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Ability of Water Lilies to Purify Water Polluted by Soap and Their Application in Domestic Sewage Disposal Facilities

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Aquatic plants have the capability to decrease water pollution level. This capability was examined using water lilies in pots. The pots were placed in 50-l aquariums. Soap was adopted as the pollutant. It is a main water pollutant from households. Purification capability was evaluated by measuring chemical oxygen demand (COD) and dissolved oxygen (DO) concentration. An evaluation index was derived using the half-width (t_w) at half maximum of a characteristic COD peak. The influences of water temperature and soap concentration on the index were examined. t_w decreased as water temperature increased, and the purification capability improved; $t_{w,}$ therefore, is a measure of purification capability. It decreased as soap concentration increased and t_w became larger. An average person uses about 3 g of soap and 50–100 l of w
ater when he showers. This amount of soap (3 g) was added to the aquariums and a predictive curve for the purification of water at 25°C was introduced. The main polluting element in a household is phosphorus. The application of water lilies to domestic sewage disposal facilities for decreasing water pollution level was considered.

1. Introduction

The Ministry of the Environment enforced a special measures law to conserve water quality in lakes in 1985. The environmental standards for COD (chemical oxygen demand) are not being obeyed in lakes and marshes. There are three types of water pollution: domestic, industrial and natural. Domestic pollution includes mainly organic matter, nitrogen and phosphorus. Industrial pollution originates from factories and livestock breeding. Natural pollution is created by farmlands and urban districts. Domestic wastewater makes up 40% among the pollutions. Consequently, it is considered that water pollution can be improved by purifying domestic wastewater. In Japan, the consumption of water in daily life has increased 1.6-fold in the 25 years from 1975 to 2000. Pollution has the greatest influence on the water quality of lakes and marshes.

Plants have the ability to purify polluted air. There are many papers describing this

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capability.(1–5) Plants also have the ability to purify polluted water.(5,6) In this study, the purification capability of aquatic plants for soap drainage was examined. The capability was evaluated using the time of the half-width at half maximum of the characteristic COD peak. In this paper, the influences of water temperature, soap concentration, and the number of aquatic plant pots on the purification of water are indicated. A method of cost reduction for the treatment of household effluent using the aquatic pot equipment is discussed. The water lily was adopted as the aquatic plant.

2. Experimental

Two water lilies (*Nymphaea*) in pots were used to examine their ability to purify polluted water. The water lily was chosen from among some aquatic plants, because it is easy to take care of and obtain. The height of each pot was 15 cm and the diameter was 13 cm. The height of the water lily was about 30 cm. An aquarium of $30 \times 60 \times 35$ cm^3 was used, and the pots were placed in the aquarium, which was filled with 50 l of water. A DO (dissolved oxygen) meter was also used in the experiment. COD (Central Kagaku Co., HC-607) and DO concentration (HORIBA Co., OM-51-L1) are effective for assessing water quality. COD and DO concentration are indexes of water pollution level. Pollution level increases as COD index increases. On the other hand, pollution level increases as DO index decreases. A test reagent (sodium permanganate) was reacted chemically with the specimen taken from the subjected water by heating the specimen for 5 min. After that, COD value is evaluated using the reacting substance. DO was identified directly by a sensor. The following household effluents were examined: water from the bath, laundry, kitchen, lavatory and car washing. Car washing is an issue of outdoor drainage. The breakdown of household water consumption is summarized in Table 1. The total water consumption per person per day is about 300 l. The proportion for bath water consumption is 32%, which is highest of the items in Table 1. Therefore the purification capability of water lilies for soap drainage from bathrooms and restrooms was investigated.

A photograph of the aquarium in which two water lily pots are placed is shown in Fig. 1. The light from outside was shaded in the experiment room. Light intensity was controlled at about 1000 lx using fluorescent lights. The water temperature in the aquarium was controlled at 15, 20 and 25˚C. The weight of soap used was set at 0.5, 1.0 and 1.5 g and the soap was dissolved in the aquarium water. The sampling for COD and DO concentration was carried out every 24 h for one week. A control experiment in which there were no plants in the aquarium was also done. COD peaked when the soap was dissolved entirely. After that, the value decreased gradually according to the purification capability of the water lilies. In this process, the capability (w_p) was derived using the half-width (t_w) at half maximum of the peak for the decreasing COD. The equation used is eq. (1). A schematic diagram is shown in Fig. 2.

$$w_p = 1 / t_w \times 100 \tag{1}$$

Table1
Quantity of water consumed per day per person.

