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Research on Capture Performance of an Induction Type Microplastics Recovery Device

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Abstract

Microplastic wastes in ocean can include the harmful chemical material, and the harmful material is concentrated by marine species. The separation and collecting methods of microplastics in ocean are researched in the world. The authors proposed the microplastics recovery device composed of the plates. Besides, the device consists of the tilted inlet/outlet and the horizontal part. In the water flow such as the tidal and ocean currents, the microplastics can be extracted from the main flow due to the vortex flow generated at the inner part of this device. In this research, the effects of the flow velocity and the inlet/outlet tilt angle on the capture performance were investigated experimentally and numerically. In the numerical simulations using the discrete phase model, the tilt angle was changed in a range between 30 degrees and 150 degrees in increments of 15 degrees, and the particle tracks of plastics were derived in steady condition. On the other hand, the capture performances in three cases of tilt angle 45 degrees, 120 degrees and 150 degrees were compared by circulation type water channel tests in which the plastics denser than the water were swept away 30 times every flow velocity. As the result, it seems that the tilt angle of 120 degrees is suitable for the wide range of the flow velocity in river and ocean.

Keywords

Capture Performance, Microplastics, Recovery Device, Tidal and Ocean Currents, Vortex Flow

1. Introduction

The potential impacts of microplastics [1] in the ocean attract attention from all over the world, and it is known that the sunlight and wave cause the degradation of plastic waste into small fragments. However, the effective reduction method of microplastics in ocean has not yet been clarified [2]. Microplastics litter [3] in the ocean is divided into the primary plastics as materials for products and the secondary plastics as the miniaturized ones after use. It is noted that there are 24.4 trillion pieces of microplastics in the world's upper oceans [4]. Most plastics flowing through river to ocean are polyethylene and polypropylene which are less dense than water, and those plastics drift along the surface of the sea [5]. On the other hand, the floating plastics sink toward the bottom of the sea due to the marine biofouling. The plastics in the ocean can include the harmful chemical materials such as carcinogenic polychlorinated biphenyls and polycyclic aromatic hydrocarbons, and the harmful materials are concentrated by marine species [6]. Therefore, the degrading [7] and collecting methods [8] of microplastics are researched in the world. Coppock *et al.* [9] proposed the portable method to separate microplastics from sediments of differing types. In 2016, Ideonella sakaiensis bacterium which can decompose polyethylene terephthalate and use the decomposed products for its growth was reported [10]. Moreover, in 2021, the project to clean up the floating plastics was carried out in the Great Pacific Garbage Patch located between Hawaii and California by the Ocean Cleanup of non-profit organization [11]. Isobe *et al.* [12] simulated the worldwide spread of ocean plastics using a particle tracking model and concluded that 66.7% of ocean plastics were heavier than seawater, which are difficult to monitor under current observation frameworks. Currently, there are several global efforts [13] aiming at action for reducing and preventing marine litter and for mitigating its impact. These efforts include worldwide initiatives such as the Global Partnership on Marine Litter (GPML) and the Honolulu Strategy.

In this research, the authors proposed the microplastics recovery device composed of the plates. The microplastics recovery device has a bilaterally symmetrical geometry and consists of the tilted inlet/outlet and the horizontal part. Besides, the upper and lower are also symmetrical geometry in this device. The microplastics which are denser than water converge on the lower part and the lighter microplastics are collected at the upper part. In the water flow such as the tidal and ocean currents, the microplastics can be extracted from the main flow due to the vortex flow generated at the inner part of this device. In case of trapping by the filter, the number of captured plastics decreases rapidly as the decrease of the flow rate due to the clogging, and the filter replacement causes the higher maintenance costs. In this paper, the effects of the flow velocity and the tilt angle at inlet/outlet on the capture performance were investigated numerically and experimentally. In this research, the tap water as the surrounding liquid was adopted instead of sea water. The flow behavior of plastics depends on the difference in density between the plastics and the surrounding liquid. The denser plastics flow through the lower area near the bottom of the sea, the lighter plastics drift near the surface of the sea. So, the tap water as the surrounding liquid is acceptable in this research aimed at the confirmation of the collecting ability.

