DISINFECTION BY-PRODUCTS IN SWIMMING POOLS: MINIMIZE OR AVOID?

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ABSTRACT

Swimming pools have to cope with large variations in bather load, upsetting the often delicate balances between physical, chemical, and biological processes which determine the water and air quality in chlorinated indoor swimming pools. As a result, main contaminants like chlorinated nitrogen-containing compounds and trihalomethanes in crowded pools can reach unacceptable levels of these by-products, at a time when least desired. A better understanding of the dynamics of these processes is key to choosing the optimal process conditions for a better control of these variations, using the mandatory treatment steps of flocculation, filtration, and chlorination only. In doing so, swimming pools can cope with reasonable variations in bather load.

The analysis qualitatively predicts when these steps are no longer sufficient, and when additional treatment steps are to be put in place to control water quality. The focus here is on Advanced Oxidation Processes (AOP's). It is explained why often-used oxidation processes have different, sometimes undesirable, effects on the control of disinfection by-products. The potential of Advanced Oxidation Processes in the minimization of chlorinated nitrogen-containing compounds and trihalomethanes is discussed. Their potential is demonstrated by model experiments, and compared with practical results.

Finally, the potential of silver-stabilized hydrogen peroxide to control the bacteriological quality in swimming pools is evaluated. Hypotheses why previous, unreported attempts were less successful, and measures to correct this, are discussed. When these measures are taken, results from a long-duration pilot experiment in a heavily-visited sauna centre show that this disinfection system can be very effective in medium and small-sized swimming pools.

Keywords	swimming pool, byproducts, disinfection, hydrogen peroxide, silver, UV, advanced oxidation.

INTRODUCTION

Swimming is one of the major physical activities in many European countries. Swimming pools have progressively changed from a place where one learnt how to swim, to a place where also many leisure activities took place and where people stayed longer, particularly during weekends. Pools with more recreational facilities, and so-called subtropical paradises were built. Pools utilized in this manner tend to release more uncomfortable disinfection by-products, particularly in the air; hence air quality became more important also. Maybe partly because of this, the last decade has seen an increased practical and scientific interest in the causes of disinfection byproducts from the interaction of chlorinated water with various precursors in public swimming pools, and ways to minimize or prevent their occurrence for health as well as comfort.

The number of disinfection by-products identified has expanded over the last years (Kogevinas et al., 2010; Blatchley et al., 2009; Zwiener et al., 2007). For most of those, the extent to which they negatively effect comfort or health, individually or combined, is insufficiently known or not known at all. Yet, they are cause for concern. The situation is further aggravated by the fact that a majority of the disinfection

by-products negatively affect comfort or health in the air rather than in the water. Nevertheless, air-quality standards in Europe are exception rather than rule, and correlations –if available- between air quality and water quality are qualitative at best (Jacobs et al., 2007). This situation is likely to remain unchanged for the near future. Meanwhile, we have to continue to develop ways in which the negative effects of disinfection by-products are cost-effectively minimized or even avoided (Lakind et al., 2010), without compromising water quality or introducing other health hazards. With our current knowledge, we can simply select

major relevant constituents of disinfection by-products, and categorize these in toxic by-products, by-products which are -suspected- carcinogenic, and irritant by-products. We have chosen to focus on trichloramine and trihalomethanes, which have long been considered to be the more relevant irritants (Massin et al., 1998) and suspect carcinogenic species (Xu et al., 2002) respectively. Moreover, it can be reasonably assumed that some of the mechanisms which determine the formation and breakdown of these compounds are equally relevant to a much larger group of disinfection by-products within each of the categories mentioned. Nevertheless, even for these categories there is no common view yet on a European level what, if anything should be addressed through swimming-pool legislation. Maybe the prime reason for this is the widely varying usage conditions in swimming pools (Guillam et al., 2007). This makes it difficult to set additional water or air quality targets based on statistical evidence. Swimming pools not only differ in the treatment systems they use; they also differ in operating conditions that affect byproduct formation and, last but not least, they experience large fluctuations in bather load during the day and during the week (Chu et al., 2002). This makes it even more difficult to select operating conditions or equipment to meet additional targets, if and when they are made obligatory. Nevertheless, some practical recommendations can already be given on how to minimize disinfection byproduct formation in swimming pools with equipped with conventional treatment systems.

