# Removal methods of nematoda contained in the effluent of activated carbon

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**Abstract** Effects of various alternative disinfectants, e.g. chlorine dioxide, ozone, ultraviolet radiation and chloramine, either alone or in combination with other physical treatments like sand filtration and membrane filtration, on the inactivation and removal of nematoda were studied. Ozone and chloramines were found to be effective for nematoda inactivation. Filtration alone was unable to remove nematoda completely. But the combination of UV radiation and sand filtration turned out to be very effective in the removal of nematoda from drinking water. 90% inactivation of nematoda needed a UV dose of ($D_{10}$-value) 135 mJ/cm$^2$, while 99% inactivation required 232.5 (135 + 97.5) mJ/cm$^2$. This study was a part of a five-year national research project "Advanced Aqua Clean Technology for 21st Century" (ACT21).

**Keywords** Activated-carbon; chloramine; chlorine dioxide; nematoda; ozone; sand filtration; UV-radiation

## Introduction

Conventional water treatment processes like rapid and slow sand filtration produce water that contains 3–4 nematoda per litre. Based on this fact, the general consensus is that the maximum allowable limit of nematoda in drinking water should be around 3 to 4 per litre. Usually nematoda is not harmful to humans, but it is one of the nuisance organisms listed in World Health Organization (WHO) guidelines for drinking water quality, and is an unfavorable organism in drinking water from the aesthetic viewpoint as an indicator of treatment efficiency. Hence, appropriate technology is necessary to remove the nuisance organisms from drinking water.

In Japan, as drinking water sources have been polluted by various contaminants, the number of water works applying granular activated-carbon (GAC) or ozonation and biological activated-carbon (BAC) as advanced drinking water treatment method for the removal of trihalomethanes (THMs), unpleasant taste and odor has been increasing. Fine quality drinking water and effective treatment can be provided by employing activated-carbon. However, bacteria and metazoa like nematoda may grow in activated-carbon beds,

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and are often observed in effluents from activated-carbon filtration. Such phenomena have been identified in various rivers, whereas few reports exist about the situation in ponds and lakes.

Given this background, the effects of various alternative disinfectants, e.g. chlorine dioxide, ozone, UV-radiation and chloramine, either alone or in combination with other physical treatments like sand filtration and membrane filtration, on the inactivation and removal of nematoda were evaluated. This study was a part of a five-year national research project "Advanced Aqua Clean Technology for 21st Century" (ACT21). In this project, eutrophic lake water from Lake Kasumigaura has been treated by a number of advanced water treatment systems since June 1997.

## Materials and methods

The experimental set-up consists of a demonstration plant A (500 $m^3$/d, Figure 1) and five smaller units of 5 $m^3$/d each, which are used in combination with medium-pressure UV disinfection units. Raw water is taken from Lake Kasumigaura. The following experiments were performed to observe the inactivation and removal of nematoda. Experiment I and III were conducted between August 1998 and March 1999, whereas Experiment II was carried out in 1996 and 1999.

### Experiment I: comparative study of the various alternative disinfectants

The operating conditions of the comparative test device are summarized in Table 1 and the UV dose as well as the injection volume of the disinfectants is shown in Table 2. Chlorine dioxide was generated on-site using hydrochloric acid, sodium hypochlorite solution, and sodium chlorite solution.

### Experiment II: trapping and removal of nematoda by filtration

Activated carbon treated water was filtered with three kinds of depth-filters of 3–100 μm pore size and the removal rates of nematoda by these filters were compared. The specifications of the filters are summarized in Table 3. The experimental program was conducted from September–October 1996. The filtration experiments with an MF membrane (1 μm pore size and 3–5 $m^3/d/m^2$ filtration flux) and diatomaceous earth filters (8.4 $m^3$/d treatment capacity) were carried out from November–December 1999.

### Experiment III: treatment with UV light

*Experiment III-1: measurement of UV intensity in various UV units*. Two models of low-pressure lamps and one model of medium-pressure lamp were used in the experiment. The average intensity of the UV radiation inside the medium-pressure unit was measured by using the coliform phage Qβ as a bio-indicator of UV dose. The flow diagram of the exper-

