is a function of Redox Potential rather than of free chlorine or its substitute, Figure (2) shows the time necessary for inactivation of E. Coli as a function of Redox Potential. The same worker showed time taken in inactivation of E.Coli is a function of pH, the resistance of germ is highest at a pH of 7.5 – 8. Figure (3). The redox potential of a solution of Ozone is dependent upon the pH, it drops sharply below 0.35 g/m^3.

3.2 The Effect of Contact Time on Virus's Inactivation Usually, a dose of 4 ppm ozone for a contact time of four minutes is generally accepted for treating drinking water in agreement with Derrick, 2014. Optimal dose and contact time should destruct 99.9% of the most common viruses as concluded by Polio, echo, coxsachia, adenoid virus, etc.).

The resistance of this microorganism depends greatly on the quality of the water this leads us to the conclusion that any simple formula for virus inactivation may lead to a big error. The difference between water treatment of drinking water and that of swimming pools is that the swimming pool water is constantly circulated and treated several times at intervals. From the great majority of researches on Virus inactivation contact time of 1-2 minutes with water containing 0.4 g, O_3/m^3 inactivate at least 90% as soon as the water has passed through the plant for the second time, inactivation will be virtually total.

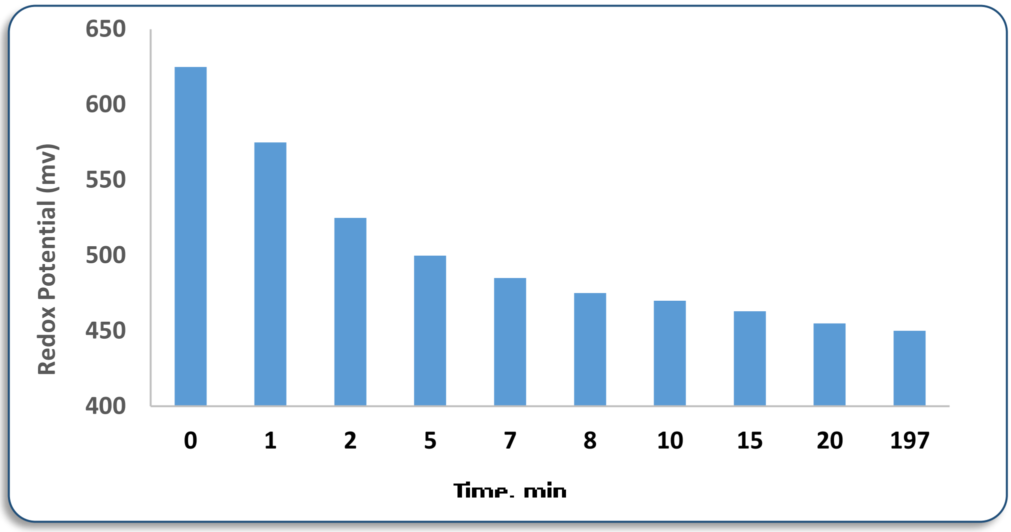

Figure (2) Lethality of *E.Coli* versus Time and Redox Potential

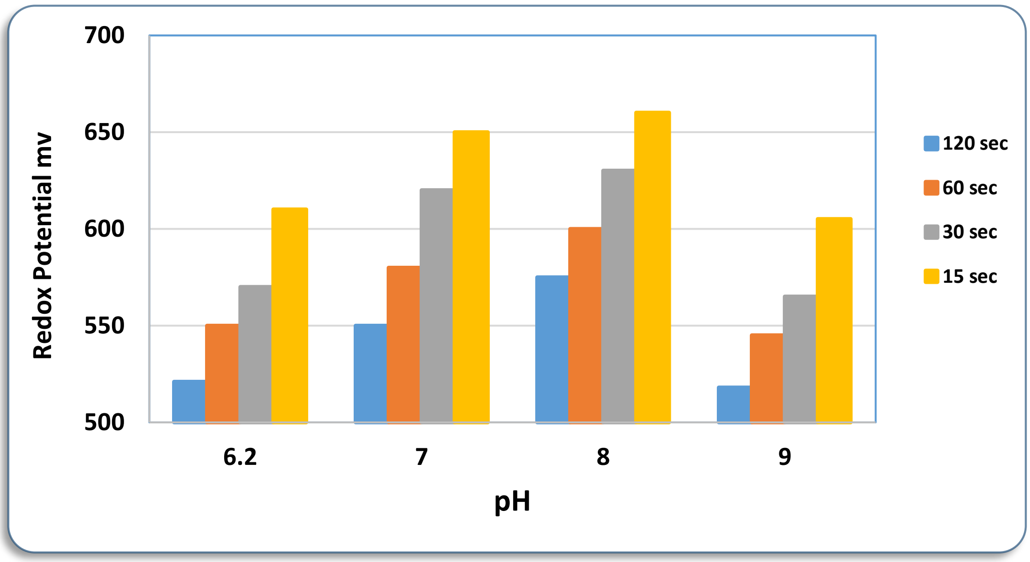

Figure (3) Lethality of *E.Coli* versus pH and Redox Potential

3.3 Filtration and Filtration Rates

Filtration step permits the elimination of substances responsible for turbidity, and this contributes to the better performance of ozonation. The common type of filters used is a fast sand filter, diatomaceous filters, dual layer filter, multi-layer filter, and classical sand filter. The rapid rate is in the range of 25 meters/hr compared with 4 meters/hr on diatomaceous substances.

The filtration rate is not the only factor that determines the process applied a very important factor is the contact time needed to reduce or to remove dissolved ozone from the water after finishing its action to a tolerable level (e.g. 0.1 mg/L) e.g. 0.4 g dissolved O_3 in one cubic meter of water will take about 120 seconds in the filter to reduce O_3 to traces (0.025 ppm) at a filtration rate of 35 m/hr.