Home drainage	Consumption (l)	%
Bath	96	32
Washing	72	24
Kitchen	69	23
Toilet	63	21
Total	300	100

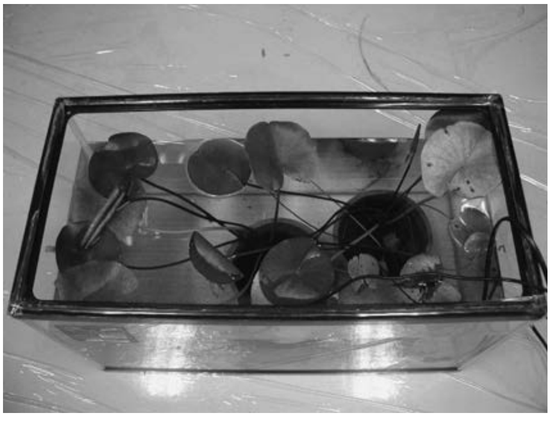


Fig. 1. Aquarium with two water lily pots.

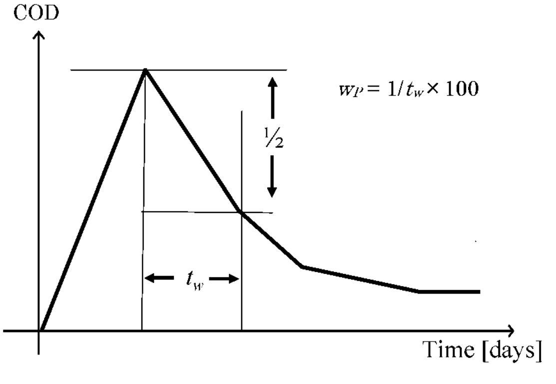


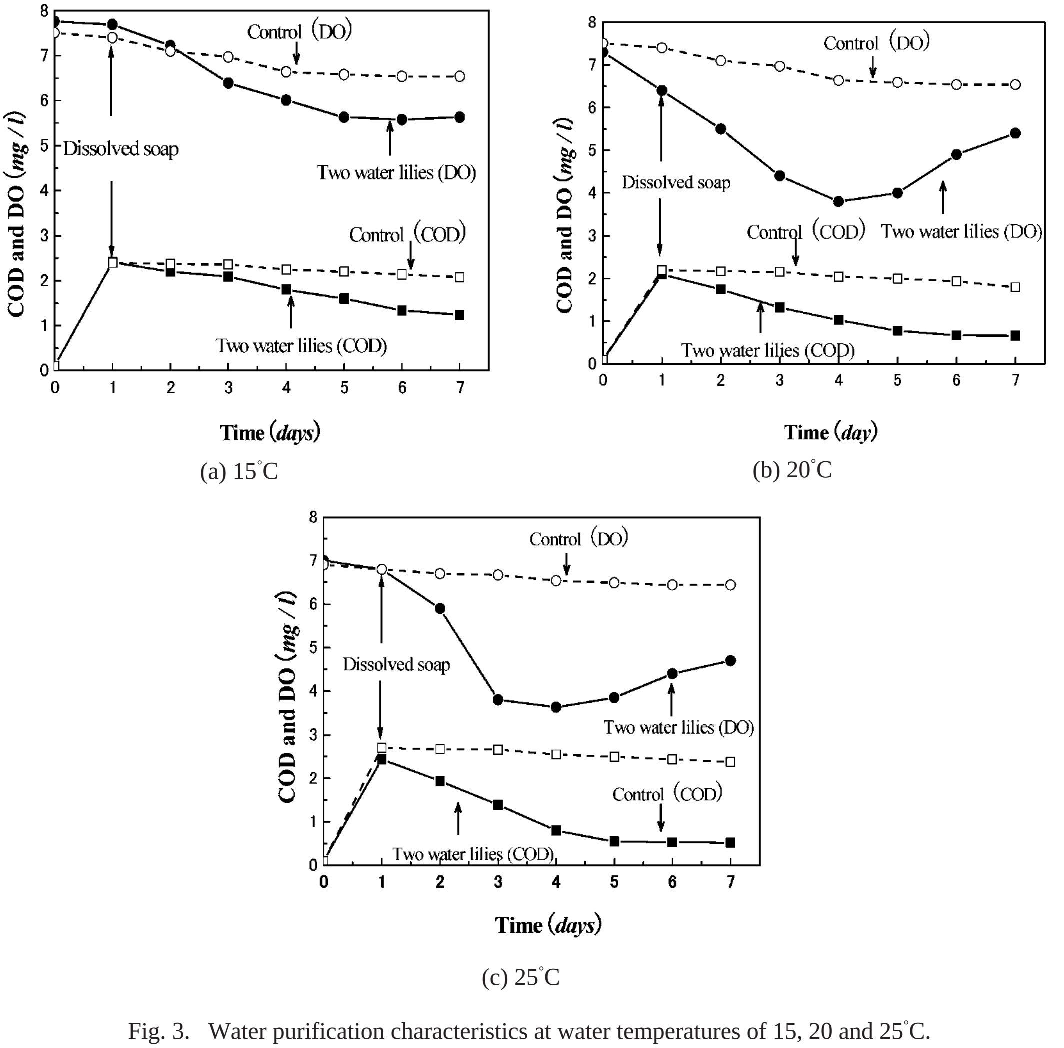
Fig. 2. Schematic diagram for purification capability.

