A Study on Flow Patterns and Fluid Mixing for Water Purification in a Pond

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ABSTRACT

The efficiency of clarification of an irregularly shaped pond, by removal, treatment and return of a stream, was examined.

In this study, the water velocity distributions and the inflow and outflow rates occurring in a typical park pond were measured to get information of a pond flow. We also calculated the two dimensional laminar flow patterns and tracer mixing numerically using a finite element method, for a range of inflow positions and inflow angles of the refreshed water. Then, based on the numerical results of the flow pattern and the temperature distribution, we examined criteria for judging flow patterns for their effectiveness in purifying the pond water.

1. INTRODUCTION

In recent years, the maintenance and clarification of ponds in recreational parks has become very important to the community, and efficiency of the process has become an important issue (Environmental Conservation Engineering, 1994). In such cases, in order to purify the pond water efficiently, the inflow position of the refreshed water returned from the purification equipment and the outflow position of the dirty pond water are important, because the flow pattern of the pond water depends on the inflow and outflow positions and the inflow angle of the refreshed water.

2. MEASUREMENTS OF THE POND WATER VELOCITY

Figure 1 shows the schematic diagram of the pond. The pond has the shape like a gourd and has a small island and a waterfall in the large side. The area is approximately $1000m^2$, and the depth of the water is about 0.4m. The outflow position to the purification equipment is at the west edge of the small side, and the water for the waterfall is pulled out from north side of the small pond.

The refreshed water from the purification equipment returns into at the northeast edge of the large pond (Inflow position:②, Inflow angle: 30°).

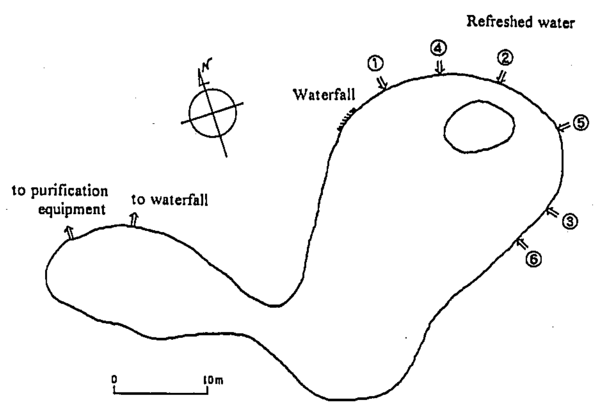

Fig.1 Schematic diagram of the pond

The flow rate of water to the purification equipment is roughly 200ton/day, and the flow rate of water supplied to the waterfall is almost the same. A schematic of the electromagnetic velocity meter (made by Alecks Electronic Corp.) and its support used in the measurements of the pond water velocity are shown in Figure 2.

The velocity meter is set in the north direction by the compass put on the support board, and velocity components are measured at 5 depths, 3cm, 10cm, 20cm, 30cm and 35cm from the water surface.

A representative result of the measured velocity distributions is shown in Figure 3. It is found from the figure that the flow near the surface is affected by the wind, but the water velocities are very slow except near the inflow of the refreshed water and the waterfall.

3. NUMERICAL SUMULATION OF POND WATER FLOW PATTERNS

In the flow simulations, the inflow position and the inflow angle of the refreshed water are changed , and the two outlet positions of the pond water and the position of the waterfall are fixed. The inflow position of the refreshed water is changed from Position ① to Position ⑥, shown in Figure 1, and the inflow angles used were -60°, -30°, 0°, 30° and 60°. As shown in Fig.4, the inflow angle perpendicular to the rim of the pond is defined as 0 degree.

The element division and the flow simulation are carried out using ANSIS and FLOTRAN, which are finite element flow analysis programs (made by ANSYS, Inc.).

