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A STUDY ON FLOW PATTERNS AND FLUID MIXING FOR WATER PURIFICATION IN A RECTANGULAR WATER TANK

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ABSTRACT

The three-dimensional laminar flow patterns and temperature mixing in a rectangular water tank were calculated numerically using a finite element method, changing the inlet position of refreshed water and the outlet position of dirty water. Then, based on the numerical results of velocity and temperature distributions, the criteria for judging a better flow pattern effective for the purification of tank water were examined. As the results, it was shown that the criteria obtained from the two-dimensional pond flow simulation, that had been reported in the previous conference, were applicable to the three-dimensional water tank.

INTRODUCTION

There are many water reservoirs, tanks and small ponds for rainwater utilization and fire prevention in our city, and we have to purify such impounded water, because the impounded water becomes dirty. In order to clarify the water efficiently, the inlet position of refreshed water and the outlet position of dirty water are important, because the flow pattern in a reservoir depends on the inlet and outlet positions. We previously reported the standards for judging a flow pattern for effective purification of pond water based on the numerical results of two-dimensional flow patterns and temperature diffusions[1)].

In this study, we calculate the three dimensional laminar flow patterns and temperature diffusions numerically with a finite element method, changing the inlet and outlet positions in a rectangular tank. Then, based on the numerical results, we examine the adaptation of the standards obtained from the two-dimensional flow analysis to the three-dimensional water tank.

For the confirmation of the numerical results of flow patterns, the visual observations of flow patterns are carried out in a rectangular test tank, as a reference.

VISUAL OBSERVATION OF FLOW PATTERNS IN A TEST TANK

Figure 1 shows the transparent tank for confirming the flow pattern in the rectangular water tank (Width: 30cm, Height: 40cm, Length: 60cm). The walls are made of transparent acrylic boards. The water depth is about 30cm. The inflow position changes from In① to In⑥. The outflow position changes from Out① to Out③ for the inflow positions of In①, In② and In③, and the outflow position changes from Out④ to Out⑥ for the inflow positions of In④, In⑤ and In⑥, respectively. The inflow and outflow angles are 0 degree, i.e. perpendicular to the wall surface. Aluminum fine powder was used as a tracer.

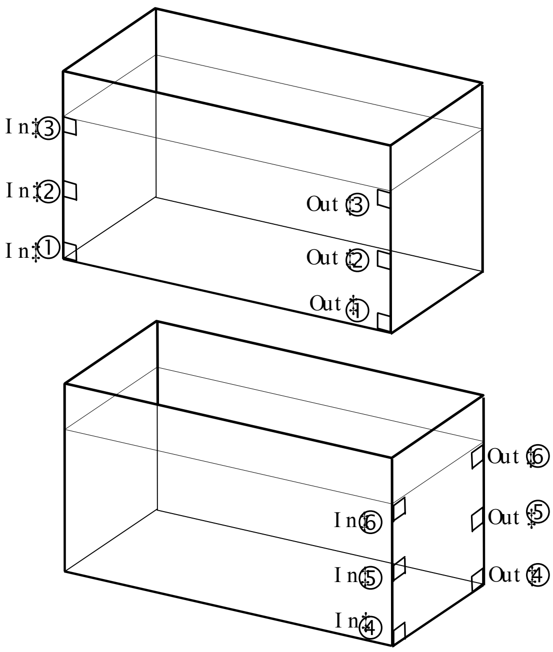

Figure 1: Transparent tank for flow visualization

NUMERICAL SUMULATION OF FLOW PATTERNS IN A TANK

Fig.2 shows the outline of the model of the water tank for this flow simulation. The inflow position of the refreshed water is changed from In① to In⑥, shown in the figure. The outflow position is changed from Out① to Out⑥ for the inflow positions of In①, In② and In③, respectively. For the inflow positions of In④, In⑤ and In⑥, the outflow positions are Out⑦, Out⑧ and Out⑨, respectively. The inflow direction is perpendicular to the wall surface.

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

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.).

The shape of the element was hexahedral and the number of element is 122852 (W: 18 elements, H: 21 elements, L: 34 elements). The Reynolds number in the inflow nozzle is 1000.