3. Experimental Results

3.1 *Influence of water temperature on purification capability*

Purification capability was examined at water temperatures of 15, 20 and 25˚C. In the experiment, 0.5 g of soap was dissolved in 50 l of aquarium water. Two water lilies in pots were placed in the aquarium. The COD values are shown in Fig. 3. The horizontal axis is the time lapse in days, and the vertical axis is the COD and DO concentration.

COD gradually decreased at each water temperature when water lily pots were in the water. The w_ps were 17 at a water temperature of 15˚C, 33 at 20˚C and 44 at 25˚C. w_p increased as water temperature increased, in the range from 15ºC to 25ºC. DO concentration at water temperatures of 20 and 25˚C decreased until the fourth day, after which they



(a) 15˚C (b) 20˚C (c) 25˚C

Fig. 3. Water purification characteristics at water temperatures of 15, 20 and 25˚C.

increased. In the first four days, the oxygen concentration decreased with increasing soap concentrations, because the oxygen was consumed by the plants and microorganisms that consume the pollutant. Oxygen concentration increased when pollutant concentration decreased, and the oxygen concentration increased because of photosynthesis performed by the water lilies. DO concentration in the experiment at 15˚C decreased until the fifth day, and remained almost constant. The reason for this feature is that the plants are less able to carry out photosynthesis and purification because of the low water temperature. COD and DO concentrations as a function of time were almost constant at the three temperatures (15, 20 and 25˚C) when there were no lily pots in the aquarium.

3.2 *Influence of soap concentration on the capability*

The purification capability of two water lily pots as the soap concentration changed was examined. The water temperature was controlled at 20 and 25˚C in the experiment. The results are shown in Fig. 4.

The w_p value decreased at all three water temperatures as the soap concentration was increased. Therefore, the capability is lower when the pollutant concentration is higher. The capability became higher at a water temperature of 25˚C in the experimental range of soap concentration compared to the one at 20˚C. The value was 1.3 times that of the one for 20˚C. The fluctuation in value for each temperature was very low.

3.3 *Influence of number of pot on purification capability*

The relationship between the water purification capability and the number of pots was examined. The results are shown in Fig. 5. In the experiment, 1 g of soap was dissolved in the water at a temperature of 25˚C, and the number of pots was changed from one to three. The w_p was 28 when one water lily pot was placed in the aquarium, 40 for two pots, and 50 for three pots. The relationship between the capability and number of pots was almost linear. The maximum number of pots was three in the aquarium used in this experiment

