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RESEARCH ARTICLE

# Removal of Microplastics by Absorption on Kelp and By Flocculation Using Kelp Extract Coagulant or Flocculant

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ABSTRACT: Microplastics (MPs), less than 5 mm in size, have toxic effects on marine life, threatening ecosystems and human health. To tackle this problem, an experiment was conducted to test a method to remove MPs from water using the absorption force of kelp. There was no significant relationship between the duration of the kelp's exposure and the number of absorbed MPs. However, an unexpected result was observed: instead of being absorbed onto the kelp, the MPs formed flocs and precipitated to the bottom of the beakers. Based on this observation, I hypothesized that alginate, a substance eluted from kelp, acted as a flocculant and precipitated the MPs. I conducted an additional experiment to determine whether alginate can remove MPs in water. While the kelp extract containing alginate acted as a coagulant rather than a complete flocculant, it still managed to remove up to 39% of the MPs from the supernatant water through flocculation. While the initial experiment suggested that using kelp's absorption force may not be feasible, the second experiment demonstrates the potential for using kelp extract as an environmentally friendly substitute for existing toxic coagulants to remove MPs in water treatment.

KEYWORDS: Environmental Engineering, Pollution Control, Microplastics, Kelp.

## Introduction

Microplastics (MPs), typically less than 5 mm in length, invade virtually every place on the earth. This increasing ecological threat has been potentially harming environmental and human health through direct and indirect food chain interactions.[1] The most common MPs found in the marine environment are polyethylene (PE), polypropylene (PP), polystyrene (PS), polyamide (PA), polyester (PES), and acrylic (AC).[2] Past studies suggested that neutral or positively charged PS particles possess a higher binding affinity for microalgae than negatively charged particles.[3] Therefore, an affinity of MPs for algal surfaces depends on the surface charges of both MPs and algae.[4] If MPs were absorbed into kelp, it would be due to their electrical attraction.

Alginate, a substance secreted by kelp, can also contribute to MPs absorbing to kelp. Kelp is rich in algin, a high molecular weight polysaccharide that forms viscous colloidal solutions or gels in water.[5] Free carboxyl groups in alginate allow it to form hydrogen and electrostatic bonding.[6] This results in the unique property of alginate, an ability to react with polyvalent metal cations, especially calcium ions, to produce strong gels or insoluble polymers.[7] The release of alginate influences the adhesion of PS particles due to the gelatinous properties of alginate.[4] Therefore, alginate could be the factor that causes the absorption.

In addition, removing MPs during the water treatment involves coagulation and flocculation. Coagulation is the process by which a coagulant neutralizes the charges of contaminant particles so that the particles do not become polar.[8] When a positively charged material is added to neutralize negatively charged colloidal particles, it eliminates the repulsive force between them, acting as a coagulant.[9] Then, the coagulant and the particles stick together by Coulombic force and Van der Waals force to form small flocs.[8] These small flocs have a larger size and a higher precipitation rate than the existing particles, but a larger floc must be formed to precipitate completely.[8] Therefore, a flocculation polymer is added to form larger flocs, and this process is called flocculation.

Furthermore, the current water treatment process, which uses an aluminum-based coagulant such as poly aluminum chloride (PAC), is toxic to crops, inhibiting root elongation and seed germination.[10] Also, alum, a polymer, has been reported to have acute earthworm toxicity.[11]

## Methods

Two separate experiments were conducted to investigate the absorption and flocculation of microplastics (MPs) by kelp.

***Experiment 1: Absorption of Microplastics to Kelp:***

The first experiment was designed to test the hypothesis that the longer the microplastics are exposed to kelp, the more absorbed MPs. This experiment investigated the absorption of microplastics (MPs) onto kelp (*Laminaria japonica*) over time. The materials used included a plastic bottle (PET), a cookie tray (PS), a cap of a bottle (HDPE), a piece of sandpaper, 5 beakers, a tweezer, 18 pieces of filter paper, a microscope, 5 Petri dishes, a 3-digit scale, 90g of kelp (8 strands), plastic wrap, 95% ethanol, 1,140 mL of distilled water, a funnel, and a cup.

The MPs were first prepared by grinding the plastic bottle, cookie tray, and bottle cap into a powder using sandpaper, with the particle size ranging from 40μm to 125μm. Then, 0.300g of each MP type was measured and mixed evenly in a Petri dish. Four beakers were labeled with different durations (Day 1, Day 2, Day 3, and Day 4), and one was labeled "No Kelp." In each



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of the 5 beakers, 0.050g of the MP mixture was placed, and 100 mL of distilled water was added and stirred. Next, 10.230g of kelp was added to the 4 beakers, while the "No Kelp" beaker remained without kelp. All 5 beakers were then wrapped with plastic wrap.

