UV AND APPLICATIONS IN WATER TREATMENT OF COMMERCIAL SWIMMING POOLS

Update and continuation of the work published in 2006 ("Effects of medium-pressure UV lamps radiation on water quality in a chlorinated indoor swimming pool", Chemosphere 62, 2006) based on more than 500 pools equipped between 2006 and 2010.

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ABSTRACT:
Swimmers introduce organic and mineral compounds into the water which react with the chlorine to give unwanted by-products. Among them are the chloramines which very often exceed the maximum value authorized in the water (French regulations of 0.6 mg/L). A part of these chloramines are volatile, especially the nitrogen trichloride (NCl_3). This molecule is responsible for numerous problems of health (irritations, respiratory ailments) among the various users (competitive swimmers, swimming Babies, lifeguards, etc.). French authorities have proposed to limit NCl_3 to 0.3 mg/m^3 in the air. To maintain quality of water and optimal air conditions below regulatory limit values, managers of swimming pools add fresh-water to dilute these by-products. The average of fresh-water used for the renewal in water is situated near 160 liters/day/ bather (almost 40 US gallons) (French Federation of Swimming). To eliminate these by-products of disinfection the treatment through UV is widely used today. Devices equipped with medium pressure lamps are the most effective to reduce all the chloramines, in particular the NCl_3. Chloramines in water are reduced to a value lower than 0.2 mg/L and NCl_3 decreased by 30%. The quality of the water and the air is improved. The water consumption of establishments is optimized (reduction between 30 to 60%) while maintaining superior quality of water and air. Technical characteristics: medium pressure type of lamp, UV dose, sizing of devices, quartz sleeves type, power regulation, certification, UV dechloramination systems have to be engineered and managed to optimize the chloramines reduction without additional formation of by-products of disinfection (ie: trihalomethanes).

Keywords ultraviolet lamp, UV dose, chloramines, nitrogen trichloride

NOMENCLATURE
Combined chlorine or chloramines in water
$CHBr_2Cl$ chlorodibromomethane
$CHBr_3$ bromoform
$CHBrCl_2$ bromodichloromethane
$CHCl_3$ chloroform
DBPs disinfection by-products
THMs trihalomethanes
NH_2Cl monochloramine
$NHCl_2$ dichloramine
NCl_3 nitrogen trichloride or trichloramine

INTRODUCTION

Swimmers introduce micro-organisms, organic, mineral and nitrogen compounds into the water such as urea and creatin (coming from the urine and sweat), the hair, mucus, saliva, particles of skin, cosmetics... These compounds produce, in reaction with chlorine, a variety of unwanted by-products called chlorinated disinfection by-products (DBPs) (Beech, 1980). These DBPs are mainly the chloramines and the trihalomethanes (THMs). However others DBPs are formed like the haloacetic acids (AHA), haloacetonitriles (HAN), chloropicrin (CPK), chloral hydrate (HC).... Chloramines include monochloramines (NH_2Cl), dichloramines ($NHCl_2$) and trichloramines or nitrogen trichloride (NCl_3). The trihalomethanes are composed by chloroform ($CHCl_3$), monochlorodibromomethane ($CHBr_2Cl$), dichloromonobromomethane ($CHBrCl_2$) and bromoform ($CHBr_3$). Parts of these DBPs are very volatile, in particular the trichloramine and THMs.

According to the literature, the formation of THMs, depends on several factors: the disinfectant type (Judd and Jeffrey, 1995), the amount of free chlorine (Montiel, 1980; Judd and Jeffrey, 1995; Kim et al., 2002), the amount of DBP precursors such as materials of human origin (Kim et al., 2002) and citric acid contained in urine (Larson and Rockwell, 1979), the amount of Total Organic Carbon (Chu and Nieuwenhuijsen, 2002), the number of bathers and turbulences which they cause (Aggazzotti et al., 1998; Chu and Nieuwenhuijsen, 2002), the increase or reduction of pH (Jiminez et al., 1993; Singer, 1999), the increase of temperature (Chu and Nieuwenhuijsen, 2002), the amount of carbon tetrachloride (CCl_4) present in chlorine (Montiel, 1980) and molecules contained in the public water supply network such as copper (Blatchley et al., 2003), bromides and ammoniacal nitrogen (Dore´, 1989). French authorities have proposed to limit total THMs to 100 µg/l in the water. In the water, chloramines are very often exceeding the maximum value authorized in the water (French regulations of 0.6 mg/L).

