Introduction and Background

In the treatment of the low-quality raw water previously used in Helsinki in the late 1970s, relatively large doses of chlorine had to be used; the result was drinking water containing high concentrations of organic chlorine compounds and with taste and odor problems.

The new raw water source, Lake Pääjärne, was of a much higher quality but the water contained humus and traces of organic residues from the wood processing industry, located along the upper reaches of the catchment basin. The residues were mostly lignosulfonates and organic chlorine compounds from pulp bleaching effluents.

Studies and pilot plant tests runs conducted by Helsinki Water showed that the use of ozone for disinfection in the water treatment process would considerably improve drinking water quality and reduce organic chlorine compound concentrations.

Ozonization began in 1979, and since the Lake Pääjärne raw water tunnel was taken into use in 1982, the quality of drinking water in Helsinki has been excellent. In ozonization, a part of the humus may decompose and cause biological growth in the distribution network. In the course of the 90s, biofilm formation in the network was being observed as water meter clogging and taste and odor problems. Due to this, activated carbon filtration was introduced to improve the removal of organic matter during the water treatment process. As activated carbon filtration is a biological process, UV disinfection also was taken into use to remove the bacteria originating from the carbon.

A schematic diagram of the current water treatment process is shown in Figure 1.

Water Treatment

Water treatment in Helsinki consists of precipitation (with ferric sulfate in Vanhakaupunki and with aluminum sulfate in Pitkäkoski), clarification, sand filtration, ozone treatment to secure disinfection and to remove odors and bad taste from the treated water. Carbon dioxide dosage raises the alkalinity of the water, and pH-value is controlled with limewater. The water received from two-stage activated-carbon filtration is disinfected with UV light. Chloramine, produced from hypochlorite and ammonium, is used for disinfection of the network.

In order to improve finished water quality, Helsinki Water modified the water treatment process in 1998 by adding activated carbon filtration and UV-disinfection units in January at the Vanhakaupunki plant and in December at the Pitkäkoski plant. The objective of activated-carbon filtration is to lower
total organic carbon content (TOC) to below 2 mg/L and to reduce levels of the biodegradable component (AOC) in order to prevent biological growth in the distribution network.

**UV-Disinfection**

Two-stage activated-carbon filtration includes a biological phase. Helsinki Water chose UV disinfection in order to guarantee that the bacterial and disinfection by-products contents would not increase in tap water. Treatment with UV light was preferred, as it needs no chemical additions.

Dimensions of the activated-carbon filtration plants and UV-disinfection units at the two plants are as follows:

<table>
<thead>
<tr>
<th></th>
<th>Vanhakaupunki</th>
<th>Pitkäkoski</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design flow</td>
<td>5,000 m³/h</td>
<td>7,000 m³/h</td>
</tr>
<tr>
<td>Carbon filters</td>
<td>20 units</td>
<td>28 units</td>
</tr>
<tr>
<td>Carbon volume</td>
<td>2,400 m³</td>
<td>3,100 m³</td>
</tr>
<tr>
<td>Contact time (EBCT)</td>
<td>28.8 min</td>
<td>26.6 min</td>
</tr>
<tr>
<td>Filtration speed</td>
<td>11.9 m/h</td>
<td>11.9 m/h</td>
</tr>
<tr>
<td>UV-units</td>
<td>3 units</td>
<td>3 units</td>
</tr>
<tr>
<td>Lamp rows/lamps</td>
<td>3 / 10 lamps</td>
<td>4 / 10 lamps</td>
</tr>
<tr>
<td>Flow per unit</td>
<td>2,500 m³/h</td>
<td>3,500 m³/h</td>
</tr>
<tr>
<td>UV dose (min)</td>
<td>250 J/m²</td>
<td>250 J/m²</td>
</tr>
</tbody>
</table>

The UV-radiation dose was designed for a minimum of 250 J/m² at the end of lamp lifetime. The target was to reduce total bacteria content to a thousandth of the amount after activated-carbon filtration (3-log removal).