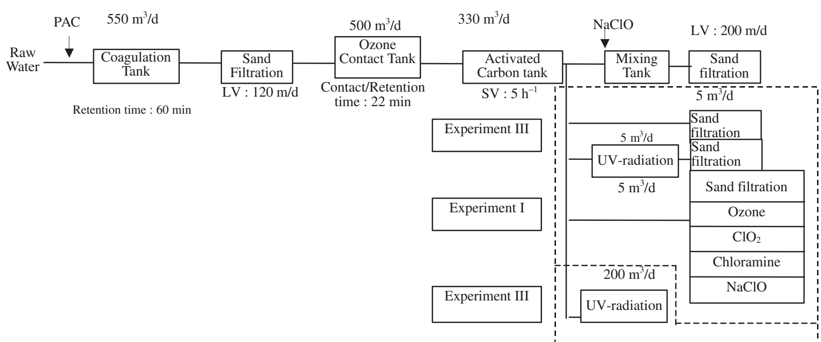


**Figure 1** Flow diagram of the experimental set-up

**Table 1** Experimental conditions for the comparative study of different disinfectant

| Disinfectant | Volume of treated water | Contact time | Comment |
|---|---|---|---|
| UV | $5\ m^3/d$ (210 L/h) | – | Output 2.4 W × 9 sec |
| $O_3$ | | 10 min | $O_3$-gas 50 L/h |
| $ClO_2$ | | 9 min | |
| Chloramine | | 9 min | Free chlorine: Ammonia = 4~5:1 |

**Table 2** Dose of different disinfectants

| Disinfectant | | Low | Medium | High |
|---|---|---|---|---|
| UV | ($mJ/cm^2$) | 15 | 26 | 68 |
| $O_3$ | (mg/L) | 1.0 | 1.5 | 2.0 |
| $ClO_2$ | (mg/L) | 0.6 | 0.7–0.9 | 1.8–1.9 |
| Chloramine | (mg/L) | 0.8–1.2 | 1.7–1.8 | 3.8–4.0 |
| NaClO | (mg/L) | 0.3–0.5 | 0.7–0.8 | 1.8–1.9 |

**Table 3** Specification of each porosity cartridge filter

| Filter make | CP (Chisso corporation) | BM (Chisso corporation) | UHE (Central filter) |
|---|---|---|---|
| Material | Polyolefin system | Polypropylene system | Polyethylene |
| Pore size (μm) | 20, 30, 40, 50, 70, 100 | 3, 7, 10 | 5 |
| Outer diam – inside diam. (mm) (thickness) | 68–30 (38) | 67–29 (38) | 70–30, 70–40 (40), (30) |
| Length (mm) | 250 | 250 | 250 |

imental method is shown in Figure 2; the specifications of each UV experimental system and the corresponding operating conditions are summarized in Tables 4 and 5. Because of the high intensity of the medium-pressure lamp, stainless steel shading was fitted inside the lamp-holder to reduce the irradiation energy from the lamp.

*Experiment III-2: removal of nematoda by a combination of UV radiation and sand filtration.* Activated carbon treated water was passed through a UV light unit and a sand filtration unit in series. The results were compared with those obtained from the treatment of the same water (activated carbon treated water) by a sand filter unit alone. The UV dose applied was $126\ mJ/cm^2$ and the LV of sand filter was 160 m/d.

*Experiment III-3: determination of the dose required for nematoda inactivation.* The UV dose required for the inactivation of nematoda was determined by varying the UV dose by

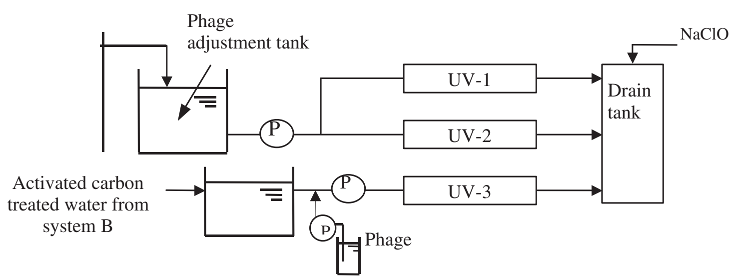


**Figure 2** Experimental set-up for the measurement of UV dose

**Table 4** Type and specification of the lamps used in each UV systems

| | UV system 1 | UV system 2 | UV system 3 |
|---|---|---|---|
| Lamp type (manufacturer) | Low-pressure UV device (Japan Photo Science Company) | Low-pressure UV device (Sankyo Electricity Company) | Medium pressure UV device (Ebara Co. Ltd) |
| Model | NUS-1/4N | SK1601B | Direct flow type UVD-20×100×01 prototypes |
| Lamp model | AY-15 | GL16KSH | BERSON HXFS-1 |
| Outline | Input 8 W×100 V×60 Hz UV-C power output 2.4 W Arc length 200 mm | Input 16 W×100 V×60 Hz UV-C power output 5.0 W Arc length 295 mm Lamp diameter 18 mm | Input 400 W×230 V×60 Hz UV-C power output 40 W Arc length 40 mm Lamp diameter 22 mm |
| Protector tube diameter mm | | 25 ∅ | 25 ∅ 34 ∅ |
| Reactive part volume | 0.52 L | 1.05 L | 2.0 L |