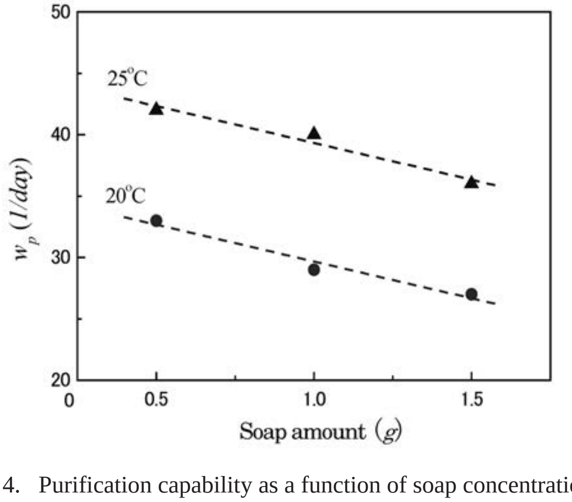


Fig. 4. Purification capability as a function of soap concentration.

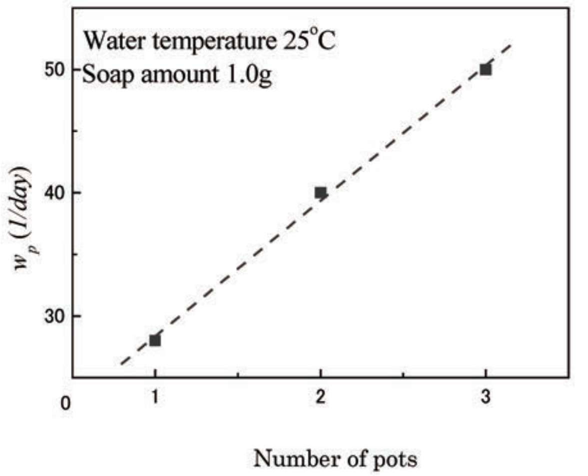


Fig. 5. Purification capability as a function of number of pots.

because at this number the leaves of the water lilies overlapped on the water surface.

3.4 *Relationship between COD and DO concentration*

DO concentration was decreased by increasing the oxygen consumption of the plants and microorganisms in the water when the pollutant concentration was higher, and the concentration returned to the original level because of photosynthesis carried out by the water lilies. DO concentration is low when COD is high in general. In this experiment, it seems that there is a correlation between the COD and DO concentration when those characteristics return to their original levels. Consequently, the correlation between the changing rates of DO concentration and COD when the DO concentration was increasing was examined. Three days after the beginning of the experiment, the DO concentration increased and COD decreased as shown in Fig. 3(c). In the figure, increasing DO concenration from the previous day is indicated as DO concentration variation and the decreasing COD from the previous day is indicated as COD variation. The relationship between these variations is shown in Fig. 6. In the figure, the plots were determined three days after the beginning of the experiment. Two water lily pots were installed, 1.5 g of soap was dissolved, and water temperature was 25˚C. The approximate equation was derived using the least squares method. It is shown as eq. (2). D means the changing rate of DO concentration, and C is the changing rate of COD. The correlation coefficient of the equation of the plot was 0.95. The variables of C and D had a high correlation.

$$D = 0.38C+0.07 \tag{2}$$

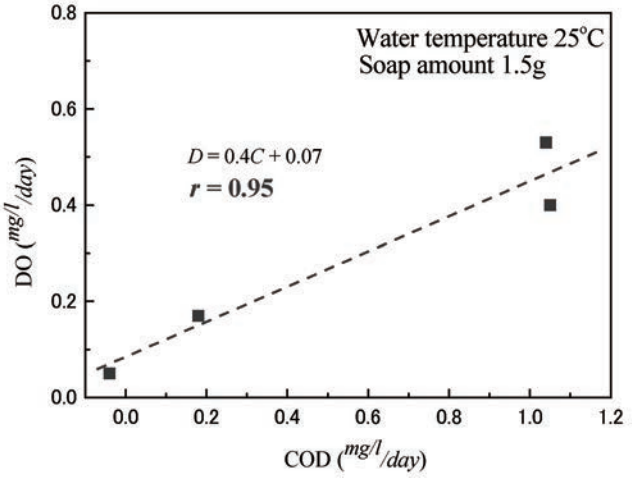


Fig. 6. Relationship between COD and DO concemtration at a water temperature of 25˚C.