The UV-disinfection system at both water treatment plants contains three units, two in operation and one on stand-by. In Vanhakaupunki each UV reactor is provided with three lamp rows and a space for a fourth row. In Pitkäkoski there are four lamp rows and a space for a fifth row in each UV reactor. Spare rows can be equipped with lamps when better disinfection efficiency is necessary. The selection of this arrangement is based on the total economy of the UV disinfection system including investments and operation costs (10 years/6%). The system’s minimal space requirements and the availability of the UV units’ semi-automatic chemical cleaning system also were beneficial.

The UV lamps are 280-watt Hg low-pressure lamps. The guaranteed lifetime of the lamps is 10,000 hours. The estimated cleaning cycle is every four months if the UV transmission of the water (100 mm) is 63%.

Figure 2 shows the UV equipment and its associated semi-automatic cleaning system. Figure 3 shows the electric distribution board for the UV equipment.

**Training**

A two-day training course was arranged at the Vanhakaupunki plant and a half-day training period in Pitkäkoski when the UV units were installed and went into operation. The poor translation into Finnish of the operating manual was a problem until the summer of 2000. A two-day training visit to the factory in Germany gave answers to the problems encountered in the handling and operating procedures of the UV reactors.
UV intensity curves of the UV disinfection units at each plant are shown in Figures 4 (Vanhakaupunki) and 5 (Pitkäkoski).

Figure 4. UV-intensity curves of UV-disinfection unit 2 at Vanhakaupunki water treatment plant.

Figure 5. UV-intensity of UV-disinfection unit 2 at Pitkäkoski water treatment plant

Problems in Start-Up

The UV reactors for Helsinki Water were the first K-type installations for a flow rate of >1,000 m³/h. Equal flow distribution, which can be disturbed by pipework bends and elbows, is important within the UV reactor. Flow straighteners, so-called baffle plates with small holes are installed at both ends of the UV units. In Vanhakaupunki, some plate welding joints at the outlet end of the reactors had become loose, causing heavy resonance and noise. As a result, the baffle-plate weldings for all UV reactors (Vanhakaupunki and Pitkäkoski) were repaired and extra support grids installed. In order to improve the flow, 15 large holes were drilled. Resonance and noise continued to be a problem in Vanhakaupunki. The UV reactors have been repaired this autumn (manufacturer’s guarantee). Thicker baffle plates with larger holes have been installed into the UV reactors. Some improvements in the flow system also were carried out at the same time. Similar flow straighteners will be installed into the UV reactors in Pitkäkoski next spring.

Activated carbon filtration and UV disinfection began in Pitkäkoski almost a year after Vanhakaupunki. The UV reactors and lamps had been purchased at the same time as in Vanhakaupunki. Short lamp lifetime and a large number of lamps not lighting up were problems in Pitkäkoski. The lamps are powered with magnetic ballast and a SOFISTART pre-heat circuit. In order to improve the starting characteristics, the pre-heating time and voltage then were adjusted by the manufacturer to better match the operating conditions. Prematurely failed lamps have been returned to the UV system manufacturer for evaluation. Based on the 10,000-hour guarantee, a proportional credit has been received for those hours not used.

On some occasions before starting activated carbon filtration in Pitkäkoski, the only way to empty a carbon filter was to lead the water into the drains through a UV-unit. Fine carbon powder fouled the reactor and washing had to be repeated several times before the UV unit could be used again.

Maintenance

The space designed for UV disinfection in the activated-carbon filtration plants was limited, especially in Vanhakaupunki. This makes maintenance work, e.g., changing lamps, removing quartz sleeves and cleaning the reactors, difficult.

The quartz sleeves have very tight bottom seals and can easily crack when taken out for cleaning inspection. Fine activated-carbon powder was detected on the surfaces of the quartz sleeves in Pitkäkoski. The carbon was easily removed with phosphoric acid, which is the recommended cleaning agent. The washing (and rinsing) cycle of one UV unit is about two hours in Pitkäkoski. When the UV unit in operation is changed, the unit is first washed and then kept empty on stand-by in order to prevent biofilm formation on quartz sleeves.
The intensity of the lamp rows has decreased quite rapidly; however, washing has not improved the situation very much. Calibrated sensors measure mainly the intensity of the first lamp in the row. The intensity change can be quite high when two lamps have been interchanged. A more reliable control system would be one that would monitor the intensity of all the lamps.