2. Numerical Simulations with Discrete Phase Model

To investigate the flow behavior of the microplastics in the recovery device, the numerical simulations with discrete phase model [14] were carried out. **Figure 1** shows the configurations of microplastics recovery devices in cases of the inlet/outlet tilt angle α = 45 degrees, 120 degrees and 150 degrees. In the simulations, the tilt angle α of inlet/outlet was changed in a range between 30 degrees and 150 degrees in increments of 15 degrees. The height and width are 200 mm, the length of horizontal part is 300 mm and the length of one side at inlet/outlet is 100 mm. The devices are composed of the plates with 5 mm thickness. The

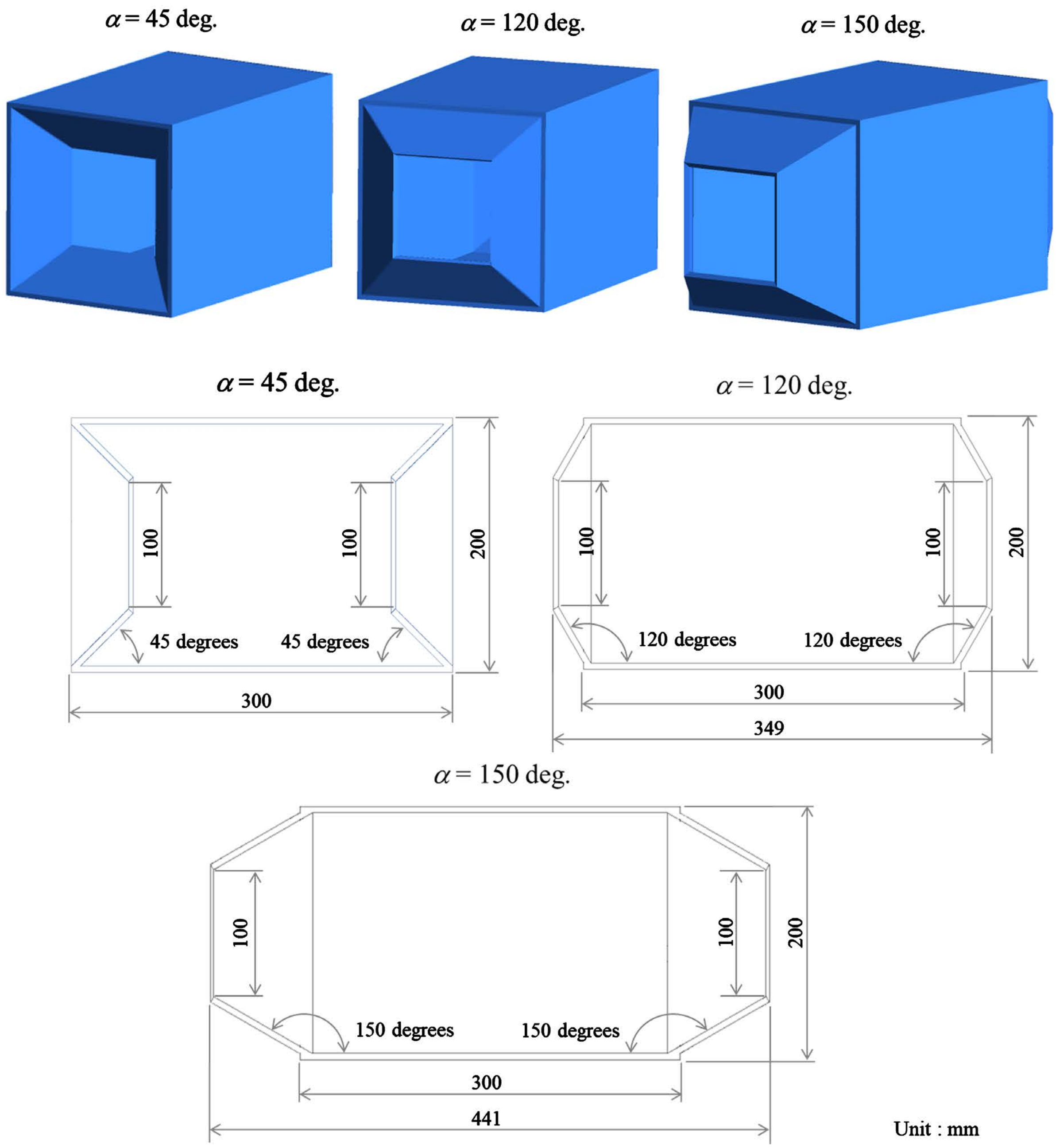

Figure 1. Microplastics recovery devices.

steady flow simulations with SST turbulent model were conducted by the commercial CFD code of ANSYS Fluent ver.19. This code calculates the discrete phase force balance by solving the interphase force equation in Lagrangian coordinates and the evaluation of the discrete phase particle tracks.

Figure 2 is the simulation domain assumed the arrangement of the recovery device in the circulation type water channel for experiments, where the width of water channel is 1.0 m and the water depth is 0.7 m. The recovery device was placed at the position of 0.35 m depth. Number of the grids is approximately 1,300,000. The surrounding flow velocity was changed from 0.9 m/s to 0.6 m/s and 0.3 m/s. The density of water is 998 kg/m^3 and the one of plastics is 1040 kg/m^3. The maximum diameter of plastics is 0.005 m, the minimum diameter is 0.0001 m, the mean one is 0.001 m. Number of the plastics is approximately 22,200.

