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Separation of micro-plastics from sea water using electromagnetic archimedes force

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Abstract

Pollution of the environment by micro-plastics is now a worldwide problem. Plastics are difficult to decompose and put a great load on the marine environment. Especially a plastic with a size of 5 mm or less is defined as micro-plastic and are carried by ocean currents over long distances, causing global pollution. These are not easily decomposed in the natural environment. In this paper, we aimed to experimentally demonstrate that micro-plastics in seawater can be continuously separated by electromagnetic Archimedes force. Using polyethylene particles of 3 mm in diameter as the separation target, a flow channel was fabricated and separation conditions were investigated by particle trajectory calculations for separation experiments. Based on the calculation results, a solenoid-type superconducting magnet was used as a source of magnetic field to conduct separation experiments of micro-plastics in seawater. Although a high separation rate was assumed in the simulation results, the experimental results did not show any significant improvement in the separation rate due to the electromagnetic Archimedes force. It was found that the gas generated by the electrolytic reaction may have inhibited the migration of the particles.

Keywords: micro-plastics, electromagnetic archimedes force, superconducting magnet

1. INTRODUCTION

Plastics have become an integral part of modern life, and a report published by the OECD in 2022 reports that global consumption continues to grow. [1] Some of these plastics are leaking into the environment without proper management, accounting for as much as 22% in 2019. [1] It has been reported that the plastics released into the environment become microscopic in the process and become micro-plastics, causing pollution of the marine and atmospheric environments on a global scale. Currently, about 82% of the micro-plastics entering the ocean originate from Asian countries. Comparing the density of micro-plastics in the ocean, East Asia is reported to be a micro-plastics hotspot, about 16 times higher than the North Pacific and 27 times higher than the global average, making it a region where the adverse effects of micro-plastics are likely to occur ahead of time. [2]

Micro-plastics themselves are insoluble and are not considered to have direct adverse effects on the human body like chemical substances. However, seawater usually contains low concentrations of POPs (persistent organic pollutants) and micro-plastics can adsorb these chemicals and concentrate them to high concentrations. [3] Thus, there is concern about a scenario in which micro-plastics with high concentrations of adsorbed POPs are taken into the human body, resulting in adverse effects such as reproductive organ abnormalities, the development of deformities, and immune and neurological effects.

Based on the above background, our research gr has been studying a method to separate micro-plastics in seawater using Lorentz force. [4, 5] This method is based on the application of a magnetic field and electric current to seawater, and uses the reaction force of the Lorentz force acting on the plastic in seawater as the driving force to separate the plastic. This reaction force has been obtained by Leenov et al. [6] and is expressed by the following (1), where F is the electromagnetic Archimedes force applied to the particle, V is the volume of the particle, J is the current density, and B is the magnetic flux density. This basic theory has been used in several applied studies, such as the removal of nonmetallic inclusions in liquid metals using the electromagnetic Archimedean method by TAKAHASHI et al [7].

$$\mathrm{F} = -3/4\mathrm{V}(\mathrm{J} \times \mathrm{B}) \qquad (1)$$

In previous studies, we have shown that it is possible to separate polyethylene and polypropylene particles by appropriately controlling various parameters that affect separation efficiency, such as flow velocity, magnetic field strength, current density, and electrode length, depending on the particle size. [5]

The purpose of this paper is to experimentally demonstrate that it is possible to continuously separate micro-plastics in seawater. After building a separation device and studying the experimental conditions, we conducted a micro-plasticseparation experiment.

2. SEPARATION DEVICE

Fig. 1 shows the built flow channel. The flow channel has a total length of 1030 mm and a cross-sectional area of

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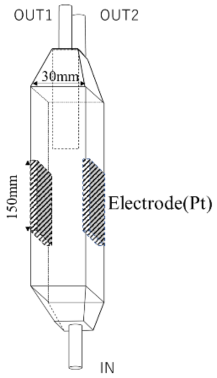

Fig. 1. Schematic diagram of the flow channel.