The average washing cycle has been twice a year. Both sensor intensity indications and microbiological analyses have been used to assess washing frequency.

**Microbiological Analyses in UV-Disinfection Control**

Heterotrophic plate counts at 20°C and 35°C were determined for activated carbon-filtered water and UV-disinfected water as well as for finished water. At the beginning, a few hundred plate counts were observed in filtered water, while UV-disinfected water showed zero results. Heterotrophic colony count analyses with a 7-day incubation period using R2A-agar and the spread plate method also were started. This is a very sensitive measurement for colony counts.

Heterotrophic plate counts in UV-disinfected water are low, but after a 7-day incubation period the counts are somewhat higher. The situation is similar at both water treatment plants. Results from Vanhakaupunki are shown in Figure 6.

Results of the total colony counts (7-day incubation, R2A-agar) for activated carbon-filtered and for UV-disinfected water at the Pitkakoski plant are shown in Figure 7. During the first nine months, the biological activity in the carbon filters was higher than after September 1999. The reason for this was a shorter ozone reaction time (lower CT value) due to maintenance work on one of the two ozonation lines. Colony counts decreased from thousands to hundreds.

The average bacteria removal calculated from these results is 3-logs. When colony counts for activated carbon filtered water are only a few hundreds, the bacteria removal is 2-logs.

The microbiological quality of the drinking water in Helsinki has remained at least the same as before the modification of water treatment, even though the residual chlorine in treated water has been reduced from 0.6 mg/L to 0.3 mg/L. The flushing of pipelines in peripheral and low-consumption areas of the distribution network has been reduced after activated-carbon filtration went on-stream. The number of water meters showing positive errors has decreased clearly, as have water-quality complaints by customers. Some oxidation of ammonia (chloramine) to nitrite has occurred in the network, and nitrite concentration values have risen slightly.

Helsinki Water has now gained almost three years of operating experience in large-scale UV disinfection with low-pressure, high-intensity UV lamps. The microbiological performance of the reactors met the guaranteed log-reduction. The manufacturer had to solve some technical problems (baffle-plate design and lamp failures). After these improvements and once operating personnel had been trained, the maintenance requirements of the UV systems were fairly low, with only two or three cleaning cycles per year.

The modification of the water treatment process by adding activated-carbon filtration and UV disinfection has improved the drinking-water quality and stability in the network.
Figure 4. Mean values of heterotrophic colony counts of two treatment lines at Pitkäkoski WTP, 20°C, 7d incubation on R2A-agar. Upper: Activated carbon filtered water; lower: UV-disinfected water.

Utilization of U.V. in the Treatment of Water

W.J. Masschelein, Dr. ès Sciences

Dr. Masschelein has published a significant document in the July-August, Sept.-Oct., issue of Tribune de l'Eau (No. 4-5, vol. 53 - No. 606-607). The document is in French, and is 109 pages in length. An Introductory section is followed by sections on Types of Lamps emitting Useable UV, Utilization of UV for the Disinfection of Potable Water, Utilization of Synergistic Processes of Oxidation + UV Light in the Purification of Water; Utilization of UV Light for the Purification of Wastewaters, then Conclusions, References and a listing of Key Words.

This excellent monograph is available for the price of 850 Belgian francs (BF) + 300 BF air mailing costs, or a total of 25 U.S. $ to be made available locally in Belgian currency from:

Tribune de l'Eau - Ed. CEBEDOC
2, Rue Armand Stéwart
4000-Liège, BELGIUM
Tel: int (0)4-252 0086; Fax: int (0)4-254-0363

Dr. Masschelein is planning to issue this book in English sometime during 2001.