Among chloramines, it is nitrogen trichloride which poses the most problem in swimming pool. Indeed, this molecule is responsible for numerous problems of health (irritations, respiratory ailments) among the various users (competitive swimmers, swimming Babies, lifeguards, etc.) (Massin et al., 1998; Bernard, 2007). Since February 2003, the respiratory affections related to this molecule are recognized like occupational diseases (Decree 2003-110, Tableau n° 66 of the General scheme: Professional rhinitis and asthmas). French authorities have proposed to limit NCl_3 to 0.3 mg/m^3 in the air.

To maintain quality of water and optimal air conditions below regulatory limit values, managers of swimming pools add fresh-water to dilute these DBPs. The average of fresh-water used for the renewal in water is situated near 160 liters/day/ bather (almost 40 US gallons) (French Federation of Swimming). To eliminate these DBPs the treatment through UV is widely used today.

The ultra-violets take part of the light spectrum and are divided into 3 parts: the UV-A from 315 to 400 nm, the UV-B from 280 to 315 nm and the UV-C from 200 to 280 nm. The latter are used in the treatment of drinking water but also in the water treatment of swimming pool. The degree of the micro-organisms inactivation and the degree of molecule destruction present in water depend on the UV-dose to which they are exposed and of the type of micro-organisms or the nature compound (the wavelength of maximum absorption, max).

In the treatment of drinking water, the germicidal action of UV (between 245 to 285 nm) is used. Indeed these wavelengths correspond to the absorption spectrum of the DNA of the micro-organisms; the maximum absorption is around the 254 nm. To inactivate various micro-organisms, UV-dose comprised between 25 to 40 mJ/cm^2 is necessary. In 2008, Dumètre et al., highlighted the effectiveness of UV on the inactivation of parasites such as *Cryptosporidium*, *Giardia* and toxoplasm whereas chlorine and ozone are ineffective with the amounts commonly used.

In the water treatment of swimming pools, the wavelengths between 200 and 400 nm will be used and more particularly the lengths between 240 and 400 nm (See part: technical characteristics). Two mechanisms of degradation intervene:

- by direct photolysis. The optimal wavelengths for the photolysis of mono, di and trichloramines are respectively to 244 nm, 294 and 336 nm (Yiin and Margerum, 1990);
- by photo-oxidation: the photons emitted are absorbed by water and residual chlorine to form hydroxyl radicals thus oxidizing chloramines and others compounds.

The emission of ultra-violet light can be realized by 2 types of UV lamps which have respective applications:

- The low pressure UV lamps, whose electric outputs can vary between 75 and 300 Watts. These lamps can measure until 1m50 length. These monochromatic lamps emit mainly at 254 nm. Their application is disinfection, for example that of the treatment of drinking water;
- The medium pressure UV lamps, whose power vary from 600 to 4000 watts in a small footprint (30 cm). These lamps are polychromatic and emit between 200 and 400 nm. This broad spectrum can have applications in treating drinking water and water treatment pools.

WORK DESCRIPTION:

State of current knowledge: Device equipped with medium pressure UV lamp for the destruction of chloramines in swimming-pools. Back to 7 years experiences.

First results from 2003: in this study the experimental conditions were specific. These conditions defined precisely the factors to be respected in the use of UV for the destruction of chloramines. The technical characteristics of UV used in this study were: UV dose of 145 mJ/cm^2, no cutoff wavelengths below 230 nm, no regulation of lamp power, sampling and analysis THMs without acidification and neutralization steps. The results show a reduction of chloramines by 67% to a value less than 0.2 mg/L. The quality of the water is improved. The water consumption of establishment was optimized (reduction by 27%). Under these experimental conditions and only in this case, it was revealed an increase in water THMs values (Cassan et al., 2006).

In order to maximize destruction of chloramines without increasing the levels of THMs, this study and the published scientific data (given below) have highlighted the factors to be master.

THE TECHNICAL CHARACTERISTICS

The technical characteristics of devices offered today are different from those proposed in the 2006 study:

1) The type of lamp used: Yiin and Margerum (1989) showed the absorption peaks of 3 chloramines in the UV. Monochloramine (NH2Cl) has a maximum absorption peak at 243 nm, dichloramine (NHCl2) at 294 nm and trichloramine (NCl3) at 336 nm. The destruction efficiency of chloramines is higher with the use of a medium pressure lamp versus a low-pressure lamp (Hamel, 2007; Oesterholt, 2009; Rasmus Andersen, 2009). Hamel (2007) shows that irradiation with medium pressure lamp at the same dose induced a greater reduction of combined chlorine as that observed with the low pressure lamp.

   In 2009, Oesterholt achieved a ranking of the best techniques for the destruction of chloramines; this happens with the best score is the average pressure ultraviolet treatment for his reduction of all chloramines.