Figure 3 shows the velocity ratio v_a/v, where the v_a is the velocity at the center of inlet in recovery device and the v is the surrounding flow velocity. The velocity v_a in the experiment was measured with the pitot tube and the v of 0.6 m/s was set. The recovery devices with the tilt angle α = 45 degrees, 120 degrees and

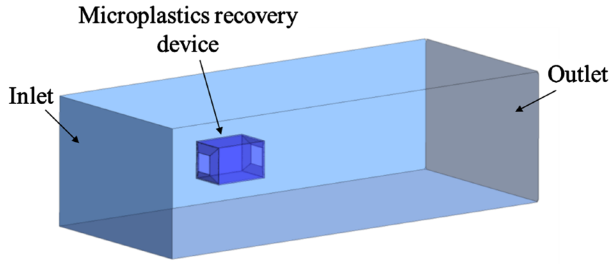

Figure 2. Numerical simulation domain.

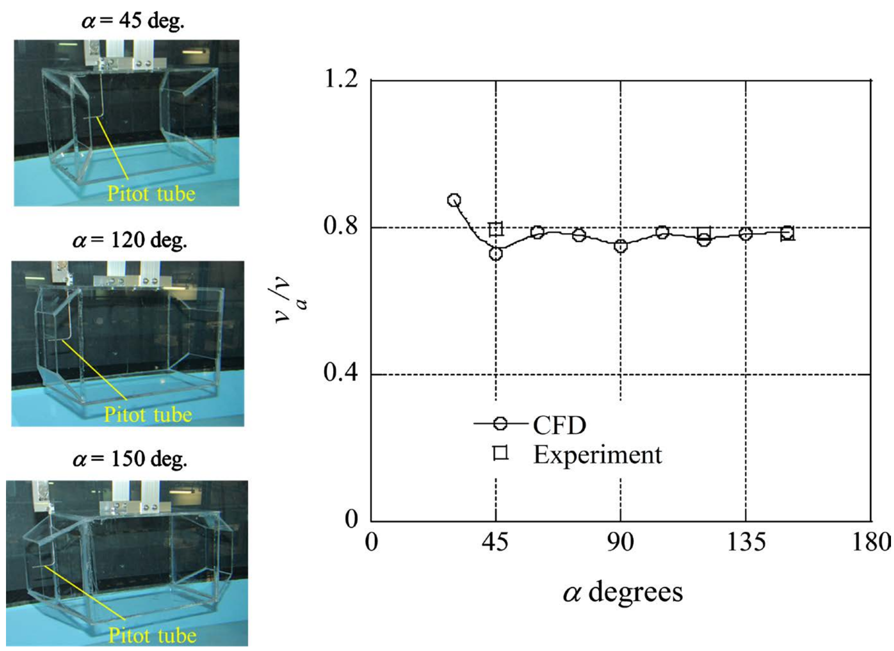

Figure 3. Changes in velocity ratio of inlet and surrounding due to tilt angle.

150 degrees were prepared for the experiments. As shown in this figure, the CFD results are in good agreements with experimental results. Besides, the v_a/v of about 0.78 on average was achieved over the range between α = 45 degrees and 150 degrees.

Figure 4 shows the particle tracks in the recovery devices at v = 0.9 m/s, where the warm color means the higher velocity and the cold color denotes the lower velocity. **Figure 5** is the particle tracks in case v = 0.6 m/s. **Figure 6** is the case v = 0.3 m/s. In these figures, there are many particle tracks with lower velocity in case with larger tilt angle, especially α = 120 degrees and α = 150 degrees.