TRICHLORAMINE FORMATION: UPSETTING A DELICATE BALANCE

Chloramines constitute the major part of a larger class of nitrogen-containing disinfection byproducts. They can be formed from the direct chlorination of organic-nitrogen compounds introduced by bathers (Li and Blatchley, 2007). Urea is the main component therein, and is also the predominant precursor for the volatile and irritant trichloramine. The main reaction pathway from urea to trichloramine is not via direct chlorination, however, but indirectly via the chlorination of ammonia. The mechanism is as follows:

When adding the nitrogen from all nitrogen compounds in swimming pool water, it is invariably found that the resulting nitrogen level is substantially higher than the level of nitrogen (nitrate) in the supplied water. The higher nitrogen level measured, therefore, must be caused by the organic-nitrogen compounds introduced by bathers. In the graph of figure 1, we have calculated the relative contribution of supplied water and bathers to the nitrogen level in pool water by carrying out a mass balance over a swimming pool basin. Taking average values for bathers load (300.000/yr), supplied water (30 L/visitor), and nitrate level in the supplied water (25 ppm), we calculate that about 50% of the nitrogen in the pool water originates from bathers! It can be shown that this value ranges from about 30% to 60% when using the extreme values found in practice. Consequently, the conclusion that bathers are a major contributor to the nitrogen measured in pool water remains valid for a wide range of pool process conditions.

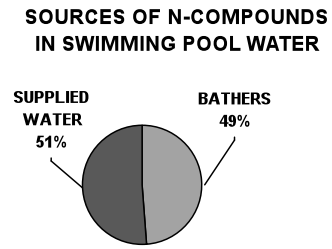

Figure 1 Relative contribution of supplied water and bathers to the nitrogen level in pool water

The nitrate concentration in the pool water is also much higher than the concentration of nitrate in the supplied water. Similar to the argument above, this can only come from organic-nitrogen compounds introduced by bathers that have been converted to nitrate, one way or the other. As urea is the principal component of organic-nitrogen, the conclusion must be that a massive conversion of urea to nitrate has occurred somewhere in the pool system. The degree of conversion can be calculated by a similar mass balance as above.
The result, shown in the graph of figure 2, is that well over 95% of the organic-nitrogen (urea) has been converted to nitrate.

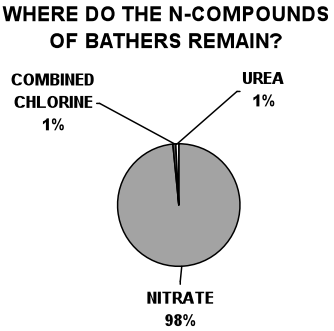

Figure 2 Fate of N-compounds, brought into pool water by bathers.

The most plausible way for this massive conversion of urea to nitrate is through the well-known bacterial nitrification of urea, a well-known process in the soil and in sand filtration of drinking water. This is a three-step process that takes place in biofilms formed on sand grains and in/on coal particles used in pool filters. Other nitrogen-compounds only give a minor contribution to this process. The three consecutive steps are: (1) urea oxidizes to ammonia by urease, (2) ammonia oxidizes to nitrite by nitrosomas, and (3) nitrate oxidizes to nitrate by nitrobacter. The second step is the rate-limiting step (Lin and Li, 2001). Hence, a fast and large increase in urea concentration in the water –caused by a fast and large increase bathers load- upsets the balance between the three steps: the first step adapts quickly, and produces much more ammonia from the urea, with which the nitrification step (2) can not cope. Ammonia is then migrating from the biofilm into the pool water, where it immediately reacts with free chlorine to form chloramines. The graph of figure 2 shows that only a very small percentage of urea is converted to chloramines; practically all urea is converted to nitrate. But this is a delicate balance: only a small

percentage shift towards the formation of chloramines leads to a large absolute increase in chloramine concentrations. This will be a combination of mono, di, and trichloramine, with the ratios between these components depending on a number of conditions discussed later. Under adverse circumstances, the balance shifts to trichloramine, resulting in malodors.