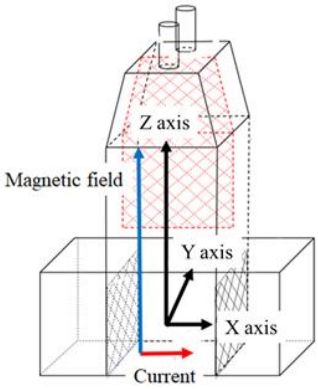

Fig. 2. Separation mechanism of plastic particles.

30 mm x 30 mm. Two platinum electrodes of 30 mm x 150 mm were placed opposite each other in the center of the channel, and a dividing plate was placed vertically above the electrode portion. At the upper end of the channel, two outlets were installed to collect plastic particles from one channel. Fig. 2 shows how plastic particles are separated using the apparatus shown in Fig. 1: a magnetic field in the positive direction of the z-axis and a current in the positive direction of the x-axis exerts Lorentz forces on the medium in the negative direction of the y-axis. If there are plastic particles, which are insulating spheres, the Lorentz force is not applied only to the area where the insulating spheres exist, and as a result, the reaction force of the Lorentz force, in other words, electromagnetic Archimedes force, acts on the plastic particles in the positive direction on the y-axis. Therefore, it is considered possible to unevenly distribute plastic particles in OUT2 channel in this condition.

Fig. 3 shows the experimental system. A solenoid-type superconducting magnet with a maximum applied field of 7 T and a bore diameter of 50 mm was used as the magnetic field source, and the flow channel was installed so that the area where electrodes were installed overlapped the area where the magnetic field was applied by the superconducting magnet. The current was applied using a DC power supply that can apply a voltage up to 20 V. Care must be taken in the experiment because the electrolysis of seawater produces chlorine gas when an electric current is applied. The plastic particles were pumped vertically from bottom to top, and the electromagnetic Archimedes force was applied to the particles in the region where the current and magnetic field were applied.

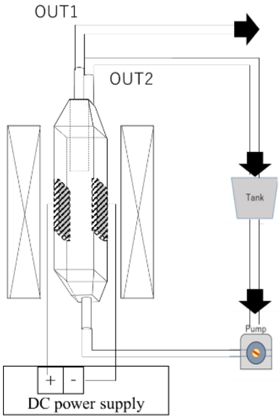

Fig. 3. experimental system.

3. CALCULATIONS TO DETERMINE SEPARATION CONDITIONS

In this paper, we decided to perform particle separation using polyethylene particles with a diameter of 3 mm and a density of 0.95 kg/m3 and simulated seawater with a density of 1.03 kg/m3, which is a 3.5 wt% sodium chloride solution, and examined the conditions necessary for separation, such as flow velocity, current density, and magnetic field, through particle trajectory calculation. Based on the following (2) and (3), particle trajectory was calculated by the Euler method. where F_z in equation (2) refers to the combined force acting on the particle in the z-axis direction, m is the weight of the particle, g is the gravitational acceleration, V is the volume of the particle, η is the viscosity coefficient of the fluid, r is the radius of the particle, v_z is the z-axis velocity of the particle, v_{fz} is the z-axis velocity of the fluid, and F_x in equation (3) refers to the combined force acting on the particle in the x-axis direction, v_x is the x-axis velocity of the particle, v_{fx} is the x-axis velocity of the fluid.

$$\mathrm{F_z} = -\mathrm{mg} + \mathrm{Vg} - 6\pi\eta\mathrm{r}(v_z - v_{\mathrm{fz}}) \tag{2}$$
$$\mathrm{F_x} = -3/4\mathrm{V}(\mathrm{J} \times \mathrm{B}) - 6\pi\eta\mathrm{r}(v_x - v_{\mathrm{fx}}) \tag{3}$$

The particle trajectory calculation was performed from the point when the particles reached the bottom of the electrode. The velocity distribution in laminar flow is assumed for the fluid. The vertical velocity of particle at this point was calculated taking into account the buoyancy, gravity, and drag forces applied vertically to the particles between the inlet at the bottom of the flow path and the bottom of the electrode. After the calculation, the time step was changed by one digit, the calculation was performed again, and the convergence of the calculation was confirmed by check that the calculation result did not change.

