

## **Practical experience with treating pool water by membrane filters, UV and electro-chlorination - The end of the era of sand, carbon and sodium hypochlorite?**

Henrik Rasmus Andersen, Associate professor, Department of Environmental Engineering, Technical University of Denmark., Denmark, Povl Kaas, Scan Research A/S, Herning, Denmark

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### **Synopsis**

The 105 m<sup>3</sup> hot water pool at Marselisborg hospital for physical rehabilitation therapy was originally traditionally equipped with sand filters and carbon filters. In 2006 the water treatment system was scrapped and replaced with ultrafiltration membrane filters, a large UV system and a chlorine generator using hydrochloric acid. Initially it was attempted to run without flocculants, but it was found that membrane cleaning problems could be solved by using a very low dose of flocculation agent.

The consumption of water, power and chemicals were characterized in the two systems and the water quality was in terms of combined chlorine, Non Purgable organic carbon (NPOC), Total Trihalomethanes (TTHM) and absorbable organic carbon (AOX) was characterised. The result of the system change was that the water quality in the new system was generally acceptable, whereas the original system often failed to comply.

The water consumption of the system was reduced to half due to more efficient filter flushing while the electric energy doubled due to the UV-lamps. 3½ ton of chlorine solution consumption was replaced by 300 L (25 %) increase in HCl consumption. In terms of running cost the new system was marginally more cost effective than the original.

### **System descriptions**

#### *Pool characteristics*

The 105 m<sup>3</sup> and 34.5 °C pool at Marselisborg Hospital opened in 2000 for physical rehabilitation therapy of patients. The pool is used by 75-160 patients per day with a weekly average number of bathers close to 1000.

#### *Original water treatment system*

The original system for water treatment consisted of particle filtration by three sand filters of 1.5 m diameter each and a filter treating the full circulating stream of 212 m<sup>3</sup>/h and a column type carbon filter treating a 6 m<sup>3</sup>/h side stream for disinfection by-product (DBP) control. Back flushing of sand filters was at first done on alternating filters every 3<sup>rd</sup> day (9 day cycle), but the frequency was later increased to flushing all filters twice per week.

Chlorination was supplied at a level of 1.2 mg/L by automatic dosing 12 % w/v of NaOCl and pH was maintained at 7.4 by automatic adding of 34 % HCl. Flocculation on the sand filter was done with polyaluminium chloride with a dose of 0.002 g-Al/m<sup>3</sup>.

Though the system was constructed according to the minimal filtering capacity and other design recommendations according to the Danish Standard DS 477 the pool experienced continuous and increasing problems with pathogenic bacteria and fungus in the water which could be traced to large aggregates of sand held together by fungus which was not broken down during backwashing of the filters. Further, maintenance of the system was unacceptable laborious. In 2005 the this water treatment system was scrapped after less than five years running time due to continuous problems with water quality and extremely high water consumption for filter flushing.

#### *New water treatment system*

The replacement system consisted of a custom build ultrafiltration vacuum membrane filter of 1000 m<sup>2</sup> for return stream filtration based on the Trisep Co., SpiraSep-950 (typical poresize 0.05 µm), which was divided in 3 units in order to make the system small enough to be transported through existing doors. The filter capacity was 50 m<sup>3</sup>/h with a typical pressure drop over the membranes ranging from 0.20 to 0.45 bar.

An UV system with 6 polychromatic lamps (APROP, Scan Research, Heming, DK) with UV-output from 410-170 nm of total of 4140 W was used to control DBP concentrations, which was expanded to 12 lamps of total 8280 W in October 2008.

Chlorine was generated online by electrolysis of 34 % HCl with a 125 g/h chlorine generator model CEOC, Tägerwil, CH and the target concentration was reduced to 0.8 mg/L. The reduced concentration was justified by higher stability of the chlorine in the pool water and reduced target pH. The pH of the water was controlled at 6.7 by dosing either HCl or NaOH depending on the balance between the alkalinity from the replacement water and the acid added by the chlorination.