Increasing filter area and lowering filtration speed will enhance many water-quality parameters, but will not suppress the fast increase in chloramine levels that are caused by a fast and large increase in urea level. Rather, the objective is to create those conditions that keep chloramines in the water (mono- and dichloramine) and prevent it from escaping into the air as trichloramine. These conditions are well documented (Davis and Elder, 1994). The cost-effective technical operating and design measures that minimize the temporary accumulation of trichloramine and its inherent malodor in the air are:

- Keeping the pH and free chlorine concentration near the lower limit without compromising robust disinfection;
- Predilution of the hypochlorite dosed with clean water;
- Frequent and short filter backwashing, rather that infrequent and long;
- Uniform flow of water in the basin and the air above it, i.e. no dead corners.

Although these measures will take care of a large percentage of the malodor problems, malodors may still develop. This happens, for instance, if the difference in bathers load during the week and during the weekend is substantial. Under these circumstances, keeping the free-chlorine level low may no longer be possible because of the non-uniformity of the free-chlorine concentration in the pool basin, combined with too high levels of chloramines in the water. Then, removing chloramines from the water is the only option left. The focus here is on removing chloramines by oxidation.

Oxidation of chloramines is often done with ozone in a bypass. This is an effective technology, but great care must be taken that the toxic ozone does not enter the main water circuit, particularly because there exists no reliable method to measure in-situ ozone concentrations in water in the presence of free chlorine. A major effort with the use of ozone in the production of drinking water is the control of the formation of the very toxic bromate from bromine. It would be prudent to investigate this effect in swimming pools also, as ozone in pools is used frequently in some countries.

UV lamps are frequently used for the oxidation of chloramines. In the UV-reactor, chloramines are presumably oxidized by OH-radicals produced by UV-irradiation of free chlorine present in the water. UV-reactors control the fluctuating levels of chloramines with widely varying degrees of effectiveness, depending on the type and power of the UV lamps installed. If, in addition, a very low concentration of trichloramine in the air is required at all times, as in Belgium (< 0.3 mg/m^3), UV-reactors with a high installed power are needed. There are no technological reasons to assume that the needed power will be different for Low Pressure lamps and Medium Pressure lamps, but research is needed for a definitive view. Unfortunately, high levels of UV irradiation increase the risk for the formation of trihalomethanes (Cassan et al., 2006), for reasons discussed in the next section.

The effectiveness of UV lamps can be greatly enhanced by combining these lamps with oxidants which generate OH* radicals upon UV-irradiation, so-called Advanced Oxidation. Suitable oxidants, in principle, are ozone and hydrogen peroxide (Glauner and Frimmel, 2006), but the previous cautionary remarks on ozone remain. The main advantage of ozone and hydrogen peroxide in swimming pool applications is the greatly increased effectiveness of the oxidation of chloramines and organic contaminants. The effectiveness of AOP in a bypass with Medium Pressure lamps+hydrogen peroxide in the removal of chloramines is shown in Table 1.

Table 1 Average and peaktime combined chlorine concentrations without and with UV/ H_2O_2 in a bypass

Combined Chlorine (ppm)	WITHOUT UV/H_2O_2		WITH UV/H_2O_2 (hydrogen peroxide < 1 ppm)	
Swimming Pool (250,000–350,000 visitors/yr)	Average	Peaktimes	Average	Peaktimes
Pool A	0.7	0.95	0.1	0.2
Pool B	0.5	0.7	0.15	0.25
Pool C	0.5	0.6	0.1	0.2
Pool D	0.5	0.6	0.1	0.2
Pool E	0.5	0.7	0.15	0.25
Pool F	0.5	0.7	0.15	0.25
Pool G	0.6	0.75	0.1	0.2
Pool H	0.5	0.6	0.15	0.25

TRIHALOMETHANES

Trihalomethanes are mainly formed by the reactions of hypochlorite with humic acids (HA) and in the supply water; fulvic acids and beauty products may contribute also. These volatile compounds are suspect carcinogenic. Levels in the water are fluctuating (Chu and Nieuwenhuijsen, 2002), and can be of great concern in swimming pools that use surface water for their supply. It has been shown that the major pathways for human intake are inhalation and percutane adsorption (Erdinger et al., 2004).

