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OZONE WATER TREATMENT FOR PUBLIC SWIMMING POOLS

Swimming pool water treatment systems which include ozone in the process will greatly improve swimming pool water quality and reduce chemical consumption costs if designed and installed properly. Sometimes ozone water treatment is recommended to improve or raise the level of swimming pool water quality for a specific use. Incorporating ozone into these systems is usually more expensive to install than the typical high rate sand filtration system. For this reason other means of improving pool water hygiene should be explored first. System improvements such as increasing fresh water intake for the pool, oversizing the high rate sand filter, increasing the turnover rate, reducing the water temperature and limiting operation of water features which increase evaporation must be studied. Continuous fresh water intake (dilution) can improve pool water quality while reducing disinfectant chemical consumption. If a continuous fresh water intake system working in tandem with improvements to the pool water distribution, filtration and disinfection system is found to be insufficient to improve the pool water quality during peak bather loading, then it may be prudent to investigate a more costly corona discharge ozone generator system.

A general description of ozone oxidation and disinfection systems is included for the interested reader.

Leisure pool with ozone disinfection as part of the water treatment process. Palm trees live in the indoor environment and there is no chlorine odor.

Pool Water Treatment Using Ozone

The primary advantage of employing ozone in pool and spa water treatment is that the oxidation benefits or ozonation can be applied prior to chlorination or bromination.

Consequently, much of the water treatment task of oxidation and disinfection can be obtained with a stronger oxidant than either halogen.

When chlorine or bromine is finally added to the treated water, less chemical is necessary to attain the desired level of halogen residual. In the absence of ozone pretreatment, all of the oxidant demand of the recirculated pool/spa water must be satisfied by the chlorine or bromine before development of the desired halogen residual.

As a consequence, the water treated entirely by chlorine or bromine contain much higher concentrations of halogenated by products. Some of theses irritating to the eyes, nasal passages and the throat.

Additionally some of the detrimental aesthetic effects of excessive halogenation and corrosion of the HVAC systems can be diminished or eliminated entirely by adequate ozone pretreatment.

The decomposition product of ozone is oxygen, which is beneficial to the treated water.

Ozone will save chemical costs currently incurred in pools and hot tubs by lowering the amount of halogen compound(s) which must be added to attain the required residual.

In turn, this will lower the amount of chemicals which must be added to maintain the pH of the waters, to promote the optimum actions of the halogens.

Ozone as a Disinfectant

In pools and spas, there is always ozone demanding material present, due to the impurities added to the water by the bathers. The rate of self-decomposition of ozone back to oxygen is faster in spas and hot tubs, where the water temperature is higher than in competition pools.

Ozone is a very powerful oxidizing agent, and is much stronger than chlorine. Therefore, ozone reacts both as an oxidizing agent and a disinfectant. Both of these reactions occur simultaneously when ozone is added to pool or spa water.

Corona discharge type ozone generator used in the five step pool water treatment process oxidizes germs and impurities in the pool. This saves chemical costs, reduces combined chlorine concentrations and provides more pleasant and less corrosive air and water conditions in the Natorium.

A corona discharge generator capable of delivering 80g/hr 0_3 continuously. This unit uses outside air and does not require the use of bottled oxygen to generate ozone (0_3).

Hypochlorous acid (free residual chlorine) is oxidized rapidly by ozone, producing chloride and chlorate ions (from the HOCI) and oxygen (from the ozone). With chloramines (combined chlorine), ozone produces both nitrate and chlorite ions as indicated in the chemistry paragraph below.

Where hypobromous acid is used as the residual disinfectant bromide ion is oxidized to bromine, which serves as a secondary disinfectant, reverting back to bromide.

Chemistry

Hypochlorous acid (HOCl) or "free chlorine" is a very weak acid and dissociates quickly as pH rises above 6 as shown below:

$HOCl \Leftrightarrow H^+ + OCl^-$

$HOCl$ = Hypochlorous Acid
H^+ = Hydrogen Ion
OCl^- = Hypochlorite Ion

Hypochlorous acid is a much stronger oxidant than hypochlorite ion and is the desired disinfectant in chlorinated swimming pool water. In order to optimize the disinfection effect in pool water a pH - 7.0 - 7.4 is recommended.

