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Styrofoam Particle Collector for Use of Coastal Cleanup using Electrostatic Effect and Van de Graaff Generator

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ABSTRACT

According to the California coastal commission, more than 26,000 volunteers throughout California removed more than 300,000 pounds of trash from beaches and waterways during the California Coastal Cleanup 2021 event.[1] I participated in Long Beach's 'California Coastal Cleanup Day'[2] and noticed many small, cultch like particles such as styrofoam that mingled within the sand across the entire coastal region. Upon closer examination, I have also learned that styrofoam is a particularly dangerous type of pollution that poses a great threat to humans, the environment, and animals.[3] I attempted to collect the styrofoam particles by hand and found it incredibly difficult to effectively pick up the pieces that litter our beaches. I have conducted further research on styrofoam and found that its chemical makeup can become electrostatically charged and mobilized under the influence of an electrostatic field. In this letter, I propose a styrofoam particle collector where the operational principle employs the electrostatic effect and the Van de Graaff generator. I also performed experiments to validate the working mechanism of the device. Finally, using a 3D modeling software and a 3D printer, the styrofoam particle collector was designed, integrated and successfully demonstrated. As a result, it is highlighted that the proposed idea is a very cost-effective method and could be scaled up in size to effectively clean up the small styrofoam particles mingled within the sand in the coastal area of Long Beach, CA as well as other areas where the styrofoam particles appear to be a major pollutant.

Introduction

Marine debris essentially includes any trash that ends up in a marine environment. It originates from a wide variety of places and often travels great distances before ending up in the ocean. No matter how remote, marine debris is found in every body of water on the planet and along every shoreline in the world. Thus, marine pollution is a global problem that impacts human health and safety, endangers marine wildlife, and costs millions in wasted resources and lost revenues.[1-4]

The major characteristics of plastic pollution in the environment and their threats to the natural surroundings and human health have been systematically reviewed.[4] Styrofoam contains polystyrene which breaks down slowly given that its atoms are bonded to one another so strongly, which makes the plastic repel water and resist acids, bases, salts, and other corrosive substances. Most of the polystyrene that ends up in landfills can take anything between 500 to 1 million years to fully decompose. Thus, Styrofoam is one of the most harmful types of environmental waste that exists today and poses an immense threat to our planet's ecological system.[3-5]

It was also reported that plastic components were found in human organs.[6] Plastic pollution creating micro plastics is a growing concern for human health. Emerging studies show that these pollutants are found everywhere: from drinking water to ocean water, and from insects to birds. A recent publication states that the Atlantic Ocean contains far more plastic pollution than previously estimated. The World Health Organization urgently called for more research to be conducted on the impacts of micro plastics on human health.[6, 7]

Due to the harmful effect of styrofoam, many cities, states, and countries have banned the commercial use of styrofoam, including California, Seattle, Washington, Manila, Philippines, Toronto, Canada, Paris, France, Portland Oregon, and Taiwan.[5] For example, the mayor of the city of Long Beach signed into the law an ordinance that bans styrofoam food containers.[8] This law will phase out the distribution of these single-use plastic products that find their way into our rivers and the ocean. The ban would extend to styrofoam take out containers, plastic cups, non-recyclable food containers, ice chests, bean bags, and even craft items made with polystyrene beads.[8-11]

I have joined the California Coastal Cleanup Day program[2] since 2021 and quickly recognized the problems with marine debris. The particular debris that has caught my attention was this styrofoam debris which are often very small, white colored particles as shown in **Figure 1**. This helped me realize the importance for a particle collector for such miniscule styrofoam debris, as it would greatly help the cleanup efficiency of marine debris.

Therefore, I have performed more research on styrofoam and its properties, and found that the styrofoam debris can become charged electrostatically and made mobile within a short distance under the influence of an electrostatic field. Thus, by applying the electrostatic field, styrofoam could be easily separated from sand and collected effectively. The purpose of this paper is to propose a concept of a styrofoam particle collector and also to demonstrate the performance of the prototype collector which is built based on the electrostatic effect and the Van de Graaff generator. Finally, this paper highlights the successful demonstration of the mini-styrofoam particle collector that can be scaled-up in size in order to effectively clean up styrofoam particles from the coastal areas without complications, which is also a cost effective method.

