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# Development of a boat equipped with UV lamps for suppression of freshwater red tide in a reservoir

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## Abstract

A boat equipped with UV lamps was developed to suppress freshwater red tide of the dinolagellate *Peridinium bipes*. The boat had two pipes at the center of the bottom with 20 UV lamps installed inside each pipe. The surface lake water was directed into the pipes and expelled. UV radiations for over 20 seconds were enough to kill 100% of the cells of the freshwater red tide when the concentration was less than $5.0 \times 10^3$ cells $\cdot$ ml$^{-1}$ while over 50 seconds were required to kill 90% of the cells when the concentration was more than $1.0 \times 10^4$ cells $\cdot$ ml$^{-1}$. Optimal velocity of the lake water in the pipes was regulated automatically between 17 to 35 cm sec$^{-1}$ depending upon the cell density ranging between $2.0 \times 10^3$ to $2.3 \times 10^4$ cells $\cdot$ ml$^{-1}$ to kill over 99% of the total cells. This boat could treat a maximum of about 700 m$^3$h$^{-1}$ of lake water and required 5 hours to treat $2.0 \times 10^4$ m$^2$ of surface area of lake water containing $1.0 \times 10^3$ to $5.0 \times 10^4$ *peridirium bipes* cells ml$^{-1}$. The quantity of water treated per hour was 10 times as much as the long hair filtration method which is commonly used.

**Key words:** freshwater red tide, *Peridinium bipes*, UV radiation, UV boat, automatic regulation

## 1 Introduction

Freshwater red tides of the dinoflagellates *Peridinium* in reservoirs have been observed in Japan since the 1970's[(1-11)]. Recently, reservoirs have become recreational sites as well as sources for water supply. Therefore, preserving the clean water and scenic surroundings of reservoirs has become a social requirement. However, freshwater red tides cause deterioration of scenic value and water quality, sometimes causing serious odor problems[(12-13)]. It is , there-

fore, important from water quality management point of view to suppress the freshwater red tide. Although many strategies for mitigating eutrophication of lakes and reservoirs have been developed[14–16]. Yet there is no effective method for suppression of *Peridinium* blooms because these organisms grow in less eutrophicated water.

The effect of ultraviolet (UV) radiation on the survival of *P. bipes* was investigated both in a laboratory culture system and in a mesocosm installed in a reservoir[17–18]. These suggested that UV radiation could be an effective means of suppressing *P. bipes* bloom in a reservoir. In order to evaluate the feasibility of UV radiation *in situ*, it was necessary to conduct experiments in a reservoir using equipment specially designed for this purpose. The objective of this study was to develop equipment for use in suppressing the fresh water red tide of *P. bipes* in a reservoir. Optimum operating conditions were also examined.

## 2 Materials and Methods

The structure of the boat (UV boat) from a lateral side is illustrated in **Fig. 1**. The exterior appearance of the UV boat is shown in **Fig. 2**. The length and width of the boat were 10.3 m and 3.6 m, respectively. The UV boat consisted of two trunks between which two pipes, 0.6 m in diameter, were fixed. Inside each pipe, 20 UV lamps with an emission intensity of 253.7 nm were installed. The number of UV lamps was determined according to the results described in the reports of Kawabata et al[17–18] so as to supply the minimum energy (2400 $\mu$W $cm^{-2}$) required to kill the cells.

Lake water was directly drawn into the pipes from the front of the boat through a 2 m wide opening, held in the pipes for a certain period of time, and then expelled. The depth of surface water flowing in the UV pipe was adjusted depending on how deep *P. bipes* existed.

Lake water containing *P. bipes* cells with concentrations ranging from $3.0 \times 10^3$ to $4.6 \times 10^5$ cells $\cdot$ $ml^{-1}$ was directed into the UV pipe and was exposed to UV radiations for 8 to 105 seconds. After exposure, the number of viable and dead cells in both the treated and untreated lake water were determined by either lack of motility, plasmolysis or destructed morphology. To confirm whether the immotile cells were actually dead, untreated and treated lake water samples were cultured for 12 days under a 3,000 lux fluorescent lamp on a 12L:12D light regime at a temperature of 20°C. no recovery of dead cells was ascertained. The experiments were conducted for 60 different combinations of emission times and cell densities.