Upon introduction of ammonia (NH_3) into the pool water from bather or ammonia laden make-up (fill) water, organic amines are formed through the following reactions:

$NH_3 + H_2O \Rightarrow NH_4OH$
NH_3 = Ammonia
H_2O = Water
NH_4OH = Ammonia Hydroxide
$NH_4OH + HOCl \Rightarrow NH_4OCl + H_2O$
NH_4OH = Ammonium Hydroxide
$HOCl$ = Hypochlorous Acid
NH_4OCl = Ammonium Hypochlorite
H_2O = Water

The ammonium hypochlorite is, as with most salts, a weak acid and disassociates into water and monochloramine.

$NH_4OCl \Rightarrow NH_2Cl + H_2O$
NH_4OCl = Ammonium Hypochlorite
NH_2Cl = Monochloramine
H_2O = Water

Hypochlorous acid is oxidized rapidly by ozone, producing chlorite and chlorate ions, oxygen and water. This reduces the available free chlorine (hypochlorous acid) thereby reducing the effectiveness of the disinfectant and results in excess chemical use.

$2HOCl + O_3 => Cl^- + H_2O + 2O_2\uparrow$

and

$2HOCl + O_3 => 2\ OCl^- + H_2O + O_2\uparrow$

$HOCl$ = Hpochlorous Acid
O_2 = Oxygen
O_3 = Ozone
Cl^- = Chloride Ion
OCl^- = Chlorite Ion
H_2O = Water

Consequently, ozone is most effectively added when the recirculating pool/spa water contains the least residual halogen, in order to avoid wasting both ozone and residual halogen compound(s).

Several additional points are important to understand. Water containing residual ozone used as the sole disinfectant is costly, it rapidly undergoes self-decomposition, thus losing its residual concentration in the pool.

More important, ozone oxidizes dissolved organic materials to oxygen containing organics and increases the dissolved oxygen concentration of the treated water.

These conditions of increased dissolved oxygen and increased oxygenated organics are ideal for promoting biological growth. Such as the condition where algae growth is promoted in outdoor pools exposed to sunlight, when there is limited residual disinfectant in the water.

Ozone Generator Basics

Corona discharge ozone generators are the only type which can generate an adequate quality of ozone at a sufficient rate to properly disinfect public pool water. The corona discharge process generates ozone (O_3) from oxygen (O_2). Ozone is the most effective oxidizer next to elemental fluorine in the natural world. It reduces (destroys) impurities in the pool water like the exoskeletons of dead (disinfected) microbial organisms which accumulate in the pool water. These exoskeletons and other irritants evaporate with the pool water and are breathed as aerosols by pool guests and workers. It has been shown that exposure can cause hypersensitivity pneumonitis a bronchial condition in some people. The ozone destroys the little organic impurities, therefore rendering them harmless, and a freshwater intake system mentioned in the previous section dilutes these impurities away to the sanitary system.

The corona discharge ozone generator dries air to a very low moisture content, as if it were at minus 76°F. This dry air is pulled by vacuum across glass tubes. The tubes are charged with up to 14,000 volts (@ 2 to 3 amps) and the energy excites the oxygen in air to become ozone. The ozone has a very short half-life and is quickly pulled into the pool water system using a venturi. The ozone is mixed and reacted whereby it must remain in contact with the water for a minimum of 3 minutes. It is then stripped off using a layer of granular activated charcoal (GAC) in the mixed bed filter.

The glass tubes in the corona discharge generator must be cooled with domestic water. The domestic water is strained and filtered prior to entering the ozone generator and leaves the generator at roughly 85°F, which is 35°F warmer than the entering temperature. Since the pools like to be between 78°F and 86°F this waste heat is piped into the surge tank where it is used as heated fresh water intake. **Refer to Figure 1.**

Water Treatment Process

One of the first ozone systems used in Europe is the "Combi-Block" process which uses the surge tank for the ozone reaction. **Refer to Figure 2.**

The Combi-Block process is no longer widely used in Europe, because it was found that ozone consumption is not optimized. This is due to the high concentration of