3.4 Contact System

Ozone is the most powerful oxidizer that contributes to oxidation and sterilization phenomena, these reactions are made essentially in contact chambers. The contact time and concentration will determine the bacterial and Viruses-Killing effects. At oxidation reduction potential of 680 mv virus inactivation occurs after 4 min with 0.4 ppm of dissolved residual ozone, compared with 30 min for 0.5 ppm of free chlorine. The principle of "true" ozonation is based on the permanent presence of a residual quantity of free ozone during a specific period. It is based on diffusion through porous media however, for large volumes of treated water partial and injection techniques are used. It would be somewhat hazardous to try extending this technique to the treatment of swimming pool water; where it is an economic necessity to bring the substances into contact by injection under pressure.

In designing a contact system the following factors should be considered:

(1) Ozone Self-destruction

This is applied to the ceasing of the oxidative ability of ozone dissipated in the pool water. It depends upon temperature and pH. A low rate of residual ozone can be maintained for a period of days at a low temperature for an ozone rate of 0.4 g/m the residual quantity will be about 0.32 after 18 min if we assumed a 20% loss. In 4 minutes and residual rate of 0.4 g/m self-destruction is completely negligible, representing at most 2% of the initial oxidizing power Figure (4).

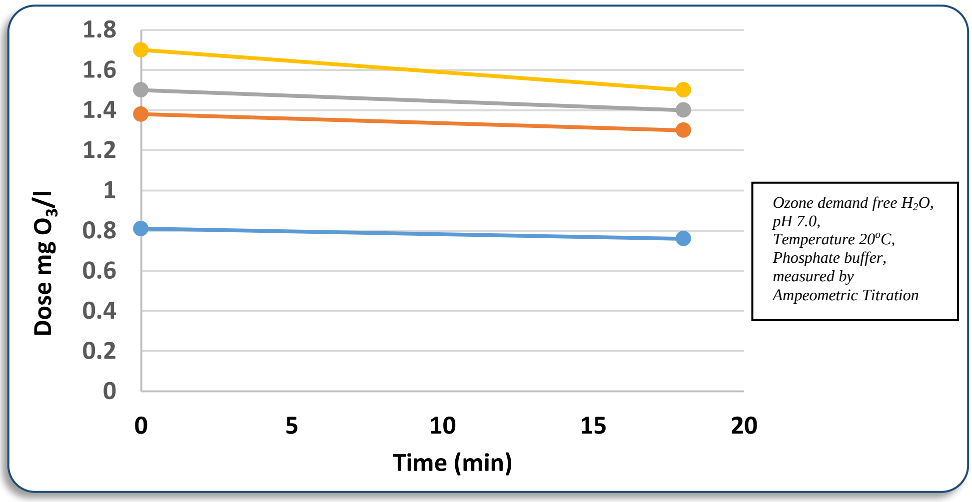

Figure (4) Dissipation of O_3 in H_2O of high quality vs Time

(2) Contact Time

In a multiple basin system ozone is diffused by porous methods to be treated circulated in parallel on counter-flow. The ozone is transferred by an exchange between the bubbles and the water, rate of dissolved ozone increased in the water during rising reach the maximum at the top, or increasing with the descending movement of water reaching its maximum at the foot of the tank.

In the second tank, dissolved ozone will decrease as a function of ozone demand. To maintain ozone concentration a quantity of ozone equivalent at the weight consumed must be added, plus any loss due to self-destruction. Porous diffusion without additional agitation is certainly less effective system, especially when applied in parallel current.