After 24 hours, the kelp was removed from the "Day 1" beaker, and the mixture was filtered using a funnel and filter paper to collect the remaining MPs. The beaker was rinsed with 95% ethanol, and the ethanol was also poured onto the filter paper to ensure the collection of all the MPs. The filter paper was then dried, and the mass of the MPs was weighed. This process was repeated for the other beakers on their respective days, and the "No Kelp" beaker was also filtered at the end of the 4 days. Finally, each kelp from all 4 beakers was observed under a microscope. This experiment was repeated for a second trial.

***Experiment 2: Flocculation of Microplastics by Kelp Extract:***

The second experiment was designed to test the hypothesis that kelp extract will flocculate the microplastics, causing the MPs to form flocs and precipitate to the bottom of the beakers, effectively removing them from the supernatant water. This experiment investigated the flocculation and precipitation of MPs using various concentrations of kelp extract. The materials used included a plastic bottle (PET), a cookie tray (PS), a cap of a bottle (HDPE), a piece of sandpaper, 6 beakers, a tweezer, 18.324g of dried kelp, a 3-digit scale, 1,200 mL of distilled water, and 12 pieces of filter paper.

The MPs were prepared in the same manner as in Experiment 1, with 0.300g of each type of MPs mixed evenly in a Petri dish. The kelp extract was prepared by placing 18.324g of dried kelp in a bowl with 200 mL of distilled water and leaving it for 12 hours to extract the kelp compounds.

Six beakers were labeled with different concentrations of kelp extract: 0%, 2%, 4%, 6%, 8%, and 10%. The appropriate kelp extract and distilled water volumes were added to each beaker, ensuring the total volume was 100 mL. Then, 0.025g of the MP mixture was added to each beaker.

After 24 hours, the supernatant water (top 3cm) from each beaker was filtered, and the mass of the remaining MPs was measured. This experiment was not repeated, as the initial results were sufficient to test the hypothesis.

## Result and Discussion

Table 1 displays the remaining mass of microplastics in the beakers after removing kelp in Trial 1, while Table 2 represents Trial 2. We calculated the average mass for each day in both trials and then recalculated the average mass shown in Table 3 for all four days combined.

**Table 1:** The mass of the microplastics remaining in the beakers after removing the kelp in Trial 1.

| Duration of the MPs Exposed to the Kelps in Water | Mass of the Filter Paper (g) | Mass of the Filter Paper After Filtering out the MPs (g) | Mass of the MPs Remaining in the Beaker (g) |
|---|---|---|---|
| Day 1 | 1.080 | 1.266 | 0.186 |
| Day 2 | 1.097 | 1.331 | 0.234 |
| Day 3 | 1.062 | 1.290 | 0.228 |
| Day 4 | 1.078 | 1.225 | 0.147 |
| No Kelp | 1.063 | 1.153 | 0.090 |

**Table 2:** The mass of the microplastics remaining in the beakers after removing the kelp in Trial 2.

| Duration of the MPs Exposed to the Kelps in Water | Mass of the Filter Paper (g) | Mass of the Filter Paper After Filtering out the MPs (g) | Mass of the MPs Remaining in the Beaker (g) |
|---|---|---|---|
| Day 1 | 1.079 | 1.146 | 0.067 |
| Day 2 | 1.097 | 1.174 | 0.077 |
| Day 3 | 1.085 | 1.167 | 0.082 |
| Day 4 | 1.062 | 1.141 | 0.079 |
| No Kelp | 1.057 | 1.109 | 0.052 |

**Table 3:** The average mass of the microplastics remaining in the beakers from Trial 1 and Trial 2.

| Duration | Average Mass of the MPs (g) |
|---|---|
| Day 1 | 0.1265 |
| Day 2 | 0.1555 |
| Day 3 | 0.155 |
| Day 4 | 0.113 |
| No Kelp | 0.071 |

Figure 1 shows two bars representing the average mass of two groups. The left bar represents the average mass of beakers labeled as Days 1 to Day 4, while the right bar represents the average mass labeled as "No Kelp." The graph indicates that the average mass of the Days 1 to Day 4 beakers is 37% higher than that of the "No Kelp" beakers. This suggests that the microplastics were not significantly absorbed into the kelp.