4. STANDARDS FOR THE EVALUATION OF THE FLOW PATTERN

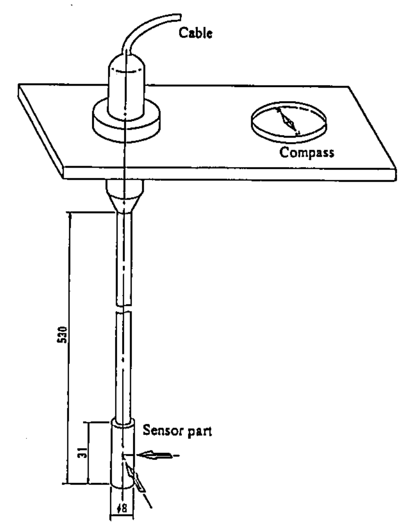

Fig.2 Outlines of the electromagnetic velocity meter and the support

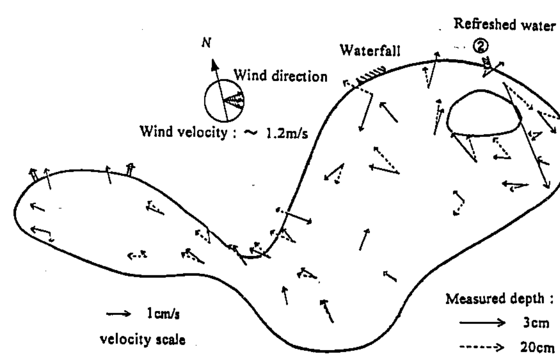

Fig.3 Representative example of measured velocity distributions

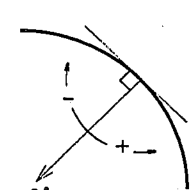

Fig.4 Definition of inflow angle

In order to purify the polluted pond water effectively, it can be considered that let the refreshed water diffused into the whole pond rapidly and let the concentration in the pond close to the same concentration everywhere, or, that let the flow pattern close to the plug flow and let the polluted water push out to the purification equipment

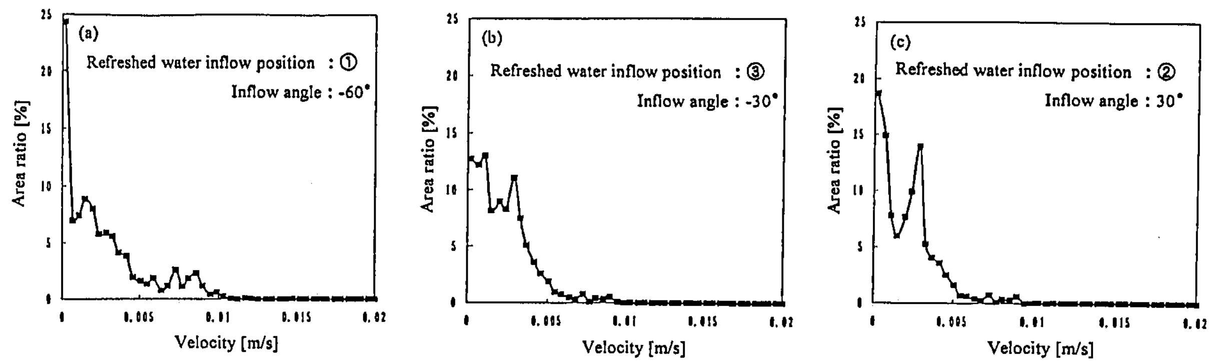

Fig.5 Representative examples of the relation between the velocity and the ratio of the area occupied by the velocity

quickly. In either case, the flows which have only small dead zones are good. In this study, evaluation of the flow pattern was performed using the mean value, the variance and the variation coefficient (sometimes called the percentage standard deviation) of water velocity distributions. The variation coefficient is defined as

$$C_v = V_{ar}^{1/2} / v_{ave} X100 \qquad (1)$$

where v_{ave} is the mean velocity, V_{ar} is the variance and C_v is the variation coefficient of the velocity distributions.