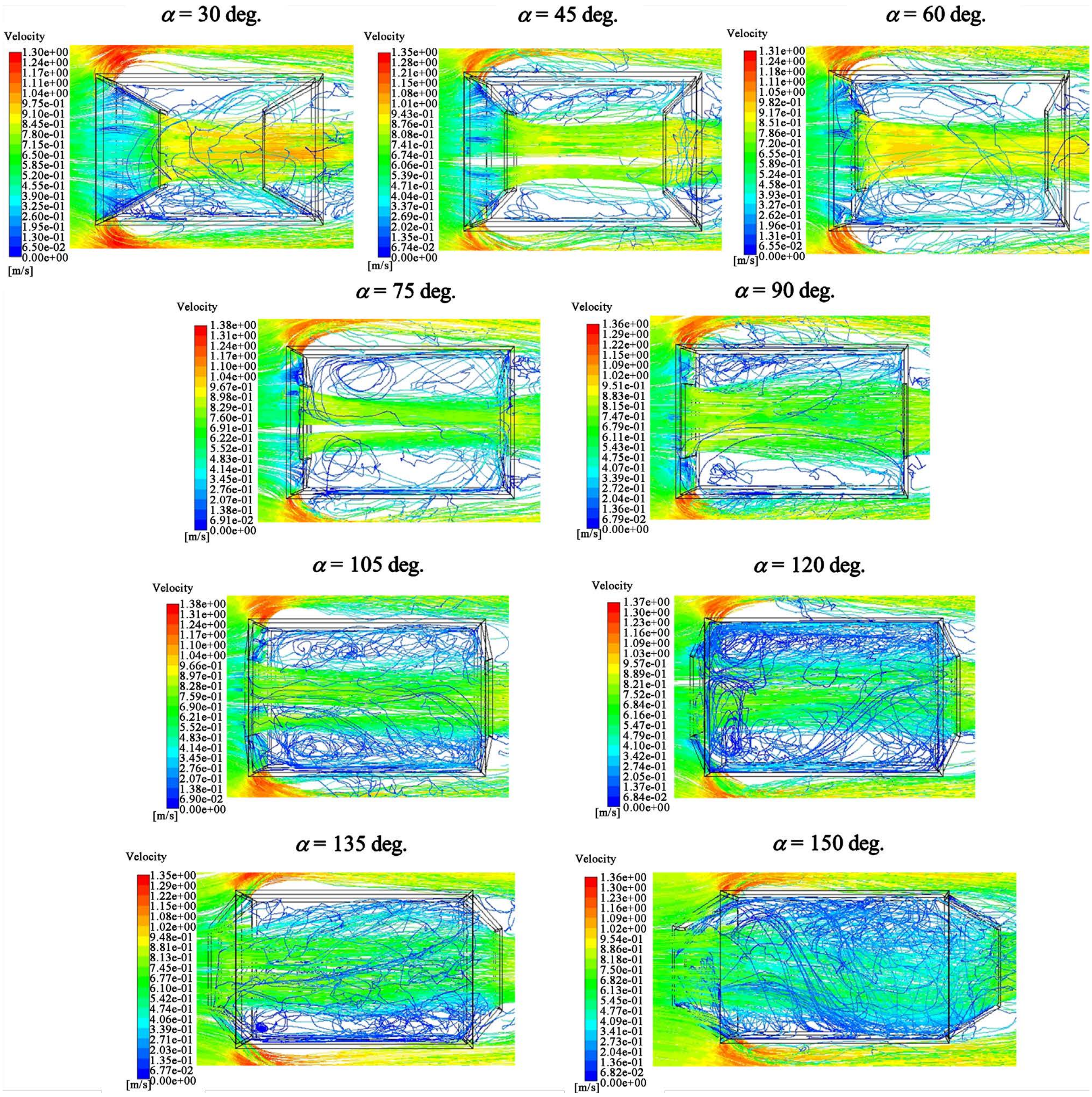

Figure 4. Particle tracks at v = 0.9 m/s.