In order to determine the concentration of the cells in the lake water from the turbidity, a correlation between turbidity and cell concentration was developed. Turbidity was measured using a turbidity meter (HACH, Type 18900) and the cell den-

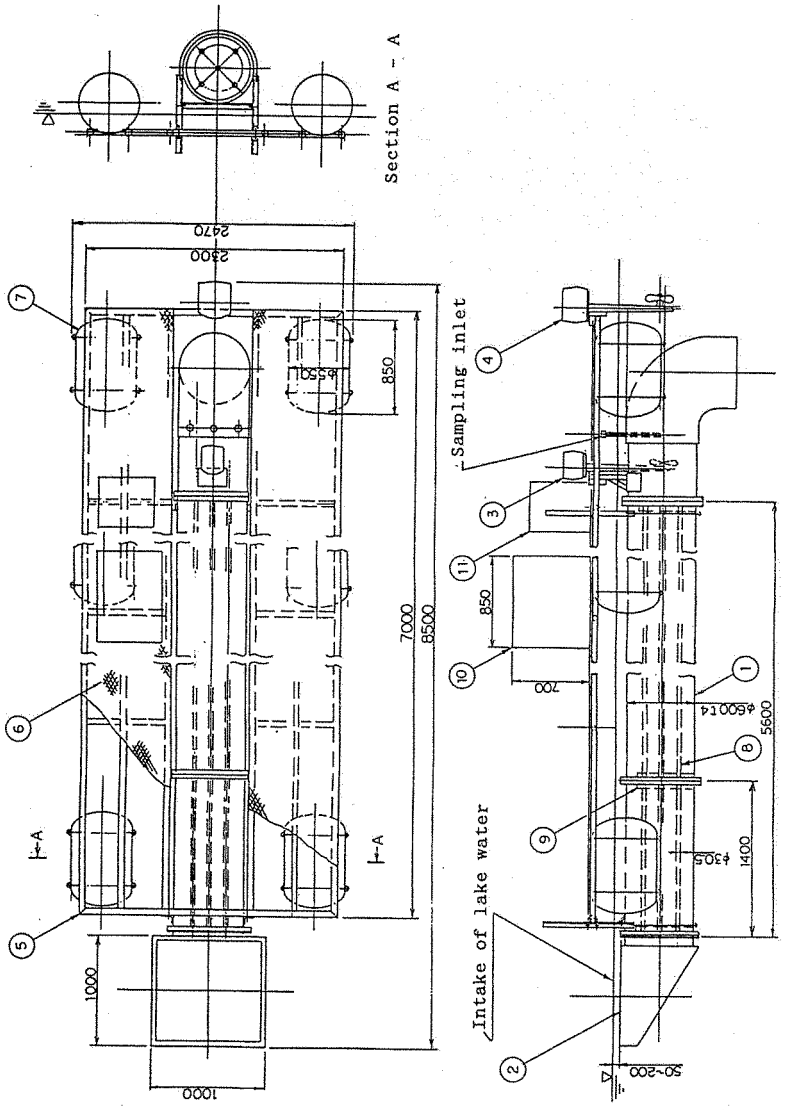


**Fig. 1** Cross section of the UV boat

1; Pipe through which lakewater flows(o $600^t$ 2, sus 304), 2; Mouth into which lake water enters (made of a galvanized iron sheet), 3; Outside engine for introducing lake water (Yamaha, 2PS), 4; Outside engine for moving (Yamaha, 30PS), 5; Frame for sustaining pipes (40 A, SGP), 6; Handy winch, 7; Float 580 mm in diameter and 1050 mm in length made of expanded polystyrene, 8; UV lamps (Sankyo Electric Co., SC9001S) with 30W, 9; Lamp support (SUS 304), 10; Electric generator and panel indicating flow volume (Denyo, GRF-5FSS, 220 V, 5 kVA).

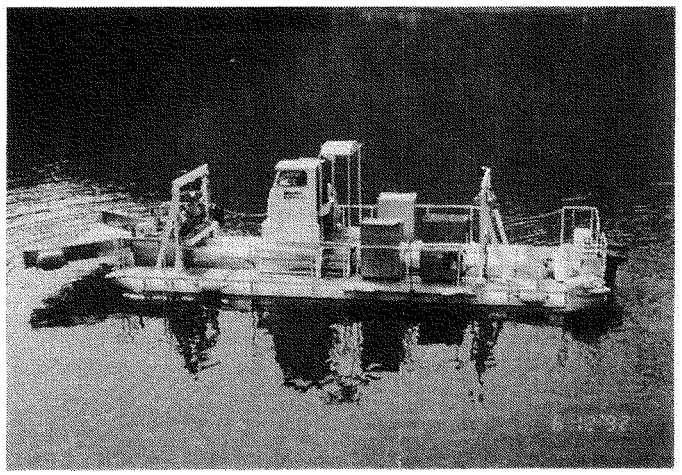

**Fig. 2.** Outside appearance of the UV boat.

sity was determined by counting the cells in a plankton counting chamber under the microscope, according to the technique of Kawabata et al[17].