Pressurized injection permits the ozone to dissolve almost instantaneously due to the very high turbulence associated with the system, which is further improved by the use of static mixers. Contact between the bubbles and the water in the reactor has only a slight effect on maintaining the dissolved ozone. It can be stated, therefore, that the dissolved ozone rate exceeds the rate measured at the end of the contact time, reaching the rate which satisfies the demand for ozone.

3.5 Renewal of Water in Swimming Pools

Good savings in operating costs can be achieved if a smaller volume of water is needed to be renewed in swimming pools. Usually, 8% water renewal is needed in conventional systems using chlorine gas for sterilization; this is to be compared with 3% per day with an ozonation system. In addition to the makeup water cost, the heating cost of the renewed water has to be considered. For a pool with a capacity of 1000 m^3, the saving is estimated to be in the range of 15,000 U.S. $ per year. Figure (5) shows water pool recycling.

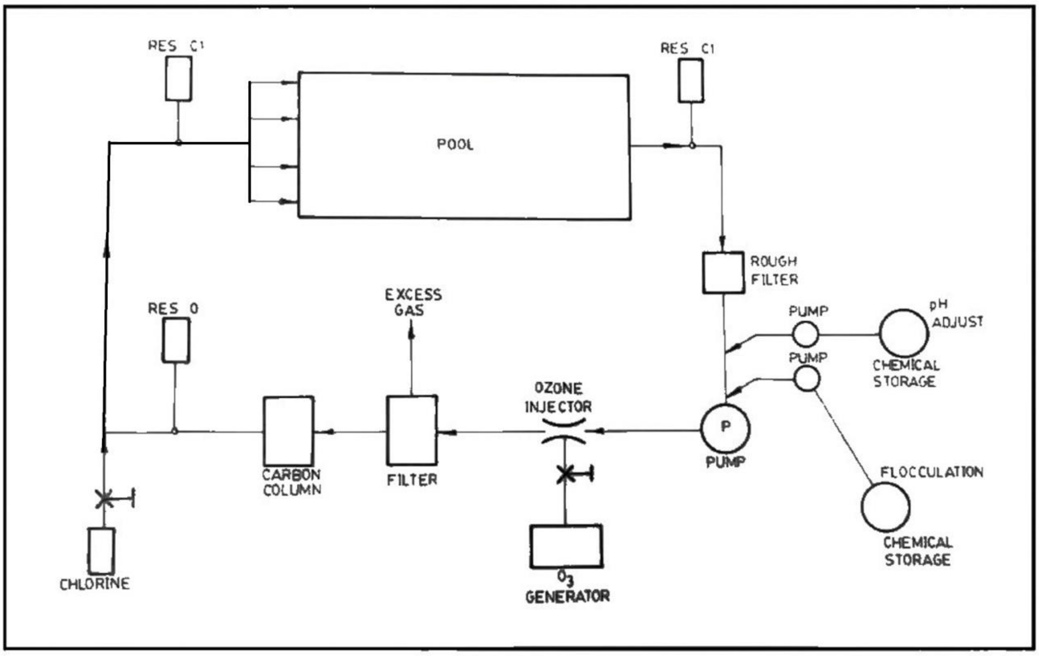

Figure (5) Water pool recycling

4. Conclusion

Ozone can be used for the purification of recycled water, solving sanitation problems created by swimming pools. However, there is a good deal more to say on this subject, the problems of swimming pool water purification are of interest to those who are concerned with the health and safety of swimming pool water. Many improvements are needed in today's techniques. One such technique might be the use of a combination of ozone and bromine, which has already been tested and which deserves our full attention. The oxidation task handled by ozone destroys organic compounds not playing the role of chlorine as a constant sanitizing residual. While in case of using nano-silver more attention must be paid for the disinfectant dose and concentration. Treatment magnetic technology concentrates on reduction of minerals in water causing hard water spots. It is much easier to manage corrosion and scaling problems caused by using high chlorine doses by using ozone due to its effect of constant – reduction potential.