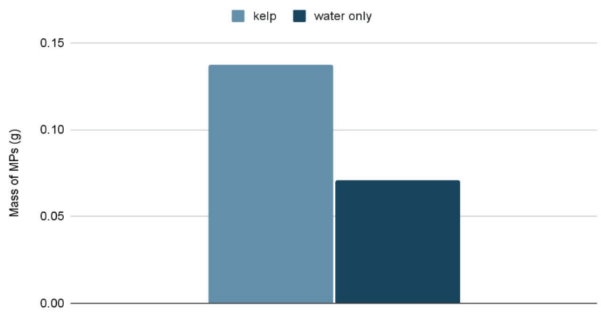



**Figure 1:** The average mass of the MPs remaining in the beakers.

Figure 2 illustrates the relationship between the duration of microplastic exposure to kelp and the remaining mass after each day. The low $R^2$ value indicates a lack of correlation between the duration and the amount of microplastics absorbed into the kelp suggesting that kelp does not possess a strong ability to absorb microplastics.

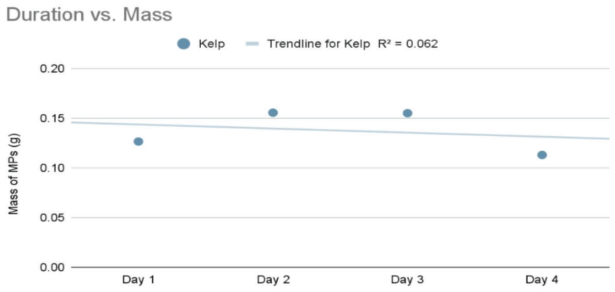
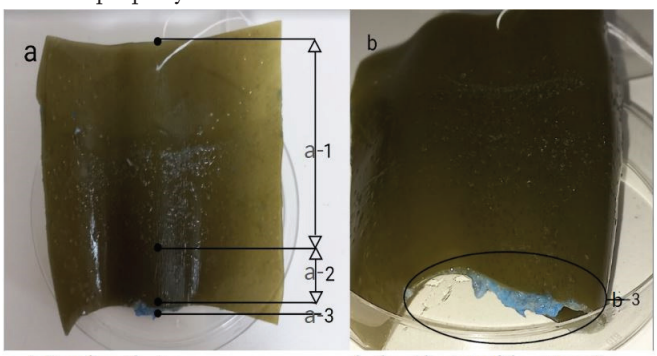



**Figure 2:** The duration of the MPs exposed to the kelp.

Moreover, as shown in Figure 3, some of the MPs were absorbed into the a-1 and a-3 sections of the kelp, and they were hardly observed in the a-2 section (1 particle/5mmx5mm according to the microscopic view). They were absorbed to the a-1 section mainly because when lifting the kelp out of the water, they were absorbed into the kelp supposedly due to the adhesive property of water.




*a-1. 8cm from the top*

*a-2. 2cm from the cut section*

*a-3. the cut section*

*b. the side view of the cut section*

**Figure 3 (left):** The kelp was removed from the Day 1 beaker of Trial 1.

**Figure 4 (right):** Close-up of the kelp removed from the Day 1 beaker of Trial 1.

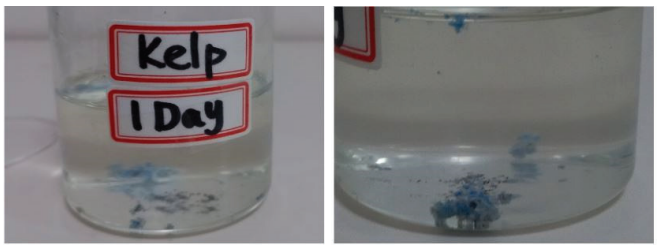



**Figure 5:** Most of the microplastics cohered together and sank to the bottom of the beakers.

This observation indicates that the kelp did not absorb a significant amount of the MPs, but rather, most of the MPs cohered and sank to the bottom of the beakers, which led me to conduct Experiment 2.

***Result of Experiment 2:***

Experiment 2 is designed to determine the ability of alginate to remove microplastics in water. In this experiment, the amount of microplastics removed from supernatant water was measured at 6 different concentrations of the kelp extract solutions: 0, 2, 4, 6, 8, and 10%.

Table 4 below represents the mass of the microplastics remaining in the supernatant water of each beaker (3cm from the surface) after 24 hours, which indicates the mass of the MPs that have not been removed by flocculation.

**Table 4:** Mass of the MPs in supernatant water of each beaker.

| | Mass of the Microplastics in Supernatant Water | | | |
|---|---|---|---|---|
| Concentration | Trial 1 (g) | Trial 2 (g) | Average (g) | Percent Change from the 0% Solution (%) |
| 0% | 0.048 | 0.033 | 0.041 | - |
| 2% | 0.028 | 0.023 | 0.026 | -37% |
| 4% | 0.024 | 0.027 | 0.026 | -37% |
| 6% | 0.024 | 0.026 | 0.025 | -39% |
| 8% | 0.032 | 0.030 | 0.031 | -24% |
| 10% | 0.029 | 0.027 | 0.028 | -32% |

Figure 6 shows the microplastics in the 0% solution and the coagulated microplastics in the 2%, 4%, 6%, 8%, and 10% solutions.