Experiments were carried out in a reservoir in Miyazaki Prefecture, Japan, where freshwater red tide was observed in late October, 1990. The plankton cells were almost all *P. bipes*.

## 3 Results and Discussion

After the dead cells were cultured, not only the protoplasm of the cells disappeared but the cells themselves disintegrated. Microbes such as bacteria attached to the surface of the dead cells were observed.

The death ratios, i.e., the number of dead cells to the total number of cells, for different periods of time of UV treatment *in situ* at different cell concentrations are shown in **Fig. 3**. For lake water with more than $1.0 \times 10^4$ cells $\cdot$ ml$^{-1}$, exposure of UV for more than 50 seconds resulted in a death ratio of about 90% and for less than 50 seconds it was 70% . Between $5 \times 10^3$ and $1.0 \times 10^4$ cells $\cdot$ ml$^{-1}$ UV exposure for more than 30 seconds resulted in more than 95% death ratio. The ratio was 100% at a concentration of less than $5.0 \times 10^3$ cells $\cdot$ m$^{-1}$ after UV exposure for more than 20 seconds.

The time required for elimination of *P. bipes* with a concentration different from that of reservoir using this UV boat was estimated, considering that *P. bipes* existed 15 cm deep and the area of fresh water red tide was $1.08 \times 10^5$ m$^2$. This scale has been regularly observed for *Peridinium bipes* red tide in this reservoir. The possible volume of lake water to be treated was 160 to 480 m$^3$, and