RESULTS OF NUMERICAL SIMULATION

Figures 3 (a), (b) show the representative results of velocity vectors for the inflow position of In ⑤ and the outflow position of Out ⑨ and for the inflow position of In① and the outflow position of Out ③

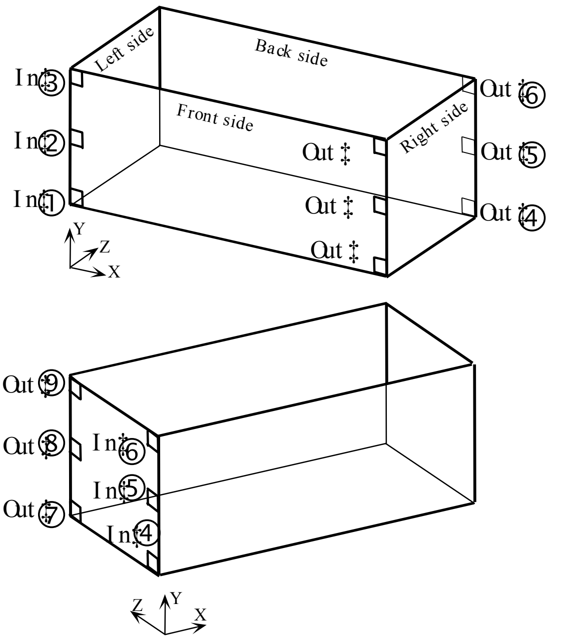

Figure 2: Simulation model of rectangular water tank

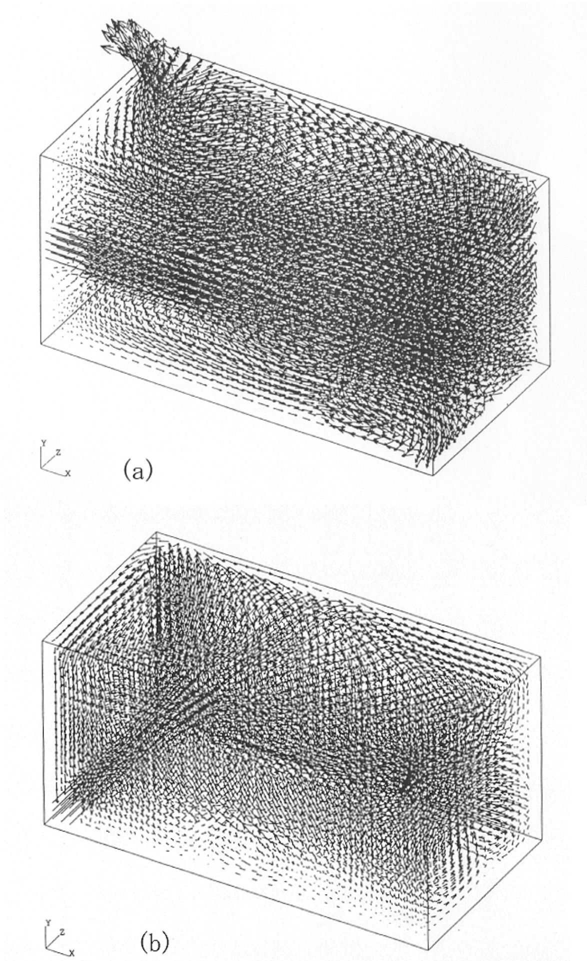

Figure 3 Representative examples of velocity vectors;
(a) Inflow position: In⑤, Outflow position: Out⑨
(b) Inflow position: In①, Outflow position: Out③

In the case of the inflow position of In ⑤, as shown in figure (a), there is the low velocity area near the left underside, but it is relatively small and the flow seems to be well as a whole. The flow pattern was similar for the cases in which the inflow and outflow positions were on the same wall of width side like this case. However, in the case of the inflow position of In①, as shown in figure (b), comparatively large low velocity area was formed near the bottom. Also there were some low velocity areas near the center of the left side and near the right side.