Initially the system was run without flocculation, but experimentation aimed at solving a continuous problem with fouling of the membranes resulted in that a low dose flocculation with a mixture of iron and aluminium was initiated from mid 2008 consisting of a 0.1 g/m<sup>3</sup> dose.

Membrane cleaning procedures was optimized over the two years of the system lifetime and the final solution which was automated used a 1 h CIP (clean-in-place) procedure at 65 °C with a detergent and pH = 11.

CIP is done in steps.

1. Heating to 65 °C
2. Addition of NaOH to pH of 11
3. Addition of Divos ADD3 from JohnsonDiversey
4. Recirculation at 65 °C for one hour. The combination of high pH and 65 °C practically steriles the membranes system.
5. Flushing with tap water until neutral pH.

The CIP sequence is done automatically during the night once per 4 months.

### Running costs

The consumption of water, power and chemicals in the two systems was compared based on measurements and the deliveries of chemicals to the facility. An overview of the results of the analysis is shown in table 1. The water consumption of the system was reduced to half due to more efficient filter flushing while the electric energy doubled due to the UV-lamps. 3½ ton of chlorine solution consumption was replaced by 300 L (25 %) increase in HCl consumption.

It is likely that the reduction in water replacement and the energy used on UV-lamps will contribute to a decrease in the use of energy for heating in the new system, but this was not quantified. The economical consequence for the changes in running cost between the systems was calculated based on actual unit prices for electric energy, water and chemicals from 2008. The result of this is shown in table 2. It is seen that the savings on water and chemicals consumption is worth more than the increased cost of electric energy. The difference is only 10 % for the final system, but if the same calculation was made with the system with only 6 lamps - as was used with satisfactory results in most of the lifetime of the new system - the savings on the running cost was more significant at 27 %.

**Table 1: Electric energy, water and chemicals consumption in the two systems.**

	<b>Original system</b>	<b>New system</b>	<b>Difference</b>
<b>Electric energy (kWh/y)</b>			
Pool service	20,510	29,750	-45%
Filters	38,808	25,799	34%
Water Chemistry	12,600	81,564	-547%
Sum	71,918	137,113	-91%
<b>Water (m³/y)</b>			
Filter flushing	4,956	1,344	73%
Measuring stream	504	504	0%
Dilution	1,260	1,428	-13%
Sum	6,720	3,276	51%
<b>Chemicals (L/y)</b>			
NaOCl, 12%	3,696	NA	NA
HCl, 34%	1,428	1,764	-24%
NaOH, 28%	NA	204	NA

**Table 2: Running cost in the two systems based on the differences in electric energy, water and chemicals consumption.**

	<b>Original system</b>	<b>New system</b>	<b>Difference</b>
Electric energy	kr 107,158	kr 204,298	-91%
Water	kr 216,989	kr 105,782	51%
Chemicals	kr 36,993	kr 15,980	57%
Total	kr 361,139	kr 326,061	10%
<i>Alternative total (Just 6 lamps)</i>		<i>kr 265,295</i>	<i>27%</i>

### Water quality

*Quality parameters from routine control*

Bacteria densities, combined chlorine, TTHM redox and pH were measured at different intervals in both systems as part of the maintenance of the system and according to the mandatory regulatory control. The result of this is summed up in table 3. It should be noted that both the target chlorine concentration and pH value was decreased in connection with the renovation of the system. This will change the RedOx, combined chlorine, TTHM and microbiological parameters in the pool by itself independent of the filter system and method of maintaining the water chemistry.