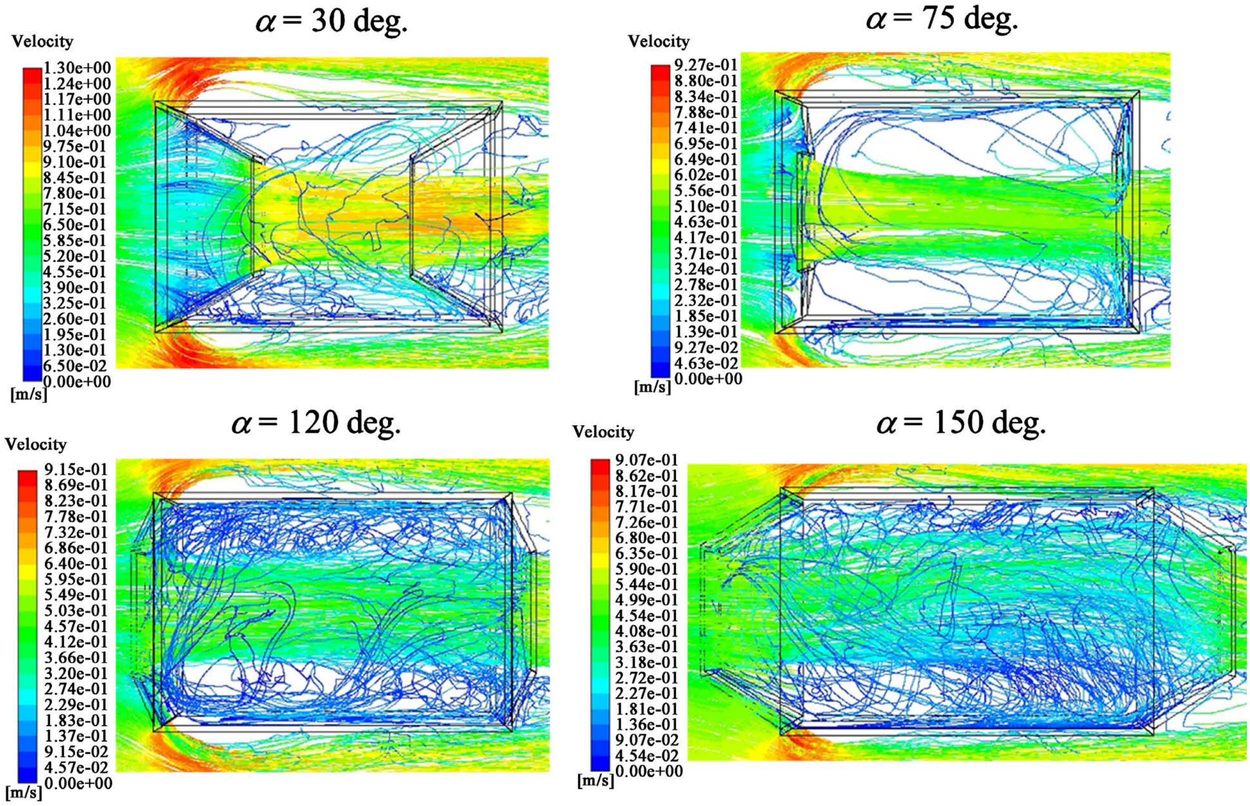

Figure 5. Particle tracks at $v = 0.6$ m/s.

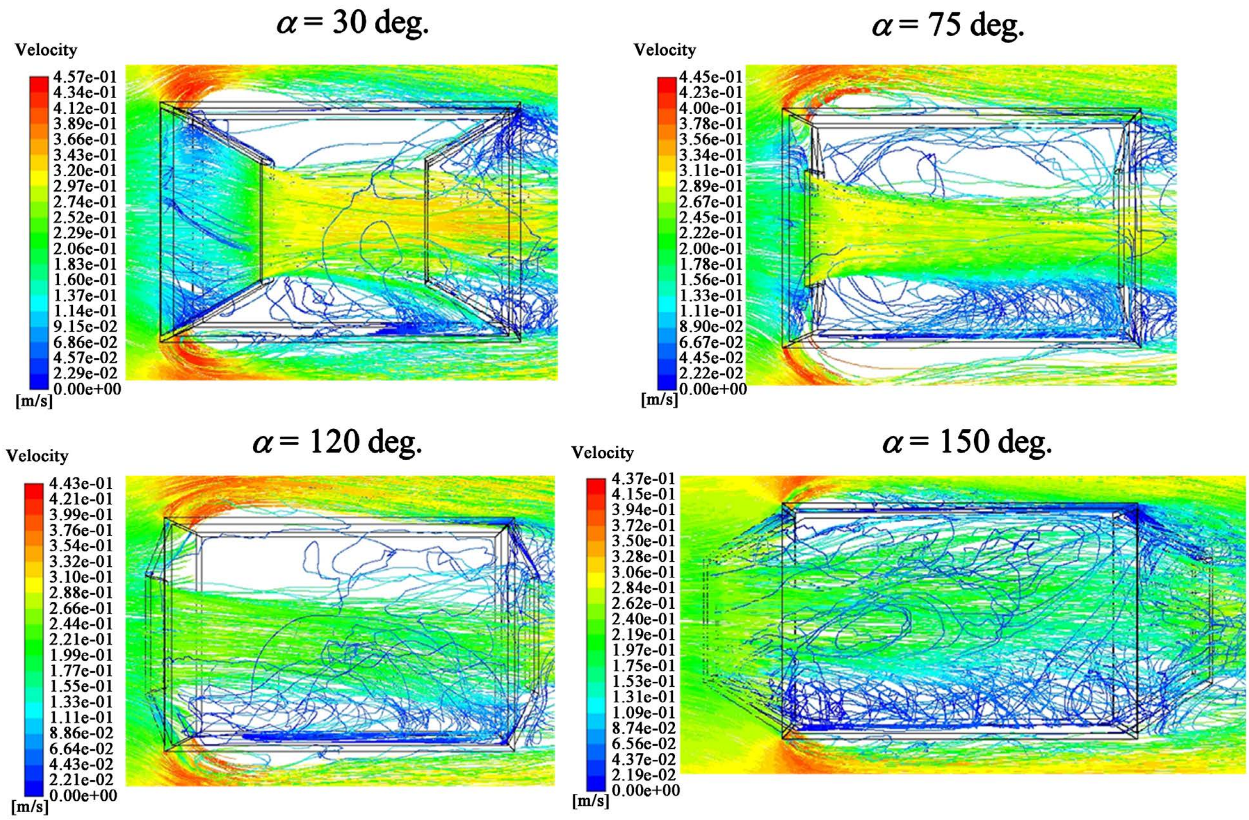

Figure 6. Particle tracks at $v = 0.3$ m/s.