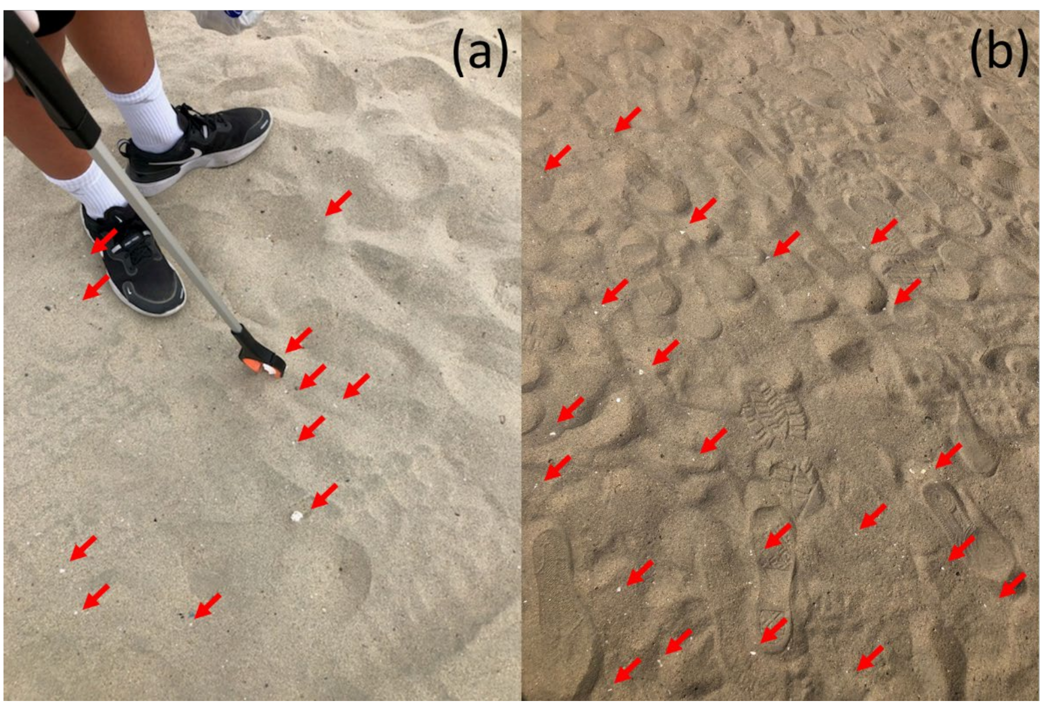

Figure 1. A photo showing the varied styrofoam particle sizes scattered on the Long Beach coastal area. Large styrofoam particles can be separated from the coastal sand mixture; however, many small styrofoam particles are not easily collectable. The red arrows in this figure indicate the styrofoam particles which are small in size. This photo was taken on September 18, 2021 (the California Coastal Cleanup Day program) in Long Beach, CA. (Figure 1a) showing larger styrofoam particles and (Figure 1b) smaller styrofoam particles.

Materials and Methods

Matter consists of positively charged protons and negatively charged electrons.[12, 13] Most materials possess an equal number of protons and electrons, which creates a situation where it is electrically neutral; styrofoam also consists of protons and electrons. By removing or shifting outer electrons from the object, styrofoam particles can become electrically charged. The charged styrofoam particles can be attracted to the oppositely charged electrode. Here, the basic mechanism of the electrostatic effect and the Van de Graaff generator that are a part of this research is briefly described as follows.