   In June 2010, the AFSSET report clearly states that chloramines absorb UV radiation. The efficiency of the process depends on absorption spectrum and quantum yield of photolysis.
2) The UV-dose required for chloramines reduction. The applied UV dose must be 60 mJ/cm2 from the beginning to the end of lamp life. The AFSSET (2010) report states that the effectiveness of chloramines reduction depends on the UV-dose. The 60 mJ/cm^2 UV dose is necessary and sufficient for the destruction of chloramines. It must be mastered, as is the case in the treatment of drinking water.
3) The design of the device remains indispensable. The choice of material, its position, its impact on fluid flow, sensors and other alarm devices and measures shall be controlled to deliver a controlled dose, appropriate and sufficient to the considering flow.)
4) Cut-off wavelengths below 230 nm. Quartz sleeves with no emissions of wavelengths below 230 nm eliminate the wavelengths which may have a role in the formation of unwanted by-products (depending on the UV dose emitted). This cutoff wavelength is required in the treatment of drinking water.
5) The power control. The power control of the lamp with high frequency allows stability and optimization of UV-C performance. This technique allows the control of the UV dose from the beginning to the end of lamp life.
6) The installation of the device. This should always be placed after the filtration system on the entire flow and before the injection of chlorine and acid.

THE BYPRODUCTS OF CHLORAMINES AND THMS PHOTOLYSIS

Monochloramine (NH_2Cl): Recent studies (Boudiaf, 2006) show that in the presence of dissolved oxygen, photolysis of monochloramine led to the formation of nitrite ions in water without accumulation because they are very quickly oxidized to nitrate ions by free chlorine (Lahoutifard et al., 2003).

Dichloramine: dichloramine photolysis lead to the formation of NHCl which react with the ammonium ion (NH_4^+) to give predominantly dinitrogen (N_2) (Jean-Luc, 2007).

The THMs: chloroform does not absorb in the UV, so it can't be photolyzed by direct route. The brominated THMs absorb UV radiation (between 200 and 300 nm) (Nicole et al., 1991). Cassan et al (2006) showed that dibromochloromethane and bromoform may be reduced by medium pressure UV irradiation.

UV RADIATION AND THMS

If all 6 above factors are met, the levels of total THMs present in water are identical with and without the use of UV device.

In addition, the AFSSET report (2010) emphasizes that the link between water pool UV radiation and increase levels of THMs in water is not clearly established. Moreover the levels of THMs in water depend on many other factors (DGS, February 22, 2008) (See part: Introduction). The hygiene of bathers playing a role on the level THMs and trichloramines (AFSSET, 2010)

Finally, it's important to note that before March, (DGS, 2009), many laboratories used the Head Space method (Section 3 of The standard NF EN 10301) for the analysis of THMs in water. This method overestimated the level of THMs. In March 2009, DGS states:

- In the case of section 3, it is necessary to add ascorbic acid to neutralize and acidify the samples;
- It is better to use the method described in section 2 of the standard EN 10301 which uses the liquid / liquid extraction and analysis by gas chromatography.

REGULATIONS AND CURRENT RECOMMENDATIONS

Combined chlorine value: maximum 0.6 mg/L (JORF, 1981).

Trichloramine: Before AFSSET report (June 2010), only a recommendation exists: not to exceed 0.5 mg/m^3, value specified by the INRS (2007). Today AFSSET recommends that the monitoring of trichloramine in the air was integrated in the mandatory control and propose to move to the limit value to 0.3 mg/m^3 air.

Given the health risks that may cause this molecule, AFSSET recommends that the pool staff has enhanced medical monitoring throughout the period of activity and after the stop.

Trihalomethanes: regarding sanitary control, AFSSET recommends monitoring the THMs values for all pools with or without UV device. A limit value in water of 100 mg/L and a guideline value of 20 mg/L are proposed as experimental basis.

RESULTS OF 7 YEARS EXPERIENCES

Since 2004, more than 500 pools are equipped. The results show a chloramines reduction in the water by more than 80%. Chloramines in water are reduced to a value lower than 0.2 mg/L and NCl_3 decreased by 30%. The quality of the water and the air is improved. The water consumption of establishments is optimized (reduction between 30 to 60%) while maintaining superior quality of water and air.

CONCLUSIONS

The health swimming pool issue is due to nitrogen trichloride or trichloramine, disinfection byproduct formed when using chlorine.

The ultraviolet treatment to eliminate these disinfection by-products is now widely used. Devices with medium pressure lamps are most effective in reducing overall chloramines including nitrogen trichloride. The quality of water and air is improved. The consumption of water facilities are well optimized while maintaining water quality and optimum air.

The technical characteristics of UV device must be mastered in order to optimize the reduction of chloramines without effect on other disinfection byproducts.

UV device with medium pressure are now widely recognized and used for the reduction of chloramines.

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