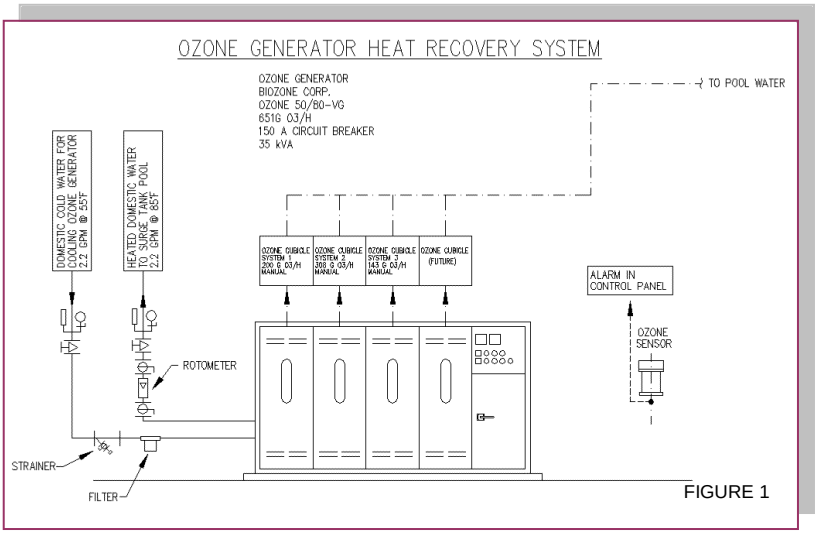

FIGURE 1

organic materials and chlorine residual brought to the surge tank from pool water effluent. The surge tank needs to be considerable larger than usual in order to provide extended contact time with the pool water. In addition, the surge tank must be cleaned often to remove mineral deposits because ozone reduces total water hardness by precipitating out dissolved solids.

Another common system is based on the "Complex Ozone" process, it is similar to the "Combi-Block" process except that an additional ozone reaction tank is provided before the high rate sand filter. **Refer to Figure 3.**

This steel reaction tank can be blown-down for cleaning and requires far less maintenance than with the reaction occurring in the surge tank. Ozone is injected into the water treatment piping before the ozone reaction tank using a multi-stage bypass pump and venturi injection fitting. The water enters the tank and maintains an average contact time with ozone of 3 minutes minimum. Once oxidized the water leaving the tank flows into a multi-layer high rate sand filter with an upper layer of granular activated charcoal (GAC). The activated charcoal strips-off all of the residual ozone and halogen products from the water. Residual disinfectant is then injected to maintain minimum pool disinfectant concentration.

The "5-step" process is the best ozone disinfection system for public swimming pools. **Refer to Figure 4.**

The advantage of this system is that the ozone is injected after the high rate sand (HRS) filter. Since the larger impurities are mechanically filtered-out of the water by the HRS filter, ozone disinfectant consumption needed to oxidize the remaining impurities is reduced. The ozone reaction tank is used to maintain an average contact time of 3-minutes with the pool water. This tank is easily blown-down for cleaning. The final tank is used as a granulated

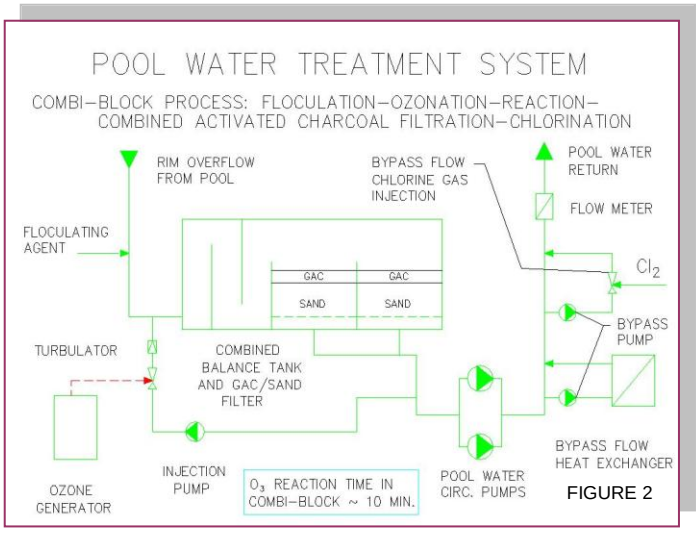

FIGURE 2

activated charcoal (GAC) filter. This filter strips-off the residual ozone and halogen disinfectant as well as chloramines. Residual disinfectant is then injected to maintain minimum pool disinfectant residual concentration.

The 5-step process is the most desirable system, but requires a greater initial investment and more floor space. Where value engineering is necessary to meet the project budget the "Complex Ozone" system would normally be recommended.

Health and Safety

Because ozone is such a strong oxidizing agent, needless exposure should be avoided. If ozone is used as the sole or terminal treatment for pool or spa water, the vapor pressure of gaseous ozone above the pool water becomes a significant consideration. If the concentration of ozone in the pool water is high it will out-gas more easily. Since the density of ozone is heavier than that of air, it's concentration in the air above the water will be higher just above the pool surface. This means that swimmers will breath some ozone, which is not desirable.

The U.S. Occupational Safety and Health Administration (OSHA) has established an 8-hour time-weighted average permissible exposure limit to ozone of 0.1 ppm (0.2 mg/m^3) for a single 8-hour shift in any 40-hour work week. This means that a worker can be exposed to ozone, but that over an 8-hour shift the average exposure to ozone cannot exceed 0.1 ppm.