References

1. Hansen, K., Spiliotopoulou, A., Cheema, W., Andersen, H., (2016). Effect of ozonation of swimming pool water on formation of volatile disinfection by-products – A laboratory study. Chemical Engineering Journal, 289, 277-285.
2. Cheema, W.,Kaarsholm, K., Andersen, H., (2017). Combined UV treatment and ozonation for the removal of by-product precursors in swimming pool water. Water Research, 110, 141-149.
3. Kima, J., Bessegatoa,G., Souzaa ,B., Silvaa ,J., Zanonia,M., (2019). Efficient treatment of swimming pool water by photoelectrocatalytic ozonation: Inactivation of Candida parapsilosis and mineralization of Benzophenone-3 and urea. Chemical Engineering Journal, 378, 122094.
4. Laat, J., Feng, W., Freyfer, D., Dossier-berne,F., (2010). Concentration levels of urea in swimming pool water and reactivity of chlorine with urea, Water Research, 45, 1139–1146.
5. Firuzi, P., Hashemi, A., Kafil, H., Gholizadeh, P., Aslani, H., (2020). Comparative study on the microbial quality in the swimming pools disinfected by the ozone-chlorine and chlorine processes in Tabriz, Iran. Environmental Monitoring and Assessment, 192,516.
6. Bataller, M., Veliz, E., Pérez-Rey, R. , Fernández, L. A., Gutierrez, M., & Márquez, A., (2000). Ozone: Science & Engineering: The Journal of the International Ozone Association. Ozone Science and Engineering, 22, 677-682.
7. Derrick, J., Helen, H., (2014). The Effectiveness of Ozone-chlorine Treatment for Reducing Chloramine Concentration Compared to Chlorine Treatment in Swimming Pools and Whirlpools. DOI:10.47339/ephj.2014.145
8. Lee, J., Jun, M.J., Lee, M.H., Lee, M.H., Eom, S.W., & Z, K.D. (2010). Production of various disinfection byproducts in indoor swimming pool waters treated with different disinfection

methods. International journal of hygiene and environmental health, 213, 465-474. doi:10.1016/j.ijheh.2010.09.005.

9. Kleiser, G., & Frimmel, F.H. (2000). Removal of precursors for disinfection by-products (DBPs) – Differences between ozone- and OH-radical-induced oxidation. The science of total environment, 256, 1-9.
10. National Swimming Pool Foundation. (2012). Pool & spa operator handbook. Colorado Springs, CO: National Swimming Pool Foundation.
11. Hansen, K., Spiliotopoulou, A., Cheema, W., Andersen, H.,(2016). Effect of ozonation of swimming pool water on formation of volatile disinfection by-products - A laboratory study. Chemical Engineering Journal. 289:277–285 (2016) DOI: 10.1016/j.cej.2015.12.052.
12. Rip G. Rice, (1995). Chemistries of Ozone for Municipal Pool and Spa Water Treatment. Journal of the Swimming Pool and Spa Industry, 1(1), 25–44.
13. Bertram, S., Swimming Pool Water Treatment With Conventional And Alternative Water Treatment Technologies. A thesis submitted to attain the degree of DOKTORINGENIEUR (Dr.-Ing.). Technische Universität Dresden, Faculty of Environmental Sciences.
14. Waqas, A., Henrik, R., Kamilla, M.,(2018). Improved DBP elimination from swimming pool water by continuous combined UV and ozone treatment. Water Research, 147, 214-222.
15. Abdel-Fatah, M.A., Hussein, N.H., Hawash, S.I., Shaarawy, H.H. Investigation of using sidr leave extracts in nano-silver preparation, ARPN Journal of Engineering and Applied Sciences, 2016, 11(19), pp. 11649–11654
16. Abdel-Fatah, M.A., Elsayed, M.M., Al Bazedi, G.A., Hawash, S.I. Sewage water treatment plant using diffused air system, ARPN Journal of Engineering and Applied Sciences, 2016, 11(17), pp. 10501–10506
17. Amin, A., Al Bazedi, G., Abdel-Fatah, M.A., Experimental study and mathematical model of coagulation / sedimentation units for treatment of food processing wastewater, Ain Shams Engineering Journal, 2021, 12(1), pp. 195–203
18. Abdel-Fatah, M.A., Shaarawy, H.H., Hawash, S.I.. Integrated treatment of municipal wastewater using advanced electro-membrane filtration system, SN Applied Sciences, 2019, 1(10), 1153
19. Abdel-Fatah, M.A., Khater, E.M.H., Hafez, A.I., Shaaban, A.F., Performance of fouled NF membrane as used for textile dyeing wastewater, Membrane and Water Treatment, 2020, 11(2), pp. 111–121
20. Abdel-Fatah, M.A., Hawash, S.I., Shaarawy, H.H., Cost-effective clean electrochemical preparation of ferric chloride and its applications, Egyptian Journal of Chemistry, 2021, 64(7), pp. 3841–3851
21. Joanna Wyczarska-Kokot and Florian Piechurski, (2017). Application of nanosilver in swimming pool water treatment technology. Conference Paper. https://www.researchgate.net/publication/321188866.