**Table 5** Operating condition of each UV system

| | UV system 1 | UV system 2 | UV system 3 |
|---|---|---|---|
| Flow rate | 208 L/h (3.47 L/min) | 1,000 L/h (16.7 L/min) | 8,000 L/h (133.3 L/min) |
| HRT | 9 s | 3.77 s | 0.9 s |

adjusting the volume of activated carbon treated water passing through the medium-pressure UV disinfection unit.

## Results

### Detection of nematoda in activated-carbon treated water

The number of nematoda in the demonstration plant study between August and December 1998 varied as follows: 0–20 organisms/L in the raw water, 0–10 organisms/L after coagulation and sedimentation, 0–6 organisms/L after the sand filtration and 11–104 organisms/L after the activated-carbon treatment. It can easily be seen that there was a marked increase in the number of nematoda after the activated-carbon treatment. In a separate study between August and October 1996, the number of nematoda that leaked from the activated-carbon contact pond was found to vary from 11–77 organisms/L. In the depth-filter examination, a maximum of 59 organisms/L was observed.

### Effectiveness of various disinfectants against nematoda

The performance of various disinfectants against nematoda is shown in Table 6. Ozone and chloramine were found to be highly effective in causing lethal damage to nematoda even at relatively low doses. Chlorine dioxide and sodium hypochlorite were found less effective at lower doses. The inactivation rate improved with increasing doses, and at higher doses each disinfectant caused complete inactivation. The effectiveness of UV radiation was also enhanced with increasing doses.

### Nematoda removal by filtration

*I. Kinds and sizes of nematoda*. Two types of nematoda were observed in the effluent from the activated-carbon process. The nematoda were 200–300 μm in length and 7–9 μm in width.

**Table 6** Treatment of nematoda by various disinfectants (unit: no. of organisms/L)

| | Low dose | | Medium dose | | High dose | |
|---|---|---|---|---|---|---|
| | live | dead | live | dead | live | dead |
| Activated-carbon treated water | 36 | 9 | 47 | 23 | 41 | 4 |
| UV radiation | 45 | 12 | 52 | 27 | 39 | 34 |
| Ozone | 2 | 46 | 0 | 104 | 0 | 73 |
| Chlorine dioxide | 27 | 18 | 57 | 38 | 0 | 80 |
| Chloramine | 2 | 46 | 0 | 77 | 0 | 75 |
| NaClO | 40 | 11 | 27 | 44 | 0 | 60 |

*II. Nematoda removal by depth-filter*. The results are shown in Figures 3–5. It was observed that there was a time lag before the leakage of nematoda after the filtration. No nematoda were detected in the treated water immediately after filtration with 5–20 μm filters. But after 2 hours of continuous filtration, the removal rate of nematoda in the 20 μm filter was less than 50%. After continuous filtration for 6 hours, nematoda were observed even in the filtrate from the 3 μm filter. Nematoda leaked to the filtrate immediately after filtration regardless of the thickness of the filter when the pore size became more than 30 μm.