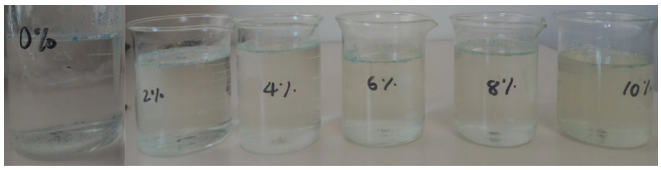



**Figure 6:** MPs are shown in 0% solution and coagulated in 2-10% solutions.

Figure 7 below shows the relationship between the concentration of kelp extract and the mass of microplastics in supernatant water. The values are from Table 4.

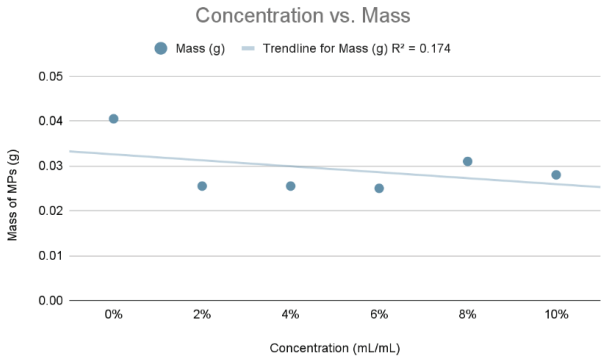



**Figure 7:** The concentration of the kelp extract and the mass of the MPs in supernatant water.

The result of Experiment 2 shows that there is no kelp extract solution in which flocculation of the MPs occurred superiorly (Figure 7). According to Figure 5, the MPs were observed to coagulate in every kelp extract solution but did not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wholly flocculate to precipitate. However, all of the kelp extract solutions showed lower amounts of the MPs in supernatant water than the 0% solution, and the greatest difference is 39% in the 6% solution (Table 4). This result can be explained by the electrical attraction between the kelp extract and MPs.[12] This means kelp extract can remove a maximum of 39% of MPs in water.

Overall, kelp does not significantly remove MPs from water by absorption, but kelp extract can coagulate MPs and eventually remove them in water.

## Conclusion

In summation, this study demonstrated the removal of microplastics (MPs) using the absorption force of kelp (Experiment 1) and the removal of MPs by flocculation using kelp extract (Experiment 2). My hypothesis for Experiment 1 was rejected because the duration of the MPs exposed to the kelp did not influence the amount of the MPs absorbed. However, I discovered that the MPs cohered, and some even sank to the bottom of the beakers, so I questioned the cause of this phenomenon.

I noticed that the mass of the filter paper — the mass of the MPs that had not been filtered — was greater than the mass of the MPs put into each beaker. This shows that there was something other than the MPs on the filter paper that did not dry out, and it suggests that an unknown substance cohered the MPs and worked as a coagulant. Since alginate, a substance eluted from kelp, can form electrostatic bonding, it can interact with electrostatically charged MPs, coagulating or flocculating. Hence, I concluded that alginate worked as a coagulant or a flocculant, and it led me to design Experiment 2 to test whether alginate functioned as a coagulant or a flocculant in removing the MPs. My hypothesis was partially accepted. The MPs were observed to coagulate in all the kelp extract solutions, but only some entirely flocculated and precipitated.

I faced some problems during the experiments because my experiments' precision and accuracy were low. The difference between the values of the collected kelp in Trial 1 and Trial 2 of Experiment 1 ranged from 0.068 to 0.157, and the difference was 0.038 for the "No Kelp" beaker. The large numerical values of these differences indicate that the experiment was conducted with low precision. The most crucial source of error was the substance released from the kelp on the filter papers. It increased the calculated mass of the MPs remaining in the water, so their remaining mass was greater than their original mass. Another source of error was the less accurately measured mass of the MPs. Due to the limited equipment, the readability of the scale I used was 0.001g, thus decreasing accuracy. These errors could be solved by using a different method of measuring the mass of MPs in water. For example, instead of filtering out MPs, measuring the turbidity of solutions could improve precision, and using a scale with smaller readability could increase accuracy.

Despite the partial acceptance of my hypothesis, the kelp extract succeeded in removing a maximum of 39% of the MPs by flocculation. We can apply this method to the current water treatment process and replace existing coagulants containing toxicity. Due to their biodegradability, kelp could be an environment-friendly alternative to toxic coagulants. To practicalize the usage of kelp extract as a coagulant, future studies such as discovering an ideal flocculant that can function with kelp extract and testing perfect environmental conditions, like identifying pH to optimize precipitation rate, could be done.

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