4. Purification Facility for Household Effluent

4.1 *Purification using water lilies for domestic waste water*

A domestic waste water treatment facility using an aquarium with water lily pots was considered. A mature person consumes about 50 to 100 l on water on average when taking a bath and uses 3 g of soap. The relationship between the t_w and the amount of soap used is shown in Fig. 7. The figure shows the results of an experiment carried out at a water temperature of 25˚C with two water lily pots in the aquarium. The approximate equation for the relationship was derived and is shown as eq. (3). In the equation, the variable v is the amount of soap.

$$t_w = 0.4v+2.17 \tag{3}$$

t_w is 3.3 when v is 3 g using eq. (3). Consequently, it takes about 3.3 days until the value becomes the half-width at half maximum when two lily pots are used. This time was estimated under the following conditions: one person takes one bath each day and uses 50 l of water and 3 g of soap. It requires $\lceil 3.3n \rceil$ facilities (a drain tank and aquariums containing two lily pots and filled with 50 l of water) for a family of n individuals. The symbol $\lceil\rceil$ is a ceiling and raises decimals to the next whole number. Continuous purification is possible using such a facility. A sewage treatment facility for household effluent is proposed and shown in Fig. 8. In the treatment facility, the domestic waste water from the bath is stored in a drain tank, and the waste water runs into the aquarium, 50 l at a time, as determined by a controller. The water is poured into the sewer when the pollution level decreases by half. With such facilities, the cost of sewage disposal in a local self-governing body can be reduced.

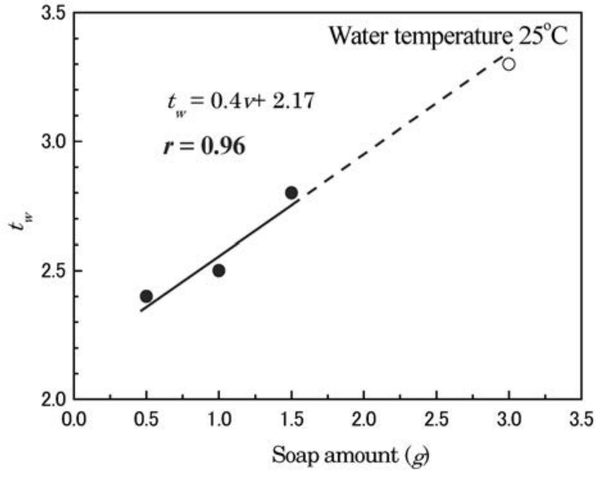


Fig. 7. The half-width (t_w) at half maximum of COD for using 3 g of soap.

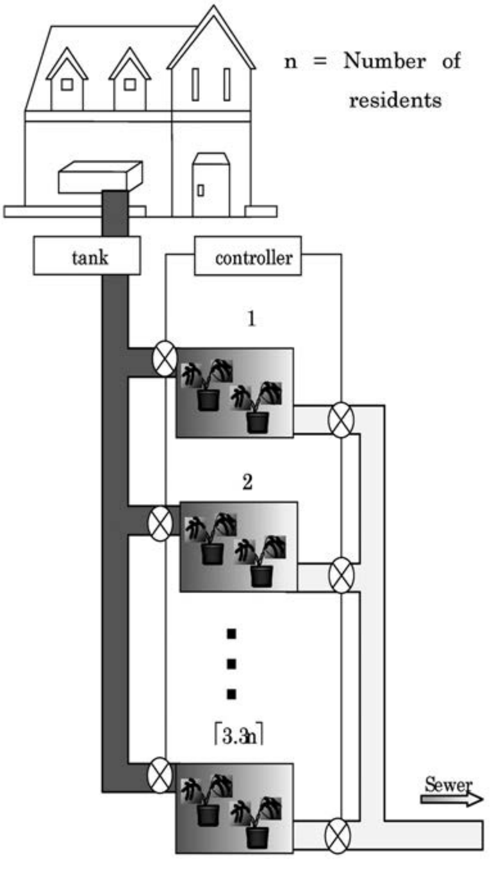


Fig. 8. A facility for purifying household effluent using water lilies in pots.