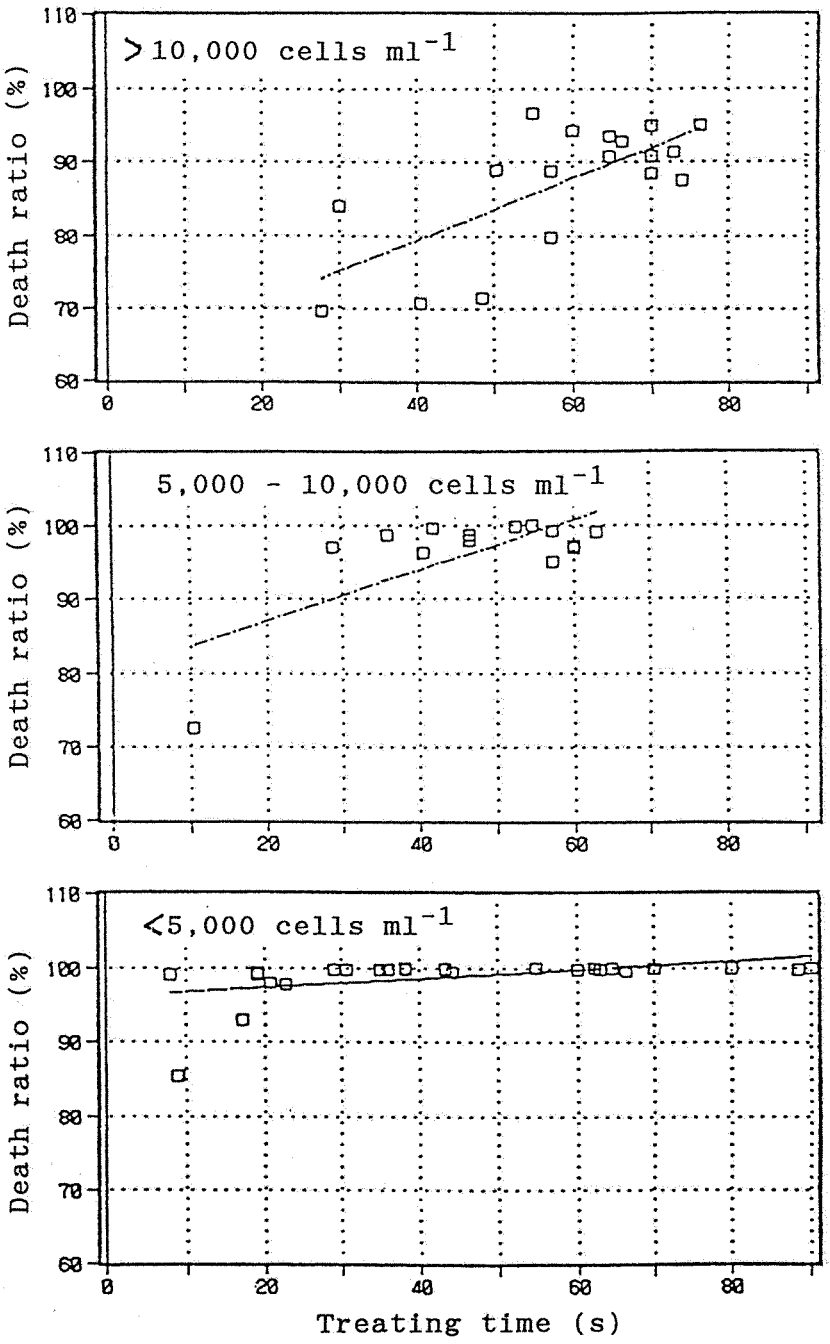


**Fig.3.** Relation between treating time and death ratio for each lake water sample with different concentrations of cells.

**Table 1.** Different conditions to kill almost 100% of the cells with a UV boat.

| | Concentration of cells $ml^{-1}$ | | |
|---|---|---|---|
| | <5,000 | 5,000 to 10,000 | >10,000 |
| Radiation time (sec) | 20 | 40 | 60 |
| Length of UV pipe (m) | 4.8 | 4.8 | 4.8 |
| Current velocity (m/sec) | 0.24 | 0.12 | 0.08 |
| Section area of the UV pipe ($m^2$) | 0.56 | 0.56 | 0.56 |
| Treatment volume ($m^3$/hr) | 480 | 240 | 160 |
| Treatment area ($m^2$/hr) | 3200 | 1600 | 1060 |
| Area of fresh water red tide ($m^2$) | 108,000 | 108,000 | 108,000 |
| Time required for treatment (hr) | 34 | 68 | 102 |

it took 34 to 102 hours for the treatment of fresh water red tide depending on the concentrations of the cells (**Table 1**). This led to the idea that for effective treatment, the volume of lake water to be treated should be regulated depending on the concentration of the cells.

The cell concentration correlated well ($p<0.05$) with the turbidity and this correlation is depicted in **Fig. 4**. This indicated that it was possible to determine the cell concentration by measuring turbidity. An automatic regulating system was developed in order to obtain optimum and stable treatment. Schematic diagram of the system is shown in **Fig. 5**. Turbidity was measured and the cell concentration was then calculated therefrom. An increase in turbidity was paralleled by an increase in cell concentration. Optimum time of exposure was calculated depending on the cell concentration and by regulating the speed of rotation of the motor which served to direct the lake water into the UV pipes. **Fig. 6** shows the results of treatment by the automatic regulating system. An increase in turbidity caused the motor to lower the velocity of the influent lake water allowing more time for UV exposure. The velocity in the UV pipes was controlled between 17 and 35 cm $\cdot$ $sec^{-1}$, depending on the cell density which ranged between $2.0 \times 10^3$ to $2.3 \times 10^4$ $ml^{-1}$, to kill over 99% of the total cells.

This UV boat could treat a maximum of about 700 $m^3h^{-1}$ of lake water and it took 5 hours to treat $2.0 \times 10^4$ $m^2$ of surface water containing more than about $5.0 \times 10^3$ cells $\cdot$ $ml^{-1}$. Treatment volume