Fig. 4 shows the results of particle trajectory calculations for a flow velocity of 1.3 cm/s and a magnetic field of 3 T, while varying the current. From these results, it was assumed that by setting the current to 2 A or higher, particles reach the channel wall before reaching the top of the electrode, and a separation efficiency close to 100% can be obtained.

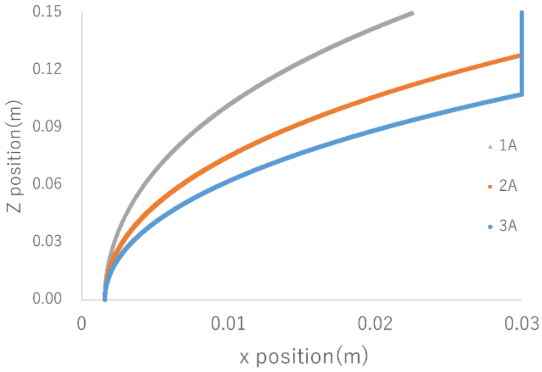

Fig. 4. Particle Trajectory Simulation of Polyethylene Spheres.

Based on these results, the experimental conditions were set as follows: the flow velocity, particle diameter and material, magnetic field, mean flow velocity are set as the same of calculation. The current was varied from 0 to 3 A. When the simulated seawater containing plastic spheres was actually poured into the channel, the channel was filled with the simulated seawater in advance, and the polyethylene spheres, the particles to be separated, were poured into the channel after the magnetic field and electric current were applied to it.

4. RESULTS AND DISCUSSION OF SEPARATION EXPERIMENTS

Fig. 5 shows the separation rate of plastic particles. Here, the horizontal axis is J x B and the vertical axis is the separation rate of plastic. The separation ratio is the ratio of the number of plastic particles collected from the outlets in the y-coordinate fence area to the number of plastic particles fed into the system, and was calculated using (4). The results shown in Fig.5 indicate that the separation ratio was 55%, roughly a 1:1 ratio, under the condition of no current flow, confirming that the flow path was designed so that the flow of the medium in the channel was symmetrical. The separation ratios when magnetic and electric fields were applied were 48% and 41% for the conditions with 2.25 A and 3 A of current flow, respectively. Although the separation ratio was assumed to be higher due to the reaction force of the Lorentz force, there was no significant difference compared to the case in which no magnetic field and current were applied.

$$\text{separation rate} = \frac{\text{Number of particles from OUT2}}{\text{Number of particles in the inlet}} \qquad (4)$$

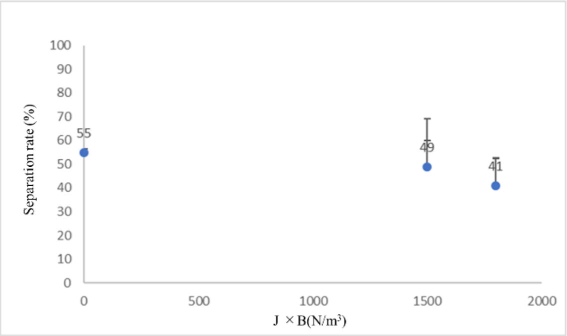

Fig. 5. Results of polyethylene sphere separation experiments.