4.2 *Reducing cost*

The facility is made up of an aquarium with aquatic plants. A drain tank and a controller were designed. The facility is intended for household use. The estimated cost of sewage treatment was calculated for a scenario in which the facility is introduced into all households in Kanazawa, a city located in the northern central part of Japan. The displacement capacity for a year and the cost of sewage disposal in Kanazawa are indicated in Table 2. The average displacement capacity per household per year is about 245 m^3, and the cost for this capacity is about 53,000 yen. In the city, sewage treatment is done for about 150,000 households (82%), and the total displacement capacity is 50 million cubic meters including sewage water from community bathhouses and hotels. The total cost of the sewage disposal is about 10 billion yen. Three grams of soap and 5 g of shampoo per person are consumed in bathing according to our survey. These materials were dissolved in an aquarium and COD was measured in this study. The water pollution load due to soap was only 16.6%, and most of water pollution load was due to shampoo. The molecular weights of the materials in shampoo are higher than those of materials in soap. The average water usage per person for taking baths is 96 l, which is 32% of the total usage per person per day.

In Kanazawa, 10 billion yen is required for sewage treatment. If all the households were outfitted with the facility, the cost would be reduced by about 0.3 billion yen. This calculation is a rough approximation. This reduction in cost is comparatively low.

5. Purification Characteristics for a Mixture of Soap and Shampoo

Shampoo, soap, and conditioner are used while taking baths and the waste water is discharged into the same drain outlet. The ability of two water lily pots to purify a mixture of soap and shampoo was examined. Soap (1 g) and shampoo (1 g) were dissolved in water at a temperature of 25°C. The characteristics are shown in Fig. 9. w_p was 20. t_w and w_p for 2 g of soap were derived using eq. (3). The w_p was 33 in the experiment. The capability decreases to 60% of that for only soap when equivalent amounts of soap and shampoo are mixed. Shampoo includes materials which are difficult to decompose, and it takes a long time to decompose these using plants. The environmental pollution load can be reduced using additive-free soap and cleaning materials.

Table 2
Cost of sewage disposal in Kanazawa.

	Kanazawa	Capacity/home
Displacement capacity	50 million (m^3)	245 (m^3)
Treatment cost	10 billion (yen)	53000 (yen)

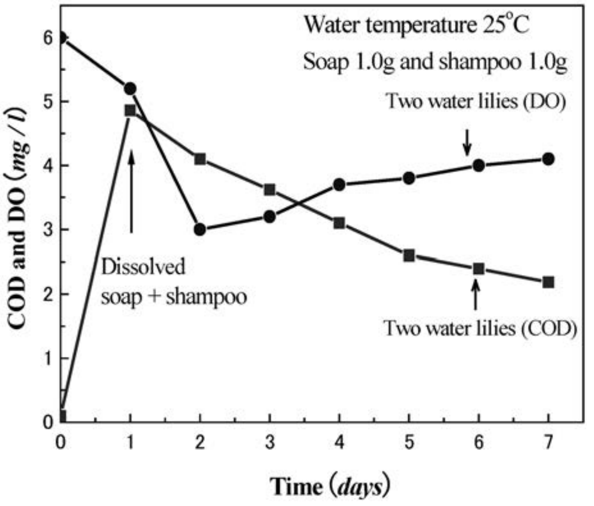


Fig. 9. Purification characteristics for mixture of soap and shampoo.

6. Conclusions

The purification of waste water containing soap was examined using water lilies in pots, which were placed in an aquarium. Temperature was controlled at 15, 20 and 25°C. The capability of the pots is highest at 25°C, which was maximum temperature set. The characteristics as a function of the amount of soap were also examined. The soap amounts adopted were 0.5, 1.0 and 1.5 g. The capability decreased as the amount of soap increased.

The capability as a function of pot number was also examined. It increased as the number of pots increased. This experiment was carried out with 1, 2 and 3 pots. The relationship was linear.

The variations in DO concentration and COD when DO concentration was increasing were examined, and the correlation coefficient for both values was 0.95. In the experiment, the water temperature was 25°C and the amount of soap was 1.5 g. The coefficent was very high. A purification facility for discharge water for household use was considered. The facility has several aquariums in which two water lilies were placed along with a drain tank and a controller. It takes a long time to purify waste water containing shampoo and soap only.

In the future, the purification characteristics of other aquatic plants will be investigated. The influence of light intensity and t he amount of water on their characteristics will also be studied.

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