On the other hand, in case with lower tilt angle around $\alpha = 45$ degrees, it seems that a lot of particles pass the recovery devices due to a short distance between inlet and outlet.

Figure 7 shows the streamlines on the vertical mid-plane at $v = 0.9$ m/s and 0.3 m/s in cases $\alpha = 120$ degrees, 135 degrees and 150 degrees. The vortex flow appears at both upper and lower in the device regardless of the velocity v in case $\alpha = 120$ degrees. Namely, the tilt angle $\alpha = 120$ degrees is recommended for microplastics collection.

3. Circulation Type Water Channel Tests

To clarify the capture performance of the recovery device, the circulation type water channel tests were carried out. The diameter of plastic particle in the experiment is 4 mm, the density of the plastic is 1080 kg/m^3. The effects of difference of density between plastics and surrounding liquid on the capture performance will be investigated in the future work. The plastic particle was discharged one by one from bottom of the pipe with inner diameter of 5 mm while counting the captured plastics. The discharge hole of plastics is located at about 100 mm upstream side from the upstream edge of recovery device and 40 mm lower side from the center of the device as shown in **Figure 8**. The flow behavior of the plastic particle was observed by a camera. **Figure 9** shows the numbers of captured plastics in three cases $\alpha = 45$ degrees, 120 degrees and 150 degrees. The captured plastics was defined as the plastics kept in the recovery device longer

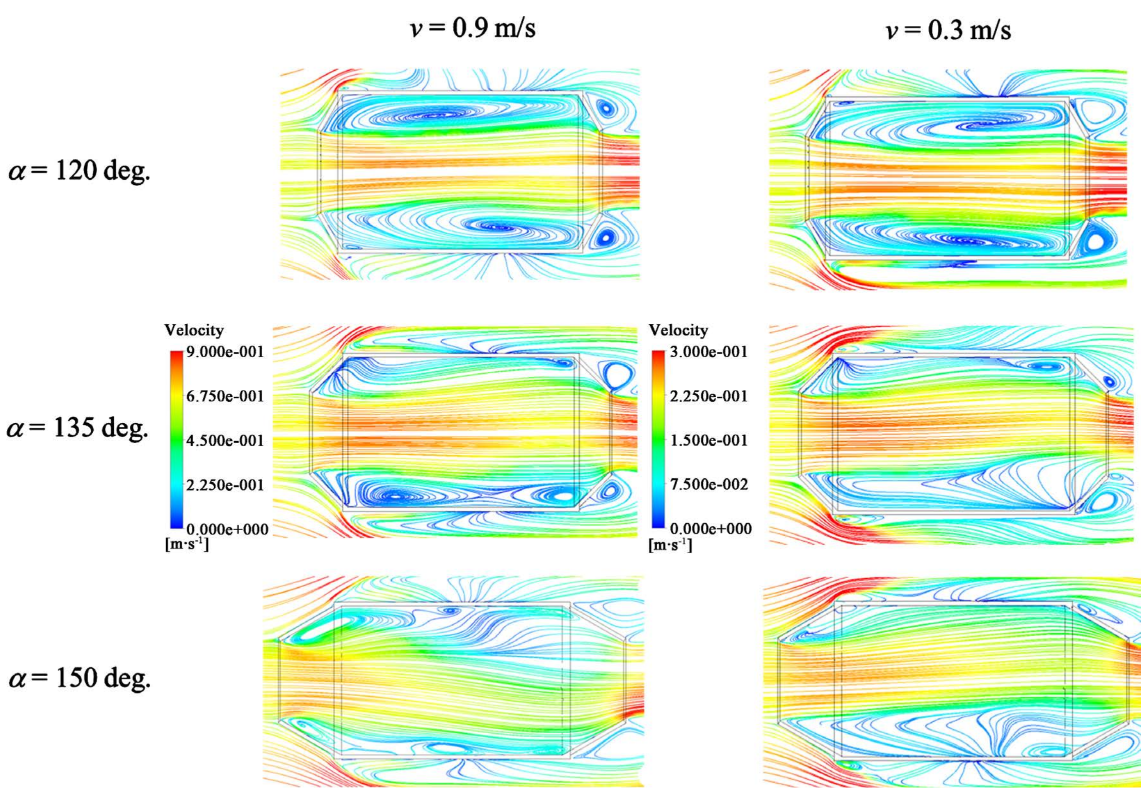

Figure 7. Streamlines on vertical mid-plane.