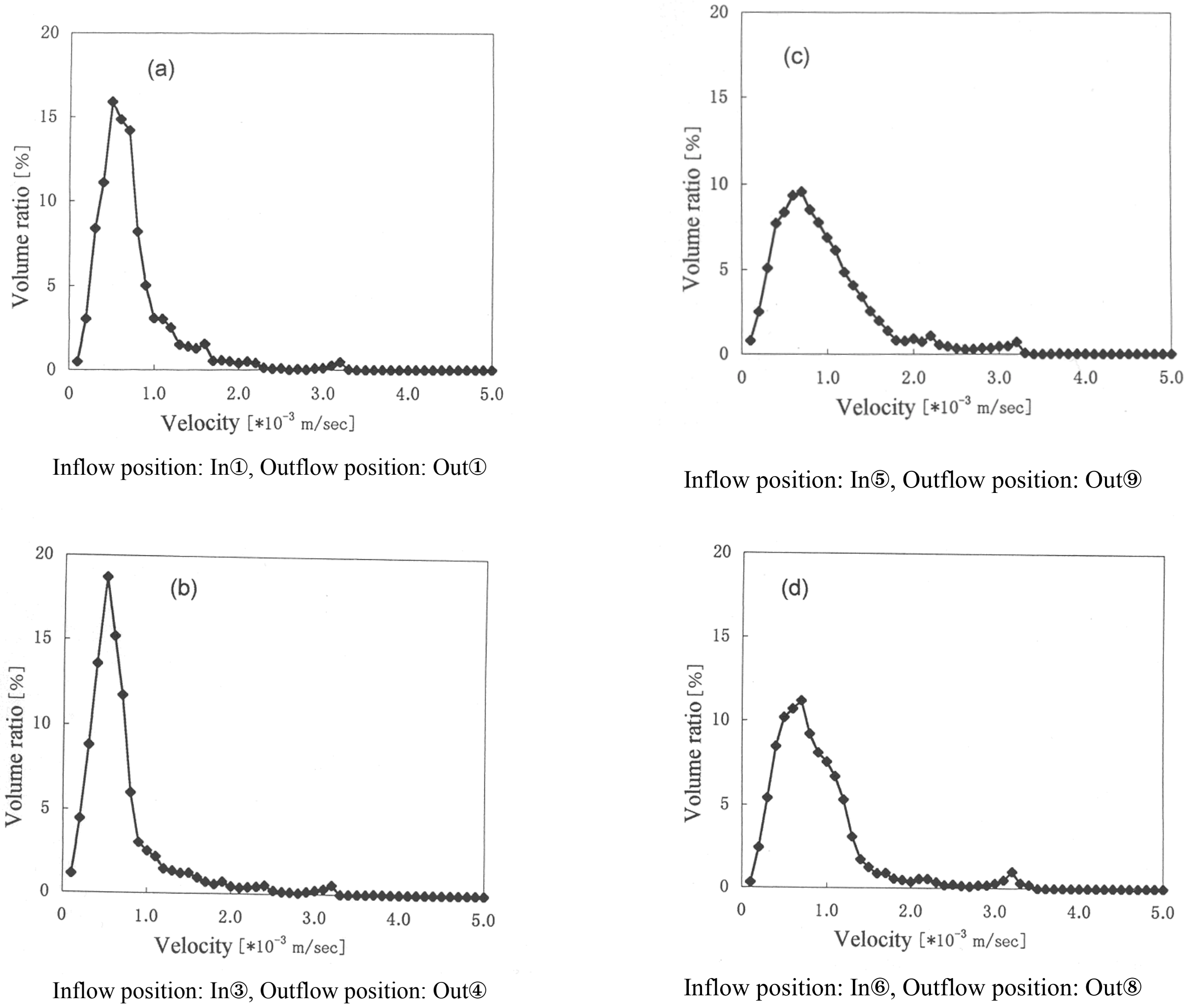

Figure 4: Representative examples of the relation between the velocity and the volume ratio occupied by the velocity

Figures 4 (a), (b), (c) and (d) show the representative examples of the relation between the magnitude of the velocity and the percentage of the volume occupied by the velocity. In the cases of the inflow position on the side wall, the volume ratio occupied low velocity was reduced and the flow pattern was comparatively well in comparison with the cases of the inflow position on the front wall.

STANDARDS FOR EVALUATING FLOW PATTERNS

In this study, the evaluation of the flow pattern was also performed using the average velocity, the variance of velocity and the coefficient of variation of velocity, the same as the case of the two-dimensional pond.