Concern over the use of UV in swimming pools has started since the publication over the potential increase in THM levels (Cassan et al., 2006). It has been postulated that this risk is potentially present only if medium-pressure (MP) lamps with a relatively high power input are being used, and that low-pressure (LP) UV lamps would not pose such a risk. However, LP UV light can also activate free chlorine to generate OH* and Cl* radicals (Feng et al., 2007). The risk then becomes a matter of light intensity applied, and not one of light source used. In this sense, UV with free chlorine can be considered an AOP, albeit a process which also generates undesired Cl* radicals.

RESULTS AND DISCUSSION

In order to test whether, in principle, the formation of chloroform is accelerated by radiation of HA with free available chlorine, an experiment was carried out in a 1-L. laboratory reactor, equipped with a 15 W LP lamp. Chloroform measurements were done by solvent extraction, followed by GC/ECD analysis. Humic acids and free available chlorine concentrations were determined by spectrophotometry.

To imitate pool conditions, the free chlorine concentration during the experiment was held as constant as possible by regularly dosing additional sodiumhypochlorite to compensate for its rapid degradation by UV. Under these experimental conditions, the result (Figure 3) shows that as long as HA is present in solution, the reaction of HA and Cl* is faster than the reaction of HA with OH*; chloroform production is thus considerably sped up. The chloroform produced from HA happens within half an hour, whereas the formation of chloroform without UV irradiation took many hours (not shown). The chloroform degradation by OH* starts after the HA has been oxidized.

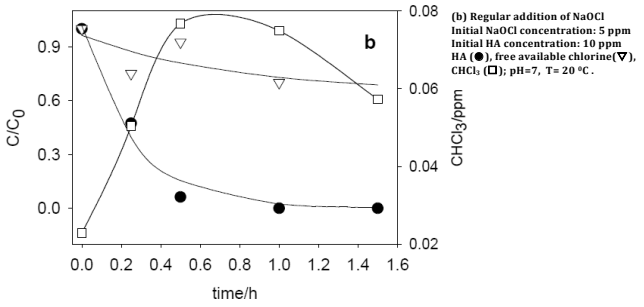

Figure 3 Chloroform formation by LP-UV irradiation of humic acid in the presence of free available chlorine.

When applying UV in swimming pools where trihalomethanes precursors are present, therefore, one has to establish if a balance exists between the minimum UV dose required for controlling trichloramine level during peak hours down to the level required, and the maximum UV dose allowed whereby the formation of trihalomethanes does not result in the increase of trihalomethanes levels. The lower the trichloramine level required, the more difficult this will become. A general statement that LP-UV is safe regarding trihalomethanes formation is not supported by this experiment. For such a statement, more data would be needed. An advantage with using hydrogen peroxide in an AOP is that only OH* radicals in the UV reactor can be formed, as free chlorine is absent in the presence of hydrogen peroxide.
For the efficient degradation of chloroform by advanced oxidation, a relatively high oxidant concentration with low UV dose is needed, and vice versa. In figure 4, the effective degradation of chloroform in a 1-l reactor with a MP- UV (150 W) is demonstrated. It is expected that the formation of OH* radicals from hydrogen peroxide is more cost-effective with MP-UV than with LP-UV, given the large fluctuations of oxidizable contaminants in swimming pools. Additional experiments, however, are needed to prove this.