Unsteady simulations of fluid mixing are carried out using temperature as a tracer. The initial temperature of the pond water and the waterfall temperature are 15° C, and the refreshed water temperature is 50° C.

Table. 1 is a summary of the mean velocity, the variance and the variation coefficient, which are calculated from the results of flow pattern simulations.

Fig.5(a),(b) and (c) show representative examples of the relation between the magnitude of the flow velocity and the percentage of the area occupied by the velocity.

Criteria for judging the efficiency of purification are discussed below.

Table 1 Summary of the mean velocity, the variance and the variation coefficient

Inlet position of refreshed water		Inflow Angle [degree]				
		-60	-30	0	30	60
①	mean velocity [x10^{-2}m/s]	0.263	0.227	0.218	0.213	0.245
	variance [x10^{-6}m^2/s^2]	0.676	0.385	0.332	0.329	0.430
	variation coefficient [-]	0.990	0.863	0.835	0.851	0.845
②	mean velocity [x10^{-2}m/s]	0.299	0.200	0.184	0.207	0.260
	variance [x10^{-6}m^2/s^2]	0.544	0.372	0.282	0.296	0.491
	variation coefficient [-]	0.781	0.966	0.913	0.830	0.851
③	mean velocity [x10^{-2}m/s]	0.267	0.221	0.228	0.206	0.237
	variance [x10^{-6}m^2/s^2]	0.506	0.293	0.365	0.337	0.490
	variation coefficient [-]	0.843	0.774	0.839	0.893	0.933
④	mean velocity [x10^{-2}m/s]	0.284	0.216	0.204	0.203	0.260
	variance [x10^{-6}m^2/s^2]	0.636	0.346	0.337	0.277	0.493
	variation coefficient [-]	0.888	0.862	0.900	0.821	0.856
⑤	mean velocity [x10^{-2}m/s]	0.284	0.200	0.211	0.214	0.247
	variance [x10^{-6}m^2/s^2]	0.534	0.335	0.318	0.335	0.503
	variation coefficient [-]	0.814	0.914	0.844	0.854	0.908
⑥	mean velocity [x10^{-2}m/s]	0.262	0.247	0.213	0.196	0.241
	variance [x10^{-6}m^2/s^2]	0.464	0.406	0.385	0.333	0.500
	variation coefficient [-]	0.823	0.814	0.922	0.933	0.927

4.1 Flow evaluation by the average velocity

Even in the cases having the same mean velocity value, the percentages of the area occupied by the low velocity are different. In the cases of the flow having extensive area of low velocity, the purification efficiency will be poor.

Accordingly, it is found that the average velocity is an inadequate criteria, because the average velocity does not contain the information on the range of velocities occurring.

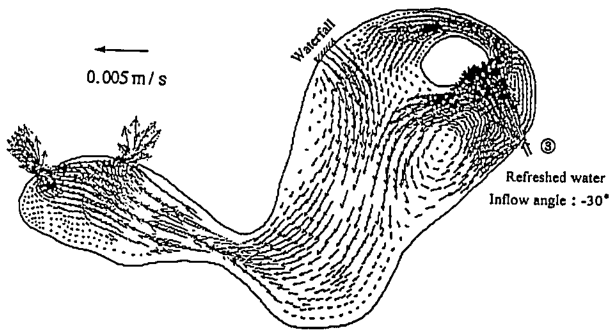

Fig.6 Representative example of velocity vectors; Inflow position:③, Inflow angle:-30°

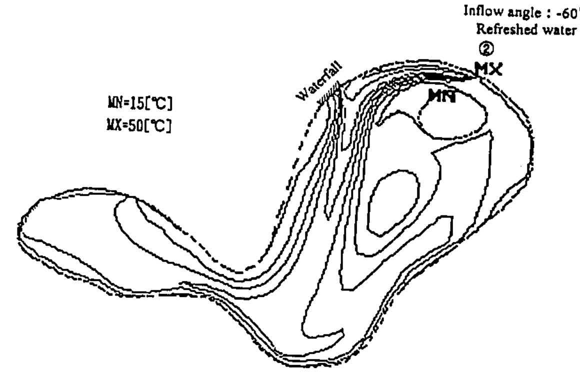

Fig.7 Representative example of temperature contours; Inflow position:②, Inflow angle:-60°