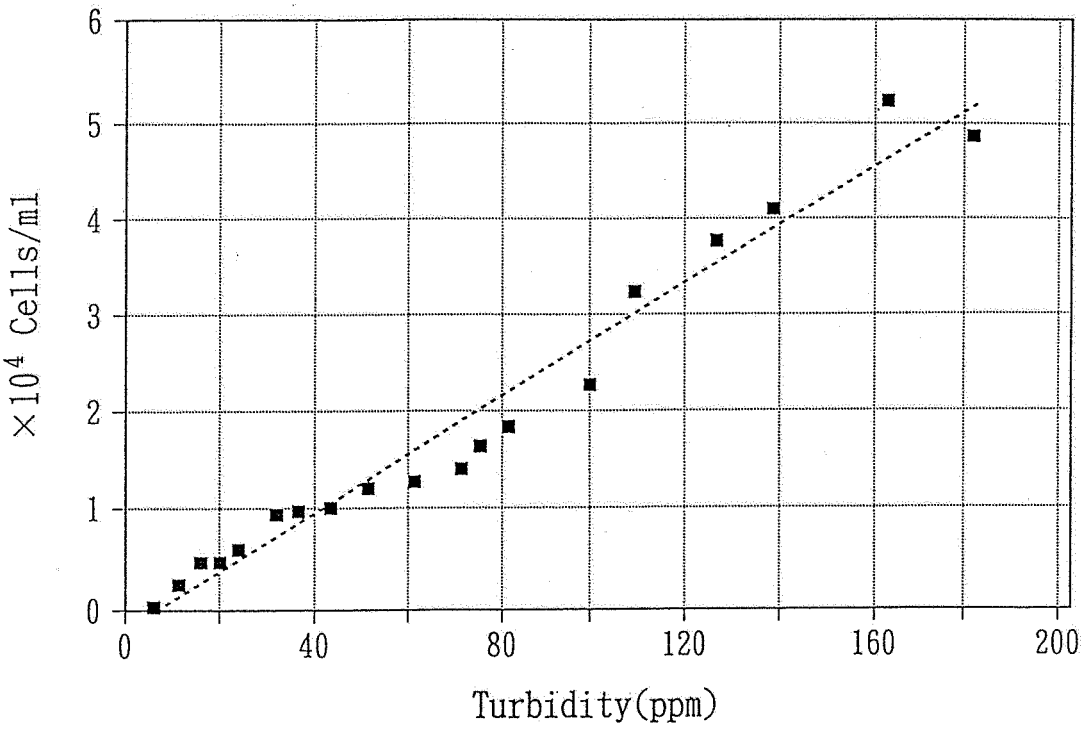


Fig. 4. Relation between turbidity ($x$) and concentrations of the cell($y$); $y = 293.9x - 224.4$. Correlation coefficient ($r = 0.984$) was significant at a 0.05 level.

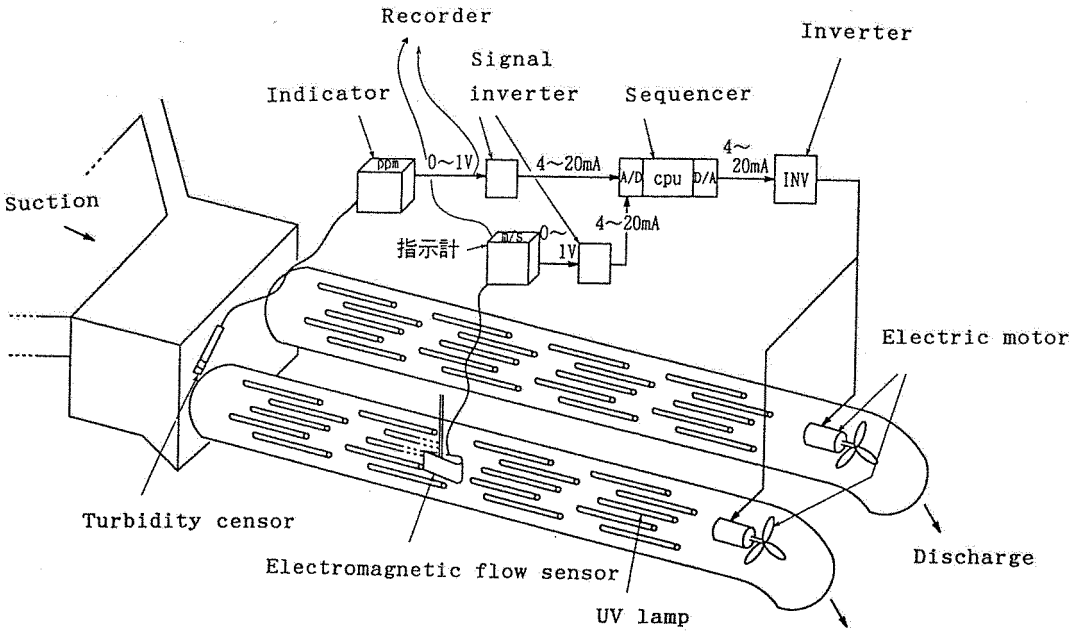


**Fig.5.** Schematic diagram of automatic system to produce the most effective flowing volume into the UV pipes depending on the concentration of the cells.