Electrostatic Effect

The electrostatic effect is created when static electricity is in use. Static electricity is caused by an imbalance of the electrical charge between dielectric materials. This form of electricity can occur either within or on the surface of materials. The charge will continue to remain on an object until there is a means to have an electrical current or electrical discharge. Static electricity is different from an electric charge because a charge flows through a conductor and transmits energy; however, static electricity is created when two surfaces are in contact and rubbing against each other where at least one of the surfaces is highly resistant to an electrical current.[14]

Van de Graaff generator

The Van de Graaff generator, or electrostatic generator, utilizes a moving rubber belt as a means to accumulate an electric charge. It has the capability to produce high voltage electricity with low current values. The generator was invented by Robert J. Van de Graaff, an American physicist, in 1929.[15] The detailed description of the Van de Graaff generator can be found in the literature[15, 16] and a simple version of it as a product is commercially available from Arbor Scientific.[17]

Proposed Electrostatic Styrofoam collection mechanism

Figure 2 illustrates a schematic diagram of a proposed styrofoam particle collector that uses an electrostatic field supplied by a Van de Graaff generator. The force is also known as Coulomb interactions or Coulomb force. Coulomb interactions show that like charges repel each other while opposite charges attract each other. The basic understanding of the working principle is explained as the following three stages. **Stage (a)**: there are styrofoam particles mixed within the sand that are uncharged. **Stage (b)**: the high voltage supplied by a Van de Graaff generator between two electrodes (one is positive and the other one is negative) generates the electrostatic field. This causes the electrostatic attraction force that in turn leads to a situation where styrofoam is being charged and then is attracted to the electrodes. Thus, as a result of the electrostatic force, the charged styrofoam particles drift to the electrodes. **Stage (c)**: Since particles adhere weakly to the electrodes, they can be collected by an air suction tool.

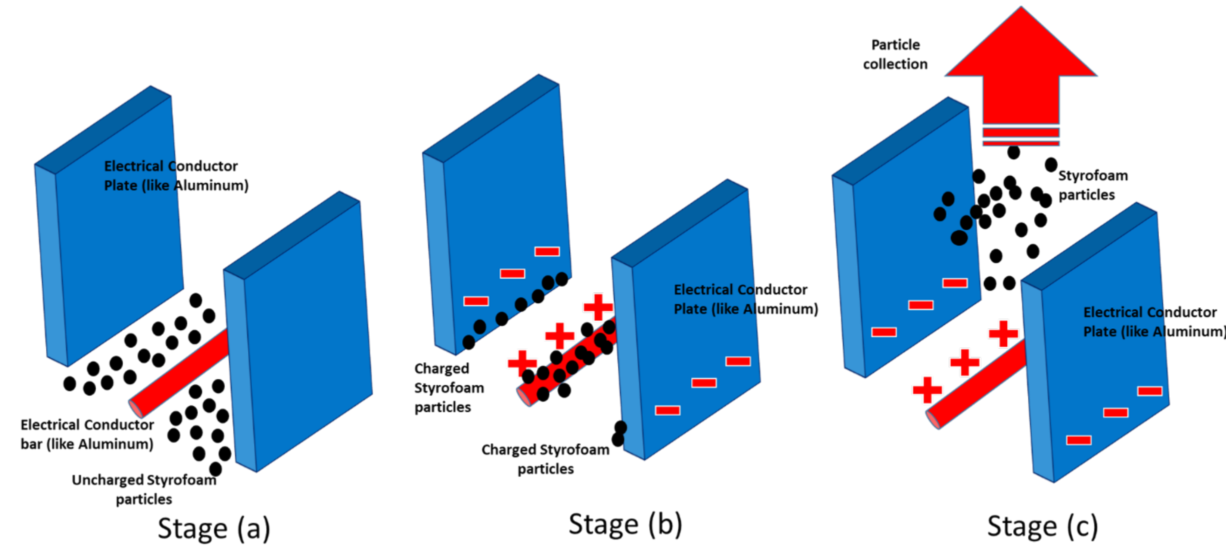

Figure 2. Diagram of the electrostatic styrofoam collector explaining the principle of the electrostatic styrofoam collection mechanism. (Stage a) when there is no electric field, the styrofoam particles are not moving, (Stage b) by applying the electrostatic field, the particles can be attracted electrostatically and be caused to drift toward to the electrodes, (Stage c) the styrofoam can be collected effectively by an air suction tool. In this experiment, the metal electrodes are made using aluminum plates and aluminum bars.

Results and Discussion

As shown in **Figure 3**, in order to identify an effective geometry of the electrodes that may provide a strong particle collection efficiency, I utilized two electrode configurations: one had two parallel aluminum plates facing each other (**Figure 3a** and **3c**) and the other had one aluminum bar parallel to an aluminum plate (**Figure 3b** and **3d**). During the experiment, many styrofoam particles were placed in between the electrodes by applying a high electrostatic field supplied by a Van de Graaff generator.[17] Then, I investigated the particle collection efficiency (e.g. the number of particles attracted to electrodes electrostatically) as a function of the separation (*d*). The height of the aluminum bar in case of **Figure 3b** and **3d** is set to be *1cm* above from the bottom.

As depicted in **Figure 4**, the number of styrofoam particles which are attracted to either side of the electrodes was counted as a function of distance (at 5cm and 10cm). It is worth noting that the styrofoam particles are uniformly distributed in between the two electrodes. The electrode configuration having an aluminum plate with an aluminum bar exhibited higher collection efficiency (the number of styrofoam particles collected) than that of two aluminum plates. For instance, **Figure 4a** shows 12~15 particles attracted when *d=5cm* and 6~8 particles collected when *d=10cm*. On the other hand, **Figure 4b** shows 6~8 particles attracted when *d=5cm* and 1~2 particles collected when *d=10cm*. Thus, it is confirmed that the electrode configuration having one metal plate and one metal bar (**Figure 3b** and **3d**) is much more effective than one having two metal plates (**Figure 3a** and **3c**). This result can be explained by the strength of the electrostatic attraction between the two electrodes. Due to the large area of the aluminum plates in the case of **Figure 3a** and **3c**, the number of electrostatic field lines per unit area is decreased. However, the electrode configuration with one metal plate and one metal bar (**Figure 3b** and **3d**) can produce a higher number of electrostatic fields per unit area under the same electrostatic condition. In turn, this results in an increased number of styrofoam particles that are attracted to the electrodes.

Thus, it is experimentally proven that using a combination of a metal bar and a metal plate (**Figure 3b** and **3d**) is an optimal candidate for the electrode geometry of the styrofoam particle collector.

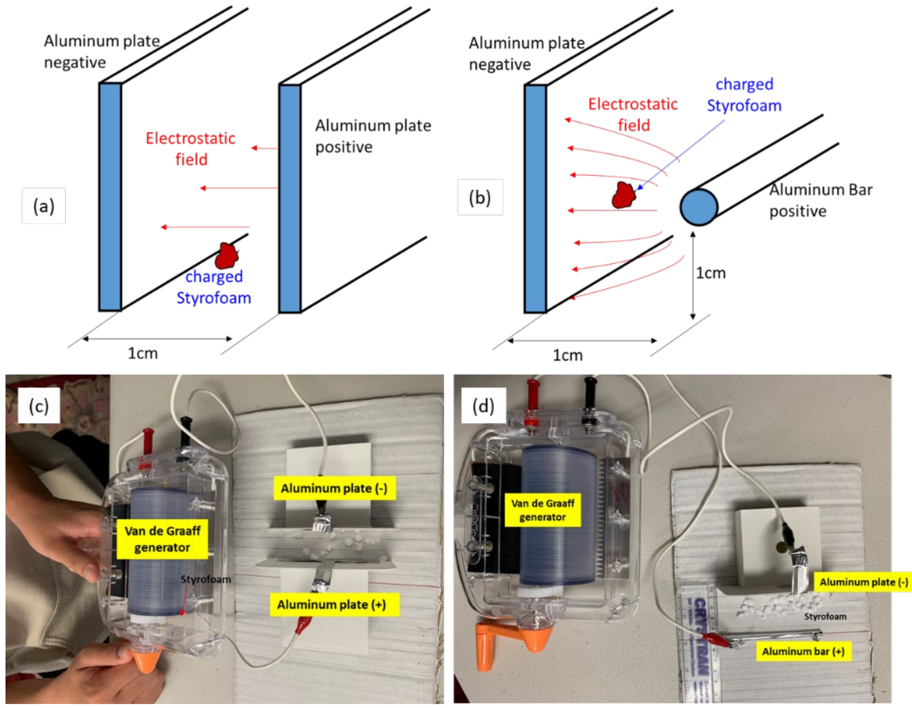

Figure 3. Schematic diagrams and photos for two electrode configurations. (Figure 3a and 3c) electrostatic field between two parallel aluminum plate electrodes, (Figure 3b and 3d) between one aluminum bar and one aluminum plate electrode. *d* is the separation in centimeters between the electrodes, and the height of the aluminum bar is set to be *1cm* from the bottom. It was found that an aluminum bar generates a stronger electrostatic field that helps to attract the styrofoam particles to one side of the electrodes. The Van de Graaff generator is commercially available from Narika Corporation (B10-1324 Electrostatic High-Voltage GENECON).[17]

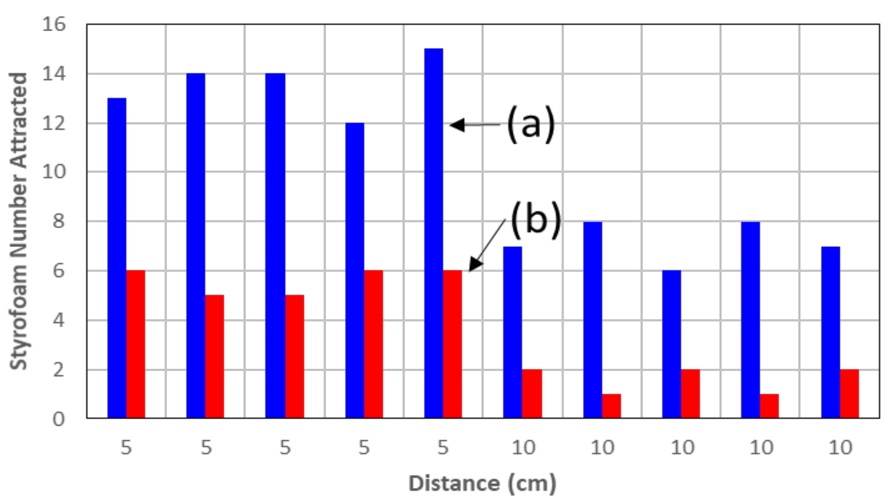

Figure 4. Number of styrofoam particles captured by the aluminum electrodes. (Figure 4a) Blue: when one aluminum plate and one aluminum bar are used, and (Figure 4b) Red: when two aluminum plates are used. The number of styrofoam particles used here was 36 in total. The experiment was repeated multiple times at two different distances (*d=5cm* and *10cm*), and their collected particles were counted.

Another experiment is conducted to investigate the effect of the orientation of the aluminum bar electrode to the particle collection efficiency for the two configurations shown in **Figure 5**. One can find that both parallel and perpendicular orientations of the aluminum bar are very effective in electrostatically attracting the styrofoam particles in this experiment. It was also found that styrofoam can be charged to be either positive or negative since particles are attached to either the negative or the positive aluminum electrode. Interestingly, when the aluminum bar was moving around horizontally (**Figure 5a and 5b**) and vertically (**Figure 5c and 5d**) at a given position, major portions of the styrofoam particles were attached to the aluminum bar electrode, which is positively charged. After repeating the experiment, it is concluded that both geometries (parallel and perpendicular configuration) are equally effective in collecting the styrofoam particles. However, in this experiment, the electrode configuration in **Figure 5a** and **5b** is selected for further research because it is convenient to make a compact styrofoam collector as will be explained later.

As shown in **Figure 6**, the effect of the position of the aluminum bar was examined as a function of distance (for instance, 1, 5, 10, and 15cm etc.). The separation between the metal electrode and the bottom surface was maintained to be *1cm* apart (as shown in **Figure 3b**). The number of styrofoam particles used in this experiment was 33 in total and the bar electrode was able to hold some of them electrostatically as shown in **Figure 6a-6d**.

In **Figure 7**, the number of styrofoam particles which are attached to the aluminum bar under the electrostatic field was counted as a function of distance (d). For instance, in **Figure 7**, the distance was varied from *1cm* to *14cm*. The metal bar was kept at the given position while supplying the high voltage obtained from the Van de Graaff generator, and in turn, the styrofoam particles reacted by drifting to both electrodes. From this, two results are experimentally found. First, most particles are negatively charged since they are attracted to the positive metal bar electrode. Second, regardless of the distance variation, the particle collection efficiency (in other words, the number of styrofoam particles being attached to the metal bar) looks similar regardless of their distances as shown in **Figure 7,** which was a surprising and unexpected result during the course of this experiment.

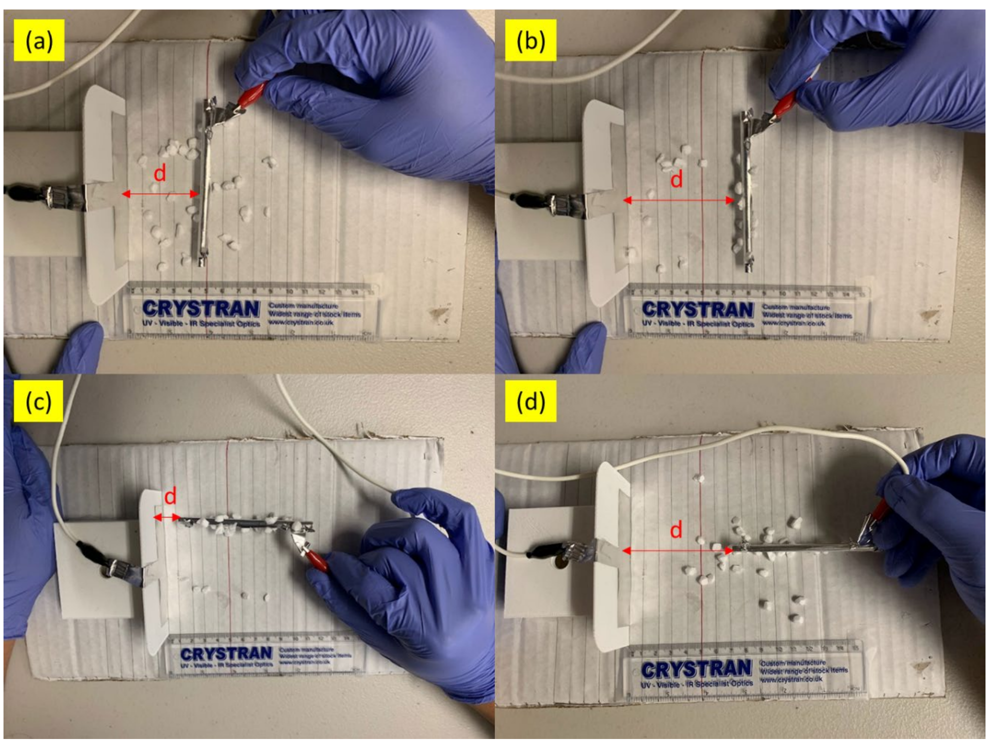

Figure 5. Two ways to test the efficiency of the particle attraction using an aluminum plate and a bar electrode. (Figure 5a and 5b) The two electrodes are in a parallel configuration. (Figure 5c and 5d) The electrodes are in a perpendicular configuration. One can find that the aluminum bar is effective in attracting the styrofoam particles during this experiment in both cases, which was unexpected.

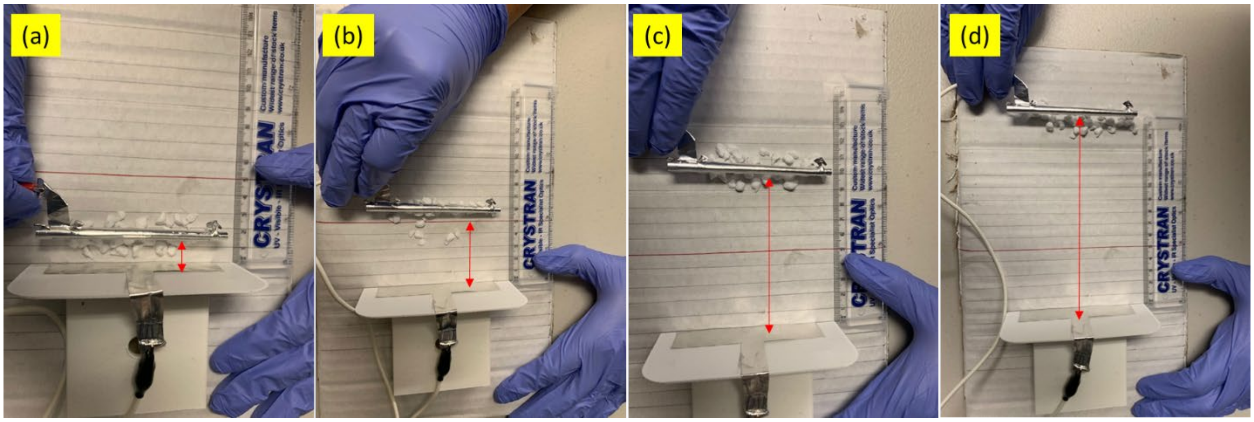

Figure 6. The collection efficiency was examined by counting the number of styrofoam particles which are attached to the aluminum bar electrode as a function of the separation distance *d*. Distances measured were: (Figure 6a) *d*=1cm, (Figure 6b) 5cm, (Figure 6c) 10cm, and (Figure 6d) 15cm apart from the aluminum plate.

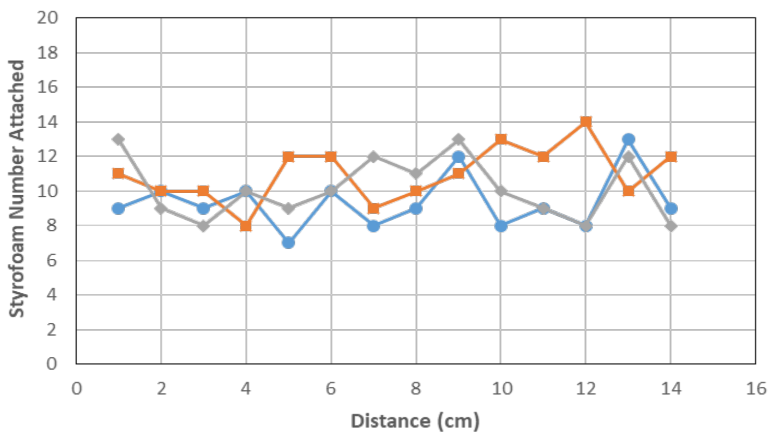

Figure 7. Number of styrofoam particles captured by the aluminum bar as a function of distance when the position of the aluminum bar was fixed at a given position and supplied with an electrostatic field. The number of styrofoam particles used here was 33 in total. The experiment was repeated multiple times.

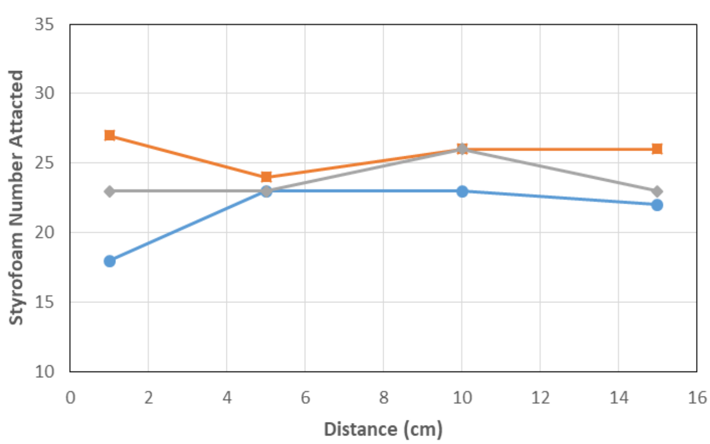

Figure 8. Number of styrofoam particles captured by the aluminum bar. The metal bar was moving around ±1 cm at the given distance (*d*) to collect more particles electrostatically. The number of styrofoam particles used here was also 33 in total. The experiment was repeated multiple times.

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In **Figure 8**, the metal bar was moved around back and forth in some of the selected distances in order to attract more particles while all conditions are maintained uniformly described in **Figure 7**. It is noticed that the number of styrofoam particles attracted in **Figure 8** is much higher than that of **Figure 7**. This is because more styrofoam particles are attracted to the bar in the experiment due to an intentional external movement (±1cm back and forth at the given distance) of the bar. Next, it was calculated that this extra movement of the metal bar can enhance the capturing capability by about 200% of the electrostatic attraction of the styrofoam particles (for instance, the average number is 11 in **Figure 7**, and 22 in **Figure 8** if d=1cm selected). Finally, from this experiment and collection capability analysis, the distance between two electrodes in the following prototype of a mini styrofoam particle collector is selected to be *1cm* apart, as will be explained later.

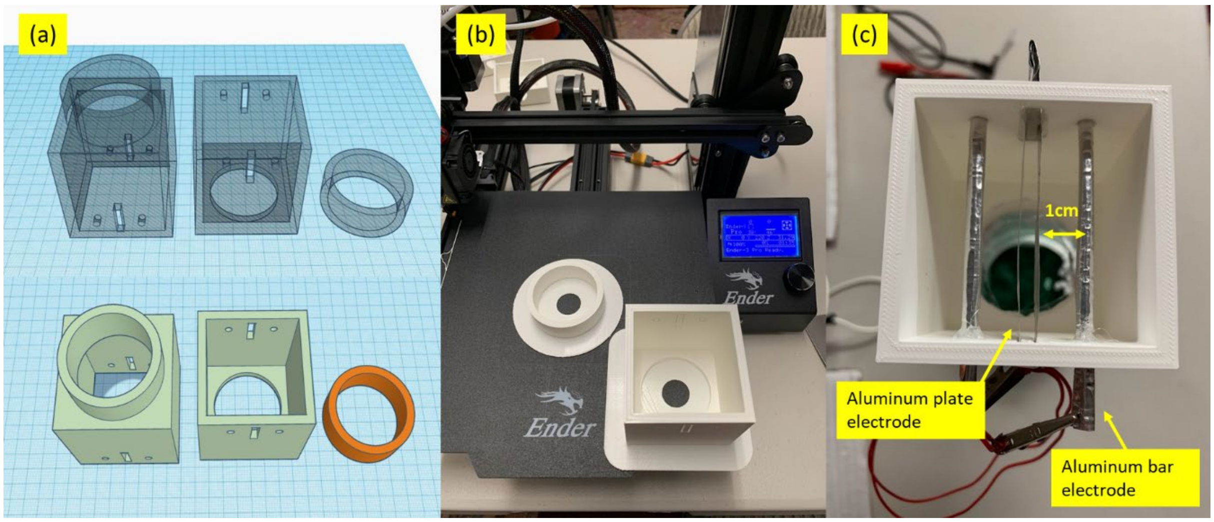

Figure 9. (Figure 9a) Component design using the 3D modeling Tinkercad software[18] showing various holes which are made for mounting the aluminum electrodes, (Figure 9b) The Ender-3 Pro 3D Printer which was used for part-manufacturing, and (Figure 9c) the mounted aluminum metal electrodes which are used to introduce the electrostatic field and the distance between electrodes is set to be *1cm* apart.