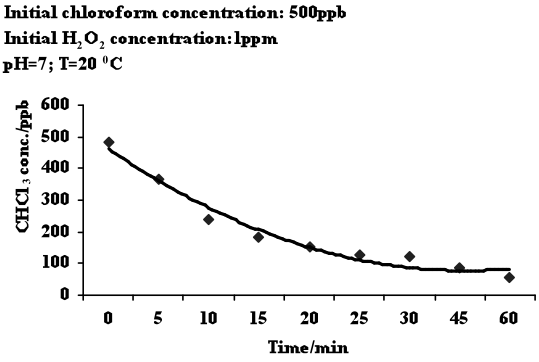

Figure 4 Chloroform oxidation using MP-UV + H_2O_2

CONCLUSION

Only when using an AOP based on UV+hydrogen peroxide does one create a situation where byproducts are degraded without any risk for undesirable by-products. OH* radicals are the only free radicals formed, and can simultaneously oxidize both trihalomethanes and chloramines present in the swimming pool. The UV dose is, in principle, without restrictions. It depends only on the levels specified by the pool operator at times when the pools are crowded.

DISINFECTION WITH SILVER/HYDROGEN PEROXIDE

The requirements for any disinfectant in swimming pools can be summarized as follows:

- It must be capable to have a log 4 reduction of Pseudomonas aeruginosa bacteria in about 30 seconds, in order to ensure that micro-organisms cannot be transferred from and among bathers during their stay in the water;
- It has to be safe and efficient;
- The concentration required for disinfection must not pose a danger to the health of swimmers;
- There is a need for a disinfectant "buffer capacity" in the swimming pool itself, able to cope with the fluctuating bathers load;
- It must be accurately measurable with a simple method by swimming pool personnel;
- It must contain sufficient oxidation power to keep human contaminants in the water at an acceptable low level;
- The formation of harmful by-products has to be controlled and restricted to an absolute minimum.

The disinfection properties of the silver ion have long been known (Silvestry-Rodriguez et al., 2007). Silver has also been combined with hydrogen peroxide, giving a so-called "silver-stabilized hydrogen peroxide" solution. This was done mainly to boost its disinfection power; it can be speculated that this is due to free-radical formation. The silver can be present in this solution as an ion or in colloidal form. The main advantages of silver-stabilized hydrogen peroxide are as follows:

- No harmful side-reactions;
- No odor nuisance in the pool area;
- Environmentally friendly because of the decomposition into water and oxygen;
- No important effect on the acidity of the water;
- Complies completely with the above requirements of a good disinfection product;

Its main disadvantages are:

- Less weight-effective than chlorine, so higher peroxide concentration required;
- Cost price higher than chlorine;
- Irritating to skin and respiratory system in the concentrated stock solution.

In the 90's, some private pools were successfully treated with a silver-stabilized hydrogen peroxide product (50% w/w H_2O_2, 0.360g/L Ag). The product does not contain halogens or quaternary ammonium compounds. This product was found to satisfy the requirement of *Pseudomonas aeruginosa* bacteria reduction by log 4 in about 30 seconds, at a hydrogen peroxide concentration of 500 ppm.

To investigate whether this alternative could be used also in public pools to replace the more and more contested sodium hypochlorite without constituting a risk to the visitors, a pilot project was launched early 2004 in a heavily-visited wellness center in Belgium with two small swimming pools, four hot whirlpools and two cold plunge pools. It was recognized from the start that a key challenge was to address the poor long-term stability of hydrogen peroxide found in tests elsewhere (verbal communications). The hypothesis we developed to explain this phenomenon was that human bacteria and cells that contained the enzyme catalase were accumulating in the filterbed. Catalase is well-known for its ability to quickly and completely decompose hydrogen peroxide. Upon reaching a critical mass after a few weeks, the cells in the filter would decompose all the hydrogen peroxide flowing through the filter, and the peroxide concentration in the swimming pool would drop to very low values, or it would disappear altogether.

METHODS

The installation was equipped with a control unit for the measurement (photometric measurement) and regulation of hydrogen peroxide concentrations in the different pools. Regular checks and reports were agreed with the appropriate authorities during the test period. The test commenced early 2004, and finished mid 2010. Every two weeks, an accredited laboratory (Labo Derva) took samples. At the same time, the installation was inspected in order solve possibly occurring problems and to prevent any risk with regard to the visitors. All analyses were executed within 12 hours after taking the samples. The samples were always transported and stored in a cool environment.

Checks were performed on the parameters presented in Table 2.

Table 2 Water quality parameters tested.

Parameters	MTC Value
1.Colour:	Blue
2.Transparency:	Bottom
3.Foaming:	Absent
4.Acidity pH Sörensen:	6.5<pH<7.5
5.Temperature: °C	>32° resp. 36°C
6.COD mg/L O_2:	<100
7.Urea mg/L:	<2
8.Turbidity NTU:	0.50
9.Stabilized Hydrogen Peroxide mg/L:	40– 80
10.Silver mg/L:	<1
11.Total Viable Count CFU/mL at 37°C	<100
12. *Pseudomonas aeruginosa* CFU / 100 mL:	<1
13. *Staphylococcus aureus* CFU/100 mL:	<1

RESULTS

Before discussing the results in more detail, some observations on the different legislations of swimming pool water versus drinking water are useful to place the results in perspective: in quite a few European countries, the maximum allowable total bacterial count in swimming pools at 37°C is many times lower than the practically allowed value for drinking water in the European legislation. Although the bacteriological condition of the water in pools remains very important, this means that more than 90% of the counts measured in the pool samples would have passed drinking water standards. It is also for this reason that the local authorities raised the maximum allowable total bacterial count to 500 CFU/mL for duration of the test period. The parameters *Pseudomonas aeruginosa* and *Legionella pneumophila* bacteria are considered the most important indicators for a good bacteriological water quality.
The tests were carried out in three separated periods, with the bacteriological results shown in Table 3.

Table 3 Bacteriological results during three periods (X is the number of viable counts in CFU/mL)

	Period 1 72 samples	Period 2 202 samples	Period 3 307 samples	Total Periods 581 samples
0 < X < 100	51 %	64 %	79 %	70 %
0 < X < 500	97 %	82 %	94 %	90 %
X > 500	3 %	18 %	6 %	10 %
Staph. aureus	8 %	10 %	3 %	6 %
Pseud. aeruginosa	6 %	4 %	4 %	4 %

EVALUATION

During the first test period, the problem of hydrogen peroxide instability was eventually resolved by flushing the filterbed with a strong oxidant at regular intervals, thus preventing build-up of bacteria and cells containing catalase. During the second period, word was spreading about the comfortable condition in the wellness center, leading to a strong increase in the number of visitors which the silver/peroxide disinfection system could not always cope with. Therefore, the peroxide concentration during the third test period was increased. More issues were resolved during the first two periods, which are discussed later. The bacteriological results from the third period are quite satisfactory: about 80% of the analyses (for the last period) for the results indicated no excess of the total bacteria count with regard to the currently applicable Belgian pool legislation, while only 6% of the analyses give a total bacterial count of more than 500 CFU/mL. The third period is therefore considered as reference period.

In about 3 % of the tests, *Staphylococcus Aureus* is present. This is extraordinary low for a pool with a similar occupancy and a relative small water surface area. The percentage of coliform and faecal coli bacteria in the test is very low: 4% for coliform bacteria and 3 % for fecal coli bacteria. *Escherichia Coli* bacteria have not been detected.

The percentage of intestinal *Enterococci* in the test was 20%. The percentage is so high because most infections were found in the cold immersion baths, at which temperatures the silver/hydrogen peroxide is less effective. Only in 2% of the test results from the swimming pools show intestinal *Enterococci*.

The cold pools, on the other hand, with temperatures just below or above 20°C showed a 9% infection with intestinal Enterococci.

The whirlpools with fairly high temperatures of above 35°C had also a 9% infection with intestinal *Enterococci*. This was due to the behavior of the visitors who almost always ignored the warning notices to shower before using the whirlpools. Without a preceding shower, dead skin cells end up in the pool on a massive scale. Thereby large numbers of intestinal *Enterococci* are found together with the catalase positive *Proteus mirabilis*. The same phenomenon is observed in chlorinated pools of other sauna complexes. This, however, never manifests itself because this parameter is not taken into account in the Vlarem II legislation as an obligatory bacteriological parameter. Generally, it can be concluded that the bacteriological results are more than satisfactory.

CATALASE EFFECTS

ATP measurements revealed that the instability of hydrogen peroxide was not only caused by the presence of catalase producing bacteria (*Proteus mirabilis*). Also, a massive amount of skin cells remaining in the water, originating from the bathers, showed a strong catalase reaction and in some cases a strong degradation of the hydrogen peroxide present. Because of this, bacteria such as the intestinal enterococci can survive for a longer time. We still have to investigate further if a more efficient flocculent dosage can have beneficial effects on the removal of catalase-containing cells, and thereby on the stability of the disinfectant system. The first results are promising, but it is still too early to judge.

pH STABILITY

The silver-stabilized hydrogen peroxide has a low buffer capacity. Therefore, in case of higher doses, the pH value usually becomes lower. To stabilise the pH and buffer the water, sodium bicarbonate was added, just as in chlorinated pools. It is well-known, however, that both bicarbonate and carbonate, but also chlorides, are free-radical scavengers. This negatively influences the effectiveness of the silver-peroxide disinfection system, and therefore the dosing of bicarbonate was discontinued very quickly.
It was remarkable, however, that catalase instability developed more slowly at lower pH values. A lower pH value had a positive influence on water quality and water consumption. The relatively low pH value of approximately 6.0 appears to have no negative effects on the experience of the visitors.

UREA LEVEL

Until now, we did not succeed in reducing the urea content to below the maximum authorized concentration for urea of 2 mg/L. Although the values have considerably decreased during the test periods, they are still above 2 mg/L. Given the fact that this is only important when there is a risk for the production of chloramines, in particular trichloramine, this effect can be ignored when using silver-peroxide.

COD LEVEL

The $KMnO_4$ method for measuring the organic oxygen consumption is not applicable in the presence of hydrogen peroxide. Peroxide preneutralization, e.g. with catalase, is also unsuitable, as the content of organic material will then increase. It was therefore replaced by the COD method, with an agreed maximum value of 100 mg/L. This corresponds with a KMnO4 value of 5 mg/L O_2. The COD target value was exceeded.

NITRATE LEVEL

The nitrate content does not cause any problems and is always below 50 mg/L i.e. the maximum authorized value for drinking water.

CONCLUSIONS

Swimming in chlorine free water was such a comfortable experience that the number of visitors increased, and remained high during the test period. There is apparently a need for swimming facilities with chlorine-free water. The advantages compared to chlorinated swimming pools are significant: no chlorine odor, better skin care. There were no cases where people became ill or complained after their visit of the Wellness center. In short, the goal of a comfortable and safe environment has been achieved. After a trial period of almost five years, we can conclude that stabilised hydrogen peroxide is a valuable substitute for chlorine, which has been used for more than 100 years already.

The bacteriological results can be considered more than satisfactory and are still getting better.

The main cause of the bacteriological excesses and the related catalase effect is attributed to the system itself, which needs to be set up more adequately. The construction and the operation of the pool when replacing chlorine as disinfectant needs much detailed attention.

This is particularly the case for the construction and the operation of hot whirlpools and cold immersion baths. On the other hand, these need detailed attention even if chlorine is used, as do baths with temperatures above 32°C and special features with air and water, such as blowers and massage jets.

The disinfection effectiveness of silver-hydrogen peroxide is less in colder baths, obviously because their lower water temperatures.

Although major hurdles have been overcome during the test periods, there are still some remaining issues to be addressed. These have been discussed above. If these can be resolved, visitors concerned about their health can enjoy safe and comfortable swimming in pool water, without any fear for the effects of harmful disinfection by-products of chlorinated swimming pool water. The need for such facilities has been clearly indicated in this pilot project.

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