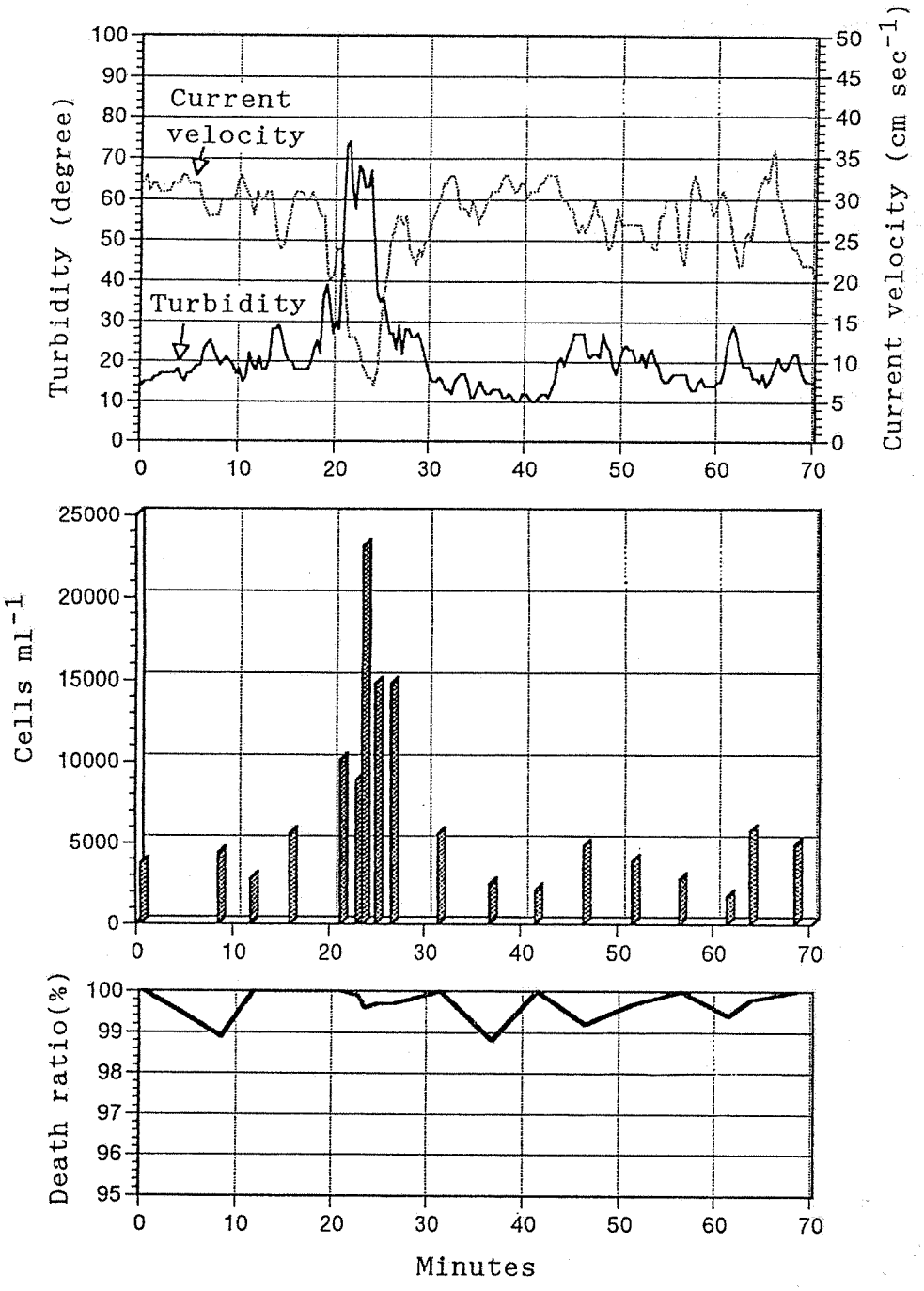


**Fig. 6.** Automatic regulation for effective treatment

per hour was 10 times as much as that of long hair filtration method[19] which is commonly used in Japan.

Since this system continuously returns the treated lake water back to the lake, the effect of dead cells on the water quality should, be examined in order to evaluate the effectiveness of the UV boat.

## 4 Acknowledgments

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