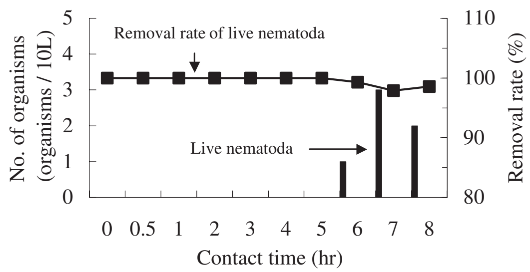


**Figure 3** Relationship between contact time and the leakage and retention of nematoda in filter (pore size = 3 μm)

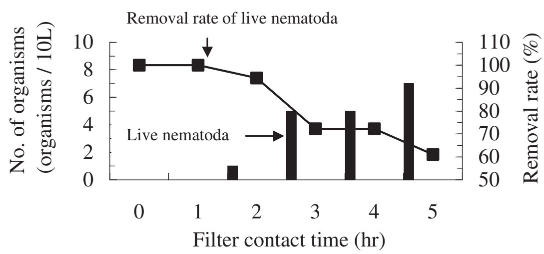


**Figure 4** Relationship between contact time and the leakage and retention of nematoda in filter (pore size = 10 μm)

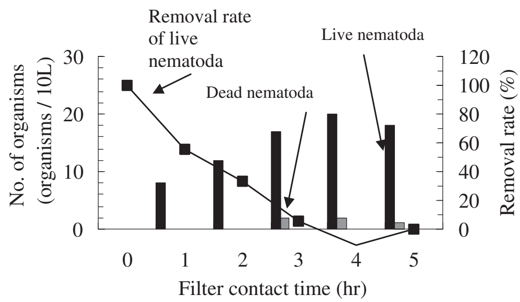


**Figure 5** Relationship between contact time and the leakage and retention of nematoda in filter (pore size = 30 μm)

Very few nematoda were observed in the raw water during the experiments with the 1 μm membrane filter and the diatomaceous earth filter due to the extremely low temperature at the time of these experiments. Hence detailed investigations of nematoda removal with these two filters were not possible.



**Effect of ultraviolet treatment**

*I. Determination of UV dose various UV units*. The inactivation of Coli phage Qβ used in our experiments follows the general expression:

$$N_t/N_o = \exp(-I \times t/D) \quad (1)$$

where, $N_t$ is the Qβ concentration (PFU/mL) after $t$ seconds of UV irradiation, $N_o$ is the Qβ concentration (PFU/mL) before UV irradiation, $I$ is the intensity of UV radiation (mW/cm$^2$), $t$ is the time in second, and $D$ is the inactivation rate constant (mJ/cm$^2$).

According to reference materials, the inactivation rate constant ($D$) for Qb has a constant value of 5.9 mJ/cm$^2$. If the Qβ density before and after the UV irradiation is measured, the average UV dose (average intensity of UV irradiation × irradiation time) in the device can be calculated from the expression 1. If this method is used, the effective dose required for inactivation can be calculated even if the UV intensity distribution inside the device and the residence time distribution are not considered.

The data from the low-pressure lamps 1 and 2 are shown in Table 7 and the data of the medium pressure lamp with shade are given in Figure 6. Assuming a linear relationship between the amount of light that penetrates from the source and the UV intensity inside the UV device, a straight line using the first order regression was applied to represent the experimental data. A very good correlation was obtained except for the data corresponding to 0.33 ratio and this validates the above assumption. The average dose of this device could be obtained by extrapolating the above regression line up to a ratio of 1. The corresponding value is 72.2 mJ/cm$^2$.

**Table 7** Qβ concentration before and after UV irradiation and calculation of UV dose

| Sample name | Qβconcentration (PFU/mL) | –log (survival rate) | Calculated UV dose (mJ/cm$^2$) | 254 nm absorbance (1/cm) |
|---|---|---|---|---|
| Source water for UV system 1 and 2. | $2.4 \times 10^6$ | – | – | 0.039 |
| After UV irradiation by UV system 1 (Japan Photo Science Company) | $2.9 \times 10$ | 4.92 | 66.8 | 0.043 |
| After irradiation by UV system 2 (Sankyo Electricity Company) | $2.7 \times 10^4$ | 1.95 | 26.5 | 0.037 |

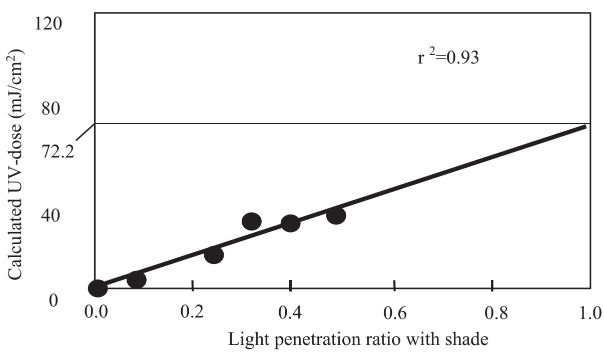


**Figure 6** The relationship between UV light penetration and calculated UV dose

**Table 8** UV dose calculation by bio-dosimeter

| Lamp type | UV system | Manufacture's specification | | UV dose calculated by bio-dosimeter (mJ/cm²) |
|---|---|---|---|---|
| | | measuring method | displayed UV dose | |
| Low pressure | UV system 1 (Japan Photo Science) | Bio-dosimeter | 68.3 | 66.8 |
| | UV system 2 (Sankyo Electricity) | UV meter | 62.5 | 26.5 |
| Medium pressure | UV system 3 (Ebara) | UV meter | 144.0 | 72.2 |



**Table 9** Removal of nematoda by UV radiation and sand filtration (unit; no. of organisms/L)

| | Activated-carbon treated water | UV-radiation and sand filtration | Sand filtration |
|---|---|---|---|
| Total | 51 | 9 | 48 |
| Live | 41 | 3 | 38 |
| Dead | 10 | 6 | 10 |

The UV doses calculated by this bio-dosimeter method for the three types of UV reactors are shown in Table 8.