4.2 Flow evaluation by the variance

It was found from Table.1 and Fig.6 that the flows having small variance values were relatively close to the plug flow and that in these cases a large recirculating flow was hard to obtain. However, even in these cases , the area occupied by the low velocity parts was sometimes large relatively. So, it is found that the flows having small variance values are not always good for the pond water purification.

On the other hand, of the cases having a large variance value, as shown in Fig.7 for example, it was found that some had comparatively good fluid mixing. In some others (eg. Fig.8), however, the refreshed water flowed directly from the inlet to the outlet, effectively short-circuiting. Besides, it was found that in the cases having the large dispersion value and the good fluid mixing, there were some cases that the area ratio of low velocity was comparatively large. In view of this range of behavior, it is hardly reasonable to judge a good flow only by the variance value of the velocity.

4.3 Flow evaluation by the variation coefficient

In the cases of the flow pattern having the "velocity - area ratio" distribution as shown in

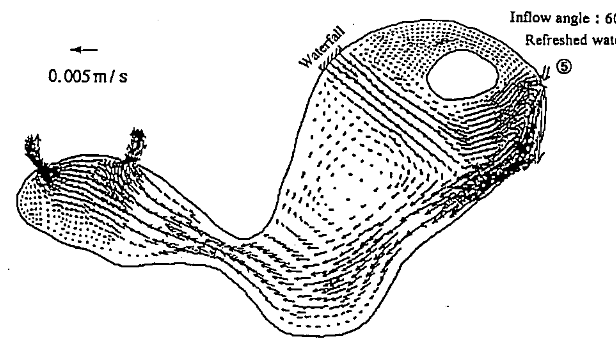

Fig.8 Representative example of velocity vectors; Inflow position:⑤, Inflow angle:60°

Fig.5(a), the area ratio occupied by the middle range of water velocity is comparatively small and the refreshed water does not spread in the pond well. In these cases the variation coefficients have considerably large values.

On the other hand, in the cases of the "velocity - area ratio" distribution as shown in Fig.5(b), the variation coefficient has a small value and the low velocity area is comparatively small.

Accordingly, it is thought that dead zones are not formed and the refreshed water can spread through the whole pond comparatively quickly.

In the case of Fig.5(c), the low velocity area is comparatively large. Accordingly, it is thought that flows having the distribution like Fig.5(c) are bad for the pond water purification because unpurified areas can be formed easily. In these cases the variation coefficient shows a low value, but, the variance value is not so small.

From these discussions, it is found that we can evaluate flow patterns for pond water purification using both variance values and variation coefficients of water velocity.

5. CONCLUSIONS

The summary of the results is as follows:

1) It was found that the flow patterns near to plug flow have relatively small variance values.

2) It was found that in the flows having large variance values, there were both cases where the refreshed water diffused relatively well and cases where the refreshed water did not diffuse well. For flows having good fluid mixing, the area occupied by the low velocity was small.

3) It was found that the variation coefficients for the flows having small low velocity area were comparatively small.

From 1),2) and 3), it is found that criteria for efficient water purification of the pond should be based on both of the variance and the variation coefficient of the pond water velocity distribution.

REFERENCES

Environmental Conservation Engineering, Vol.23, No.7, pp.452-466(1994) (in Japanese)

Electromagnetic Velocity Meter (Model ACM-200s); made by Alecks Electronic Corp., Kobe-City, JAPAN.

ANSYS / FLOTRAN Program; made by ANSYS, Inc, US.