If ozone is employed as the sole water disinfectant, care must be taken to insure that its concentration in the water is sufficiently low so that its concentration above water will be below this limiting value.

Exposure to ozone levels as high as 1.5 to 2 ppm for two hours can cause

the following symptomatic reactions in humans:

- *Dryness of throat and mouth.*
- *Constrictive type of chest pains.*
- *Lessening of mental ability.*
- *Difficulty in coordinating and articulating.*
- *Loss of appetite.*
- *Coughing.*
- *13% loss of vital capacity.*

were complied which support calculations performed to estimate the annual energy cost of corona discharge ozone generators used for a typical 6,500 SF leisure pool maintained at 84º F. The estimated annual electricity cost to operate the corona discharge generator, desiccant fan motor and high pressure injection pump is:

Ozone Injection	≈ 200-250 g/h @ 1 kWh per 45 g 0^3
Electrical Input	≈ 5.6-6.6 kW
Max. Annual Electricity Consumption	≈ 57,800 kWh ($3,400 per yr.)

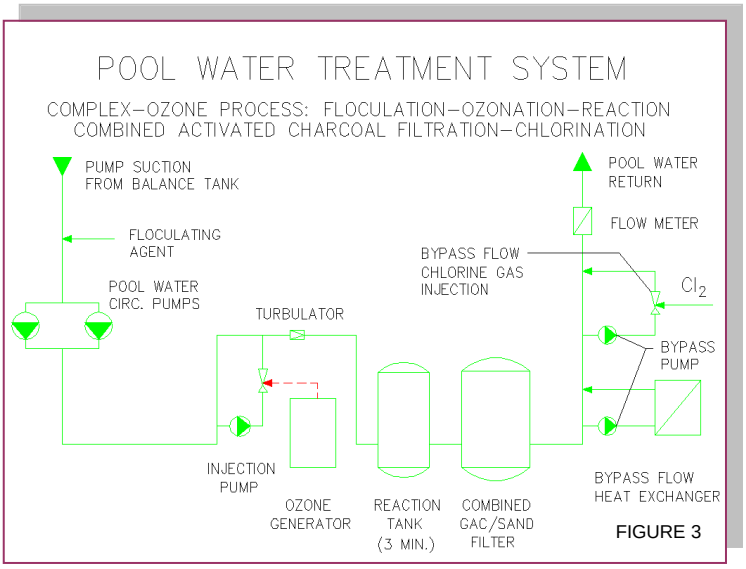

FIGURE 3

Leisure pools, spas/whirlpools and other types of pools with high bather loads experience increased water surface agitation which increases the ozone concentration above the pool water surface. For this reason it is becoming more generally accepted that the ozone should be removed from the pool water during the filtration process, and that the disinfectant residuals in the pool should be maintained by either chlorination or bromination.

Energy Cost of Ozone System

When an indoor swimming pool water treatment system is considered for use with ozone, then ozone injection, reaction and removal (stripping) is recommended. This can be accomplished in a number of ways. Detailed operating parameters describing these systems will not be given here. However, actual operational measurements and historical data

Final Remarks Concerning Ozone Systems

The advantages and disadvantages of using ozone in pool water treatment systems are often misunderstood. The previous description highlights some important considerations in the decision whether or not to provide improved quality pool water for the bathers. An important consideration is always cost. Ozone systems are not inexpensive. A good, safe complex ozone system will cost an additional $125-175 per gallon per minute of the pool water recirculation capacity, which is roughly $115,000 above cost for the standard high-rate sand filter system for a 5,000 square foot leisure pool. However, as the public learns more about the superior hygienic advantages with properly designed and installed ozone water treatment systems in their swimming pools, they will almost certainly choose to swim in ozone oxidized and disinfected water.

Bibliography

ASHRAE, Applications Handbook, 1991. I-P. Edition. *American Society of Heating, Refrigeration and Air-Conditioning Engineers, Inc.* Atlanta, GA.

Beddow, B. 1995. Improvement of Water Treatment Systems in Public Indoor and Outdoor Swimming Pools, Leesburg, VA.