*II. Nematoda removal by a combination of UV irradiation and sand filtration*. The average number of nematoda detected after the combined UV radiation and sand filtration process and the stand alone sand filtration process are shown in Table 9. Assuming that about 80% of the nematoda in the activated-carbon treated water are alive, it could be seen that living nematoda are not trapped by the sand filtration. The combined UV radiation and sand-filtration treatment reduced the total number of nematoda to about 20–25%. The combined treatment also increased the trapping rate in the sand filter and reduced the number of living nematoda to less than 50%. It is believed that UV radiation either inactivates the nematoda or impairs their movement, thus rendering them unable to pass through the filter.

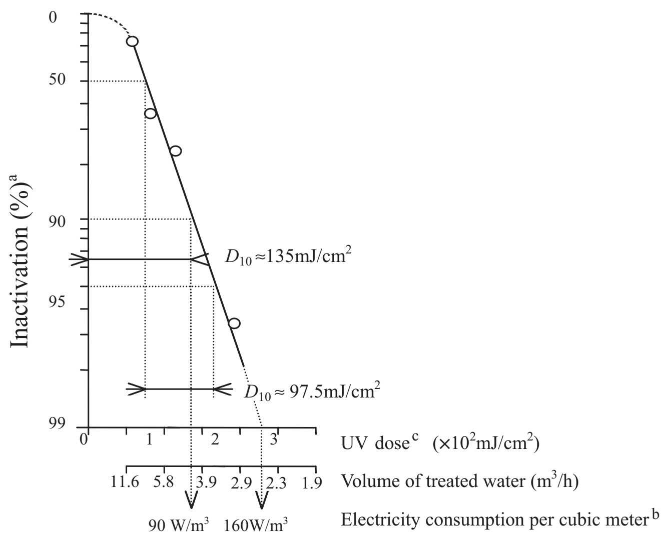


**Figure 7** Inactivation curve for nematoda. Note: [a] is the inactivation rate = no. of live organisms at the entrance – no. of live cells at the exit)/no. of live cells at the entrance of the UV reactor; [b] is the fixed electric power, 400 W conversion; [c] is the calculated dose

*III. Determination of the dose required for nematoda inactivation*. The inactivation of nematoda by UV doses from 52.5–577 mJ/cm$^2$ is shown in Figure 7. The inactivation followed a logarithmic pattern that can be explained by the multiple hit target theory. The necessary UV dose for 90% inactivation ($D_{10}$-value) was found to be 135 mJ/cm$^2$; 99% inactivation required a further UV dose of 97.5 mJ/cm$^2$. The power consumption for 90% inactivation was 93 W/m$^3$ and that for 99% inactivation was about 160 W/m$^3$.

## Conclusions

The following conclusions can be drawn from the present study.

- Ozone and chloramine were found to be more effective than chlorine dioxide and sodium hypochlorite against nematoda.
- Nematoda were not completely removed even when a depth-filter with a pore size as small as 3 μm was used. It is believed that the use of depth filter alone is not very effective in the removal of live nematoda and a combination with a biocidal agent is necessary to yield a better result.
- The combination of ultraviolet irradiation and sand filtration was effective for the inactivation and removal of nematoda.
- 90% inactivation of nematoda required a UV dose ($D_{10}$-value) of 135 mJ/cm$^2$; 99% inactivation required a further UV dose of 97.5 mJ/cm$^2$ (total: 135 + 97.5 = 232.5 mJ/cm$^2$ ).

## References


Japan Waterworks Association (1995). *Study Report on the Microorganisms in the Water Treatment Process*. Japan Waterworks Association, pp. 237–240.

Kamiko, N. and Ohgaki, S. (1989). RNA coliphage Qb as a bio-indicator of ultraviolet disinfection efficiency, *Wat. Sci. Tech.*, **21**(3), pp. 227–231.

Miwa, M. and Morizane, K. (1988). Behavior of metazoas in ozone-granular activated-carbon treatment process. *Water and Wastewater*, **30**(9), 32–37(in Japanese).