The variation coefficient is defined as

$$C_v = V_{ar}^{1/2} / v_{ave} \times 100 \qquad (1)$$

where v_{ave} is the mean velocity, V_{ar} is the variance and C_v is the variation coefficient of the velocity distributions.
In the previous report[1)], the following conclusions have been obtained from the two-dimensional pond flow simulation:

(1) The flow patterns near to plug flow have relatively small variance values.
(2) When the variance was large, there were both cases in which the refreshed water diffused relatively well and cases in which the refreshed water did not diffuse well.
(3) For the flows having good fluid mixing, the area occupied by the low velocity was small, and .the variation coefficients were comparatively small for the flows having small low velocity area.

Table 1 is the summary of the average velocity, the variance of velocity and the coefficient of variation of velocity, which were calculated from the results of the 3D flow simulations. As shown in Table 1, when the inflow position is In①, variance values and C.V. values are small. In the cases of inflow position of In①, the area occupied by low velocity is relatively large and the average velocity is also lower compared with others. So, this inflow position In① is not very good.

However, in the cases of inflow positions of In⑤ and In⑥, variance values are large and C.V. values are small. In these cases, the area of low velocity is comparatively small and the fluid mixing is well. So these inflow positions are good.
These results coincide well with the standards obtained in the two-dimensional pond.

Outflow Position		Inflow Position		
		In(1)	In(2)	In(3)
Out(1)	Vave $[\times 10^{-3} m/s]$	0.682	0.761	0.729
	Var $[\times 10^{-6} m^2/s^2]$	0.207	0.295	0.261
	C.V. [%]	66.7	71.4	69.9
Out(2)	Vave $[\times 10^{-3} m/s]$	0.672	0.699	0.722
	Var $[\times 10^{-6} m^2/s^2]$	0.207	0.267	0.252
	C.V. [%]	66.8	73.9	69.5
Out(3)	Vave $[\times 10^{-3} m/s]$	0.673	0.739	0.737
	Var $[\times 10^{-6} m^2/s^2]$	0.213	0.293	0.257
	C.V. [%]	68.5	73.3	68.8
Out(4)	Vave $[\times 10^{-3} m/s]$	0.684	0.746	0.663
	Var $[\times 10^{-6} m^2/s^2]$	0.208	0.288	0.267
	C.V. [%]	66.6	71.9	78.1
Out(5)	Vave $[\times 10^{-3} m/s]$	0.673	0.756	0.681
	Var $[\times 10^{-6} m^2/s^2]$	0.201	0.266	0.261
	C.V. [%]	66.4	68.2	75.1
Out(6)	Vave $[\times 10^{-3} m/s]$	0.665	0.719	0.766
	Var $[\times 10^{-6} m^2/s^2]$	0.205	0.278	0.261
	C.V. [%]	68.1	73.4	66.6

Outflow Position		Inflow Position		
		In(4)	In(5)	In(6)
Out(7)	Vave $[\times 10^{-3} m/s]$	0.778	0.906	0.825
	Var $[\times 10^{-6} m^2/s^2]$	0.271	0.322	0.324
	C.V. [%]	66.9	62.6	69.1
Out(8)	Vave $[\times 10^{-3} m/s]$	0.713	0.812	0.836
	Var $[\times 10^{-6} m^2/s^2]$	0.252	0.283	0.313
	C.V. [%]	70.5	65.4	66.9
Out(9)	Vave $[\times 10^{-3} m/s]$	0.681	0.911	0.799
	Var $[\times 10^{-6} m^2/s^2]$	0.248	0.354	0.327
	C.V. [%]	73.2	65.3	71.6

Table 1: Summary of the average velocity, the variance of velocity and the coefficient of variation of velocity.

CONCLUSIONS

In the rectangular water tank, the flow pattern in which the refreshed water spreads well is better. The following conclusions were summarized:

(1) The criteria for judging a flow pattern by the variance and the variation coefficient of the velocity distributions were adaptable for the three-dimensional water tank.

(2) In the rectangular water tank, when the inflow and outflow position were put on the same wall of width side (narrow side wall) and the inflow position was near the water surface, the area occupied by low velocity was reduced and the diffusion of refreshed water was relatively well.

REFERENCES

1. KAWASHIMA, Y., MURAI, K., (1997) Proc. of Int. Conf. on CFD in Mineral & Metal Processing and Power Generation, p.253
2. ANSYS/FLOTRAN Program; made by ANSYS Inc., US.