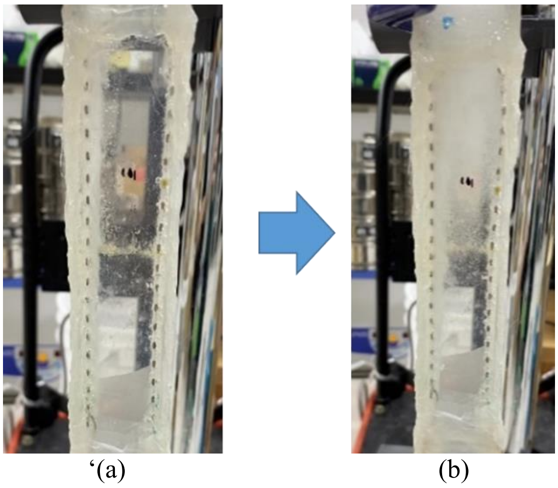

Fig. 6. Gas generation by electrolysis.
(a) is immediately after the start of electrolysis and (b) is time after the start of electrolysis.

One possible reason for the low separation rate of polyethylene spheres, despite the high separation rate expected from the particle trajectory calculation results shown in Fig. 4, is the inhibition of particle migration by the gas produced by the electrolysis reaction. Fig. 6 shows the behavior of gas produced by electrolysis in the channel. After the start of electrolysis, the gases generated from the electrode surface on the channel wall initially move vertically upward near the channel wall as shown in Fig. 6(a), but then quickly spread to the center of the channel as shown in Fig. 6(b). These gases could inhibit the horizontal movement of the polyethylene particles. The formation of such gases was not taken into account in the particle trajectory calculation, which may explain the large discrepancy between the simulation and experimental results. The bars in Fig. 5 show the variation of the separation ratio, with the upper end representing the maximum value and the lower end the minimum value. The results show that the experimental results with no magnetic field and current applied have a small variation, whereas the experimental results with magnetic field and current applied have a larger variation. This suggests that the experimental conditions may not be steady, which is consistent with the influence of gas behavior.

5. CONCLUSION

In this study, we have conducted experiments to demonstrate the feasibility of the separation of microplastics in seawater based on the electromagnetic Archimedes force. As a result, the separation rate of polyethylene spheres under the condition of applying electric current density and magnetic field did not change or the separation rate decreased compared to the condition without applying electric current and magnetic field. This result was different from that assumed by the simulation. The reason for this discrepancy between the simulation and experimental results was thought to be the effect of gas from the electrolytic reaction. In the future, it is necessary to construct a system in which gas does not interfere with the migration of plastic particles in the separation region. Specifically, if the superconducting magnet and flow path are rotated by 90° and the particles flow in a horizontal direction, rather than in a vertical direction as in this paper, the gas generated from the electrode is expected to flow along the edge of the flow path, thus reducing the obstruction to the movement of microplastic particles by the gas. This is thought to reduce the obstruction to the movement of microplastic particles by the gas.

REFERENCES

[1] Organisation for Economic Cooperation and Development, Global Plastics OutlookEconomic Drivers, Environmental Impacts and Policy Options, 2022

[2] Atsuhiko Isobe, Keiichi Uchida, Tadashi Tokai, Shinsuke Iwasaki,East Asian seas: A hot spot of pelagic micro-plastics,Marine Pollution Bulletin,Volume 101, Issue 2,2015,Pages 618-623

[3] Mato Y, Isobe T, Takada H, Kanehiro H, Ohtake C, Kaminuma T. Plastic resin pellets as a transport medium for toxic chemicals in the marine environment. Environ Sci Technol. 2001 Jan 15;35(2):318-24.

[4] N. Nomura, F. Mishima, and S. Nishijima, Study of micro-plastics separation from sea water with electro-magnetic force, Progress in Superconductivity and Cryogenics Vol.23, No.3, 2021, pp.10~13

[5] N. Nomura, F. Mishima, and S. Nishijima: Study of micro-plastics separation from sea water with electro-magnetic force, IEEE, Transactions on applied superconductivity, Vol. 32, No. 6, September 2022

[6] D. Leenov and A. Kolin, “Theory of Electromagnetophpresis I. Magnetohydrodynamics Forces Experienced by Spherical and Symmetrically Oriented Cylindrical Particles”, J Chem.Phys.22 (1954) 683-688

[7] Koichi Takahashi and Shoji Taniguchi, ISIJ International, Vol. 43 (2003), No. 6, pp. 820–827