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# Photolytic removal of DBPs by medium pressure UV in swimming pool water


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## Practice of use of UV for combined chlorine control and perspective for removing other byproducts

Combined chlorine including $NCl_3$ is efficiently removed by treatment with polychromatic ultraviolet radiation (UV) irradiation. In 1976, the first UV system was installed in a swimming pool in Denmark and today there are estimated to be thousands of UV installations in public swimming pools in Europe. However, since this treatment was invented many other disinfection byproducts (DBPs) of concern have been described in swimming pool water.

A recent study identified over 100 DBPs in pool water and reported a higher number of nitrogen-containing DBPs than typically found in chlorinated drinking water with several of the chemicals not identified in drinking water (Richardson et al., 2010. Environ Health Persp. 118:1523-30).

Previous investigations on the effect of UV on trihalomethanes in swimming pools have reported conflicting results ranging from increased to decreased concentrations which suggests that full scale swimming pools are to complex systems for investigating a single effect on water treatment. The objective of this research was to investigate the photo degradation of 12 of the most common chloro/bromo-organic DBPs (besides chloramines) by irradiation with a polychromatic UV lamp in a laboratory system and compare it to a swimming pool UV system.

## UV system in laboratory and swimming pool

The removal of DBPs was investigated in a quasi-collimated beam apparatus with a medium pressure lamp (Fig. 1) which was doped to produce an enhanced emission in the far UV-range (Fig. 3). Additionally the removal of combined chlorine in real swimming pool water was determined in both the quasi-collimated beam apparatus and a commercial UV system (Fig. 2) in a public swimming pool. The flow rate and number of UV active UV-lamps could be varied in the system to achieve variable UV doses. Both systems used the UV burner SR HUV700 (European patent 1463091A2).

Both UV systems were from Scan Research and are commercially available from SR-Light (kaas@srlight.dk).

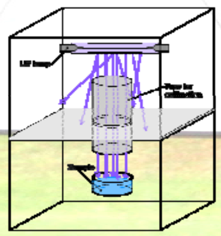


Figure 1. Schematics of the collimated beam irradiation apparatus.

Figure 2. Schematics and picture of the commercial UV system from the public swimming pool: Gladsaxe sportscenter.

## Calibrating UV doses

The removal of free and combined chlorine in the full scale system was measured at different electrical energy doses. The energy needed to remove 90% of free and combined chlorine was 0.2 $kWh/m^3$ and 1.0 $kWh/m^3$, respectively (Fig. 4a). In the collimated beam apparatus the removal of combined chlorine in swimming pool water sample was determined (Fig. 4b). 90% removal was achieved at 10.5 min which should be equal to 1.0 $kWh/m^3$. Thus 1 min of irradiation in the collimated beam apparatus equals 0.095 $kWh/m^3$.

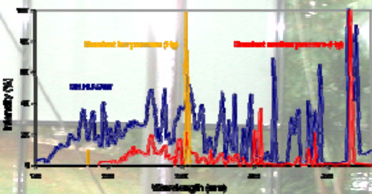


Figure 3. The emission spectra for low pressure (yellow) and medium pressure (red) mercury UV lamp compared to the doped halogen UV burner (blue).

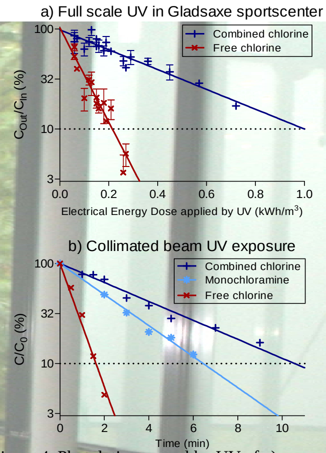
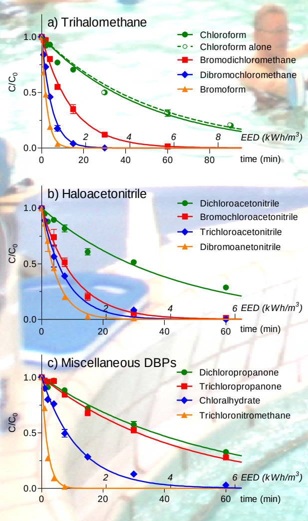



Figure 4. Photolytic removal by UV of a) free and combined chlorine in pool water in full scale flow through UV system and b) combined chlorine in pool water, monochloramine and free chlorine in the laboratory UV irradiation setup.

## Efficiency of DBP removal by UV




The removal of the investigated DBPs followed a first order kinetic (Fig. 5). In general it was found that the rate constants increased with bromine substitution. The electrical energy required for 90 % removal (EEO) can be calculated for first order removal by the given equation, where $C_{in}$ and $C_{out}$ is the concentration in the inlet and outlet respectively and EED is the electrical energy dose.

$$\log\left(\frac{C_{out}}{C_{in}}\right) = \frac{-1}{EEO}\cdot EED$$

From the calibration of the energy dose and the achieved removal the EEO was calculated.

Figure 5. The removal of BPs with fitted lines according to first order kinetics. The second horizontal axis (italics) indicates the estimated equivalent energy in full scale treatment.

Table 1. Energy per order (EEO) for photolysis.

| | | kWh/m³ |
|---|---|---|
| THMs | Chloroform | 11 |
| | Bromodichloromethane | 3.1 |
| | Dibromochloromethane | 1.1 |
| | Bromoform | 0.6 |
| HANs | Dichloroacetonitrile | 9.1 |
| | Bromochloroacetonitrile | 2.3 |
| | Dibromoacetonitrile | 1.1 |
| | Trichloroacetonitrile | 1.7 |
| Inorganics | Free chlorine | 0.2 |
| | Monochloramine | 0.6 |
| | Combined chlorine | 1.0 |
| Misc. DBPs | Trichloronitromethane | 0.4 |
| | Dichloropropanone | 12 |
| | Trichloropropanone | 9.9 |
| | Chloral hydrate | 2.6 |

## Effect of UV on DBP concentrations in pool

The UV system in the investigated pool regularly use 4 UV-burners (each 0.7 kW) running continuously for 50 $m^3$ water. This gives an applied electrical energy dose from UV of 1.34 $kWh\cdot m^{-3}\cdot d^{-1}$. The removal by the UV process only of the investigated DBPs in the real swimming pool water was calculated (Fig. 6). A high removal of the brominated DBPs and trichloronitromethane was predicted. Thus UV treatment for combined chlorine control may result in significant removal of trichloronitromethane, chloral hydrate and brominated haloacetonitriles and trihalomethanes. However, in order to quantify the effect of UV treatment on pool water concentrations, formation rates and rates for competing removal processes need to be quantified and considered.

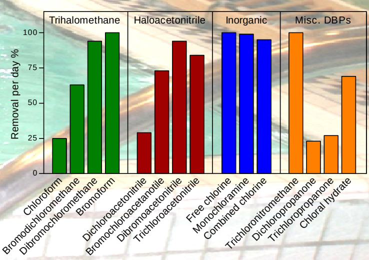



Figure 6. Estimate of removal of DBPs by a UV treatment dose of 1.34 $kWh/(m^3\cdot d)$ relative to the equilibrium concentration.

Hansen, KMS et al. (2013) Photolytic removal of DBPs by medium pressure UV in swimming pool water. *Science of the Total Environment*, 443, 850-856.