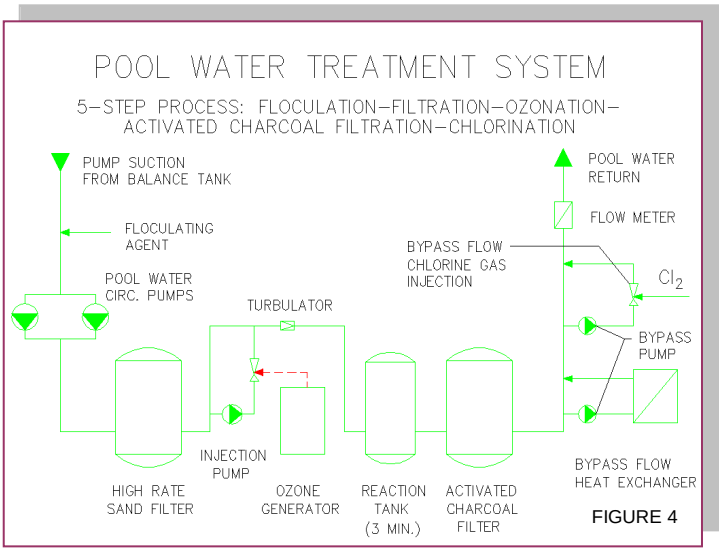

FIGURE 4

Beddow, B. 1995. Planning, Construction and Operation of Whirlpools, Leesburg, VA.

Beddow, B. 1997. Principals of Energy Conservation in Commercial Indoor Swimming Pools, Leesburg, VA.

Beddow, B., 1995. Ventilation in Natatoria, Leesburg, VA.

Haines, R. 1991, HVAC Controls. *TAB Professional and Reference Books*. Blue Ridge Summit, PA.

Hunsaker, D.J., 1983 *Designing a Natatoria, American Alliance for Health, Physical Education, Recreation, and Dance,* Reston, VA.

Deutsches Institut für Normung (DIN 19643), 1993. Aufbereitung und Desinfektion von Schwimm-und Badebackenwasser, Berlin, Germany.

Eichelsdorfer, D. Jandik, J., Weil, L. Volume 5, 1981. Bildung und Vorkommen von organischen Halogenverbindung im Schwimmbeckenwasser. *Archiv des Badewesens.* Wiesbaden, Germany.

Herschman, W., 1980. Aufbereitung von Schwimmbadwasser. *Krammer-Verlag.* Düsseldorf, Germany.

Kannewischer, B. Volume 1, 1993. Badewasserdesinfection mit Chlorgas und mögliche Alternativen. *Umwelttechnik*. Zürich, Switzerland.

Kannewischer, B., 1988. Optimieruug der Wasseraufbereitung in öffentlichen Hallen – und Freibädern, *Umwelttechnik*. Zug Switzerland.

Kannewischer, B., 1979. Badewasseraufbereitung für öffentliche Bäder. *BAG Brunner Verlag.* Zurich, Switzerland.

Kurzmann, A., 1978. Schwimmbeckenwasser aufbereitung mit oder ohne Ozon. *Beratungsbüro und Laboratorium für Ozon - und Wasser - Technologie.* Walldorf, Germany.

McGregor, R., Walenczak, W., Rogers, R., Magnetti, L. Volume 2, 1993. Case Study: Ozone-Based Water Treatment for High - Quality Air and Water in a Municipal Swimming Center. *Proceedings: Eleventh Ozone World Congress.* San Francisco, CA.

Mood, E.W., 1981. Public Swimming Pools: Recommended Regulations for Design and Construction, Operation and Maintenance. *American Public Health Association.* Washington, D.C.

Pacik, D. Volume 4, 1992. Trihalogenmethanein neues Problem? *Archiv des Badewesens*. Wiesbaden, Germany.

Pitrak, P.J., Rennell, D.S. Second Edition, 1992. Basic Pool & Spa Technology. *National Spa and Pool Institute.* Alexandria, VA.

Primarvesi, C.A., Althaus, M., 1980. Wert Bestimmung für das “Hydrozon-Kompaktverfahren” durchgeführt durch das Hygiene-Institute des Ruhrgebiets, Gelsenkirchen. *Hygiene-Institute*. Gelsenkirchen. Germany.

Recknagel, H., Sprenger, E., Hönmann, W. 66th Edition, 1992. Taschenbuch für Heizung und Klimatechnik. *R. Oldenbourg Verlag GmbH.* München, Germany.

Roeske, W., 1980. Schwimmbeckenwasser Anforderungen – Aufbereitung – Untersrchung; *Verlag otto Haase*, Lübeck, Germany.

Saunas, C., 1989. Planung von Schwimmbädern, Bau und Betrieb von privaten und öffentlichen Hallen – Sowie Freibäern einschlieBlich Whirlpools and medizinische Bäder, *Krammer – Verlag*, Düsseldorf, Germany