than about 30 seconds. For the practical use, the holding ability of microplastics in the period from capture to de-installation of this device is required, but it is the future research objective. Figure 10 is an example of flow behavior of captured plastic in recovery device at $v = 0.6$ m/s in case $\alpha = 120$ degrees. The flow velocity was varied in two cases 0.6 m/s and 0.3 m/s, the particle was swept away 30 times every flow velocity in each case of the tilt angle. As the results, the total captured times at $v = 0.6$ m/s and 0.3 m/s are 26 times in case $\alpha = 45$ degrees, 37 times in case $\alpha = 120$ degrees and 33 times in case $\alpha = 150$ degrees. In case $\alpha = 45$ degrees, the captured plastics number at $v = 0.6$ m/s is 9 and the number at $v = 0.3$ m/s is 17. These captured numbers are low compared with the case $\alpha = 120$ degrees as shown in above simulation results. In case $\alpha = 150$ degrees, many

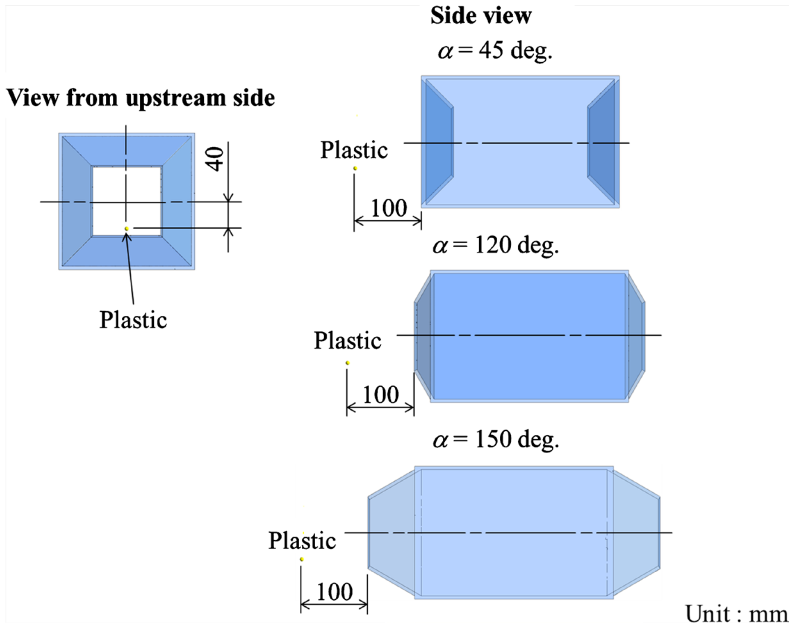

Figure 8. Discharge positions of plastics.

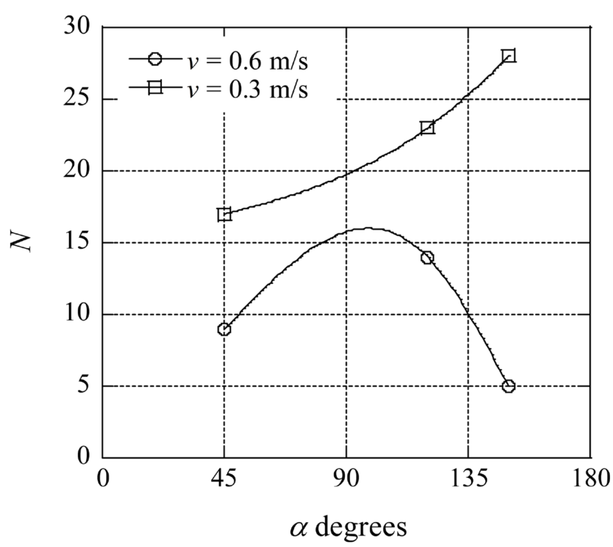

Figure 9. Numbers of captured plastics in experiments.

particles were discharged from the outlet at higher velocity 0.6 m/s, although a lot of plastics can be collected at lower velocity $v = 0.3$ m/s because of a wider bottom. On the other hand, in case $\alpha = 120$ degrees, the captured times are 14 at $v = 0.6$ m/s and the number of times at $v = 0.3$ m/s are 23. It is noticed that many plastics were trapped on average as shown in Figure 10. So, it seems that the tilt angle $\alpha = 120$ degrees is suitable for the wide range of the water flow velocity in river and ocean.

4. Conclusions

In this research, the effects of the flow velocity and the tilt angle α at inlet/outlet of the microplastics recovery device composed of plates on the capture performance were investigated experimentally and numerically. The concluding remarks are as follows.

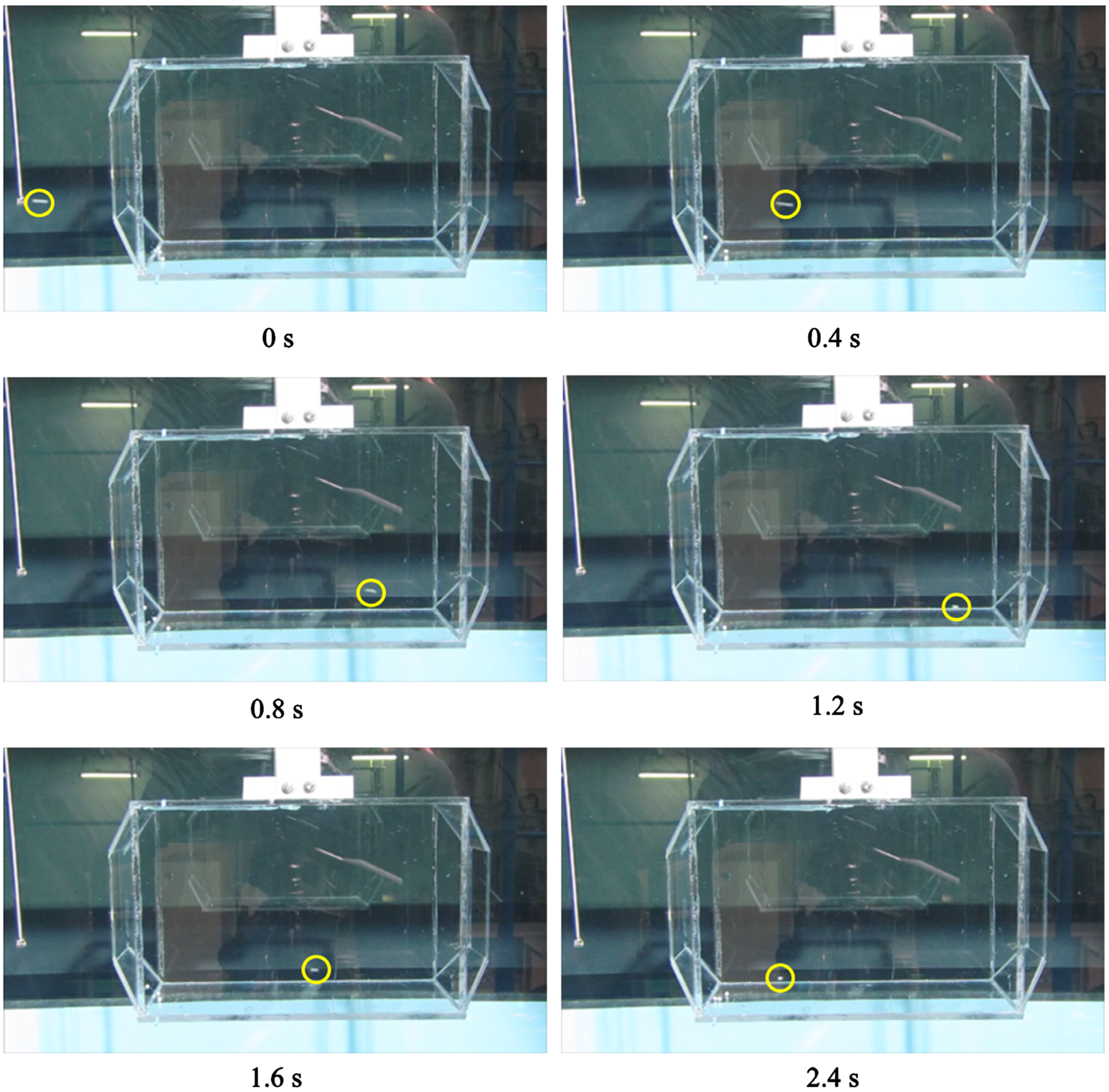

Figure 10. Example of flow behavior of captured plastic in recovery device at $v = 0.6$ m/s in case $\alpha = 120$ degrees.

1) The ratio of inlet velocity v_a and surrounding velocity v of about 0.78 on average can be achieved over the range between $\alpha = 45$ degrees and 150 degrees.

2) In case with lower tilt angle around $\alpha = 45$ degrees, a lot of particles pass the recovery devices due to a short distance between inlet and outlet.

3) In case $\alpha = 150$ degrees, many particles were discharged from the outlet at higher velocity $v = 0.6$ m/s, although a lot of plastics can be collected at lower velocity $v = 0.3$ m/s because of a wider bottom.

4) In the simulation results of the case $\alpha = 120$ degrees, the vortex flow was confirmed at both upper and lower in the device at $v = 0.9$ m/s and 0.3 m/s. It seems that the tilt angle $\alpha = 120$ degrees is suitable for the wide range of the water flow velocity in river and ocean.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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