**Table 3: Water quality parameters from historic data related to control and maintenance of the pool.**

Parameters	Original system				New system				
	Average	min	max	n	Average	min	max	n	
	pH	<b>7.3</b>	7,10	8.3	1280	<b>6.67</b>	6.5	7.27	1120
Daily control values	Free chlorine (ppm)	<b>0,96</b>	0,10	1,90	1280	<b>0.78</b>	0.09	0.90	1120
	Combined chlorine (ppm)	<b>0,34</b>	< 0,03	1,40	1280	<b>0.08</b>	< 0,03	0.28	1120
	RedOx	<b>682</b>	620	770	1280	<b>835</b>	760	900	1120
Chemical spot samples	Total Trihalomethanes (µg/L)	<b>35</b>	16	48	4	<b>28</b>	21	33	4
	Turbidity	<b>2,7</b>	1,8	3,6	4	<b>&lt; 0,10</b>	< 0,10	< 0,10	4
Microbiological spot samples	Heterotrops 37 °C, (100 ml) <sup>-1</sup>	<b>290</b>	< 1	3500	48	<b>19</b>	< 1	210	42
	P. Aeruginosa (100 ml) <sup>-1</sup>		< 1	8	48		< 1	< 1	42
	Coliforms (100 ml) <sup>-1</sup>		< 1	< 1	48		< 1	< 1	42

The most significant change in the control parameters is the reduction in combined chlorine which is achieved by the fact that the UV-treatment is more effective at maintaining a low concentration since a larger fraction (25 %; 12½ m³/h) of the circulation stream is treated continuously compared to the old system there the carbon filter was responsible for controlling combined chlorine but only treated a small fraction of the circulation water (3%; 6 m³/h). Other indicators that suggested that the pool water contained fewer pollutants are the decrease in turbidity and lower incidence and concentration of cultivatable bacteria.

*Sampling campaign for NPOC, THM, AOX and NCl<sub>3</sub> in the new system*

A sampling campaign was undertaken in November and December 2008, which was aimed to describe the day to day variation in NPOC, THMs, and AOX.

The three measured parameters for the water quality shown good agreement as seen in figure 1. The graph surprisingly shows initially high concentrations off all three parameters which exhibit a marked continuous fall in concentrations of AOX and NPOC during the first three weeks of the sampling period and more stable lower values in the latter three weeks. This was explained by the pool attendant by to be likely to be caused by a malfunction during the cleaning procedure of the membrane filters immediately before the sampling period began during which 25 L of concentrated detergent solution spilled into the pool. Due to this it was decided to use only the data from samples taken between the 4.th and 30.rd December to characterize the water quality.

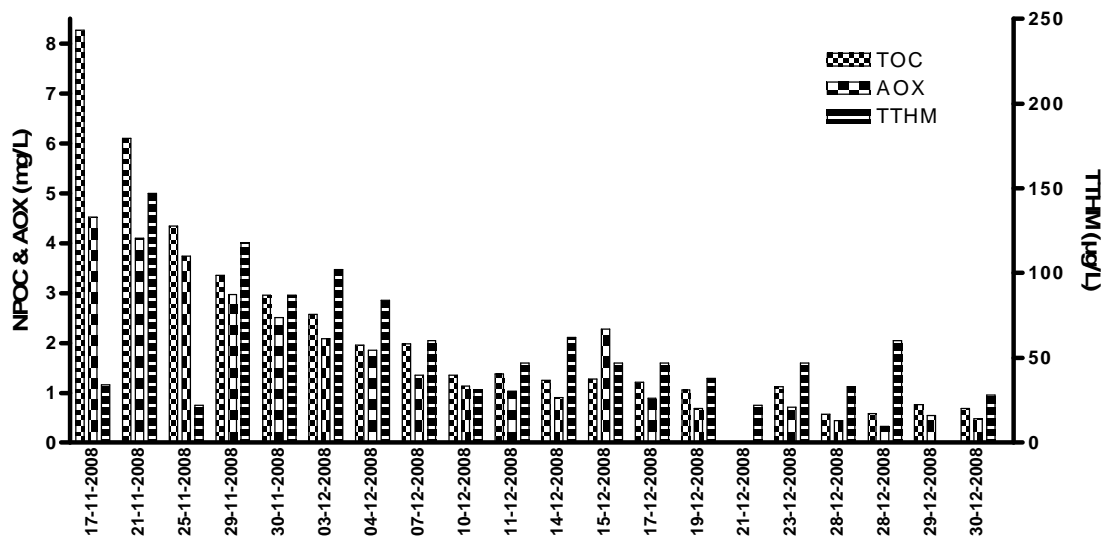


Figure 1: Variation in NPOC, AOX and TTHM in the sampling period of November and December 2008.

In the last half of the sampling campaign the average NPOC concentration varied between 0.68 and 1.98 with an average of 1.21 mg/L. The filling water used varied in the same period between 1.17 and 1.27 with an average of 1.24 mg/L.

The AOX concentration varied between 0.52 and 2.28 with an average of 1.00 mg/L and TTHM varied between 22 and 62 µg/L with an average of 42 µg/L. There was a fairly constant ratio between the different trihalomethanes showing that about 20 % of the TTHM was bromdichlormethan and 5 % dibromchlormethan, while bromoform (CHBr<sub>3</sub>) was only detected with indicated values about 0.2-0.8 µg/L.

Samples of NCl<sub>3</sub> in the air above the pool were taken three times. The result were 0.1259, 0.2923 and 0.2134 mg/m<sup>3</sup> which are considered to be very low concentrations for public swimming pools and is consistent with that the room that the pool is in rarely has any “chlorine smell”.

## Experiences and problems

### Membrane fouling

The biggest problem experienced at the vacuum driven membrane plant has been deposits, which have been quite difficult to remove from the membrane surface. The deposits consisted mostly of

- A calcium-protein-complex
- fatty substances from skin lotion and oils
- skin particles

Initially the plant was operated without flocculation. However, after 1 month the trans membrane pressure had risen from -0.16 bar to -0.62 bar. Cleaning with NaOH and nitric acid could only partially remove the deposits. An element was sent back to the manufacturer which inspected the element. It was found that a cleaning with a phenol-based detergent at 65 °C followed by citric acid cleaned efficiently. The challenge was that the detergent used was not allowed in EU since it is hardly biodegradable. It was then decided to initiate flocculation in an attempt to minimize fouling. In cooperation with Kemira a flocculent was developed, which could be dosed directly into the membrane plant and that solved most of the problems. To solve the remaining cleaning issues several detergents and complexion agents were tested without complete success. The key factor which helped to maintain stable operation was the fact that cleaning could be done at 65 °C and up to 80 °C is allowed.

#### *Maintenance work load*

In terms of handling of chemicals solutions the maintenance work load has been reduced since the 3½ ton/y of sodium hypochlorite is no longer used. The working safety and environment has also benefitted from the elimination of handling and storing of chlorine.

Another major maintenance task in the traditional system has been the biweekly manually controlled filter flushing which was performed after the closing of the pool (22:00) in order to avoid complains related to the temperature decrease in the pool water then a large volume of tap water entered the system as replacement for the water used for flushing. In the membrane system this was completely by an automatic procedure and the water loss was too little to give a noticeable temperature difference.

#### **Conclusion**

A complete change in technology of the water treatment system for a highly loaded hot water pool was tested and has been run for two years.

Both water quality and running costs were acceptable according to comparable pools and significantly better than the unusually poorly performing traditional water treatment system which it replaced.

We predict that this achievement marks the beginning of a time then membrane filters will be considered as comparable alternatives to sand filter systems both for new pools and as replacements for renovation of traditional sand filter systems.

#### **Acknowledgement**

The staff and management at the Marselisborg centre is acknowledged for a huge effort in skilfully taking all samples and registering consumption of water, chemicals and energy consumption during the two month investigation period as well as contributing to the cost of chemical analysis.

The Danish Ministry of the Environment has supplied financial support for chemical analysis and we are grateful for the dispensation from the current code by Miljøcenter Øst that has

allowed the running of the pool with lower than prescribed recirculation stream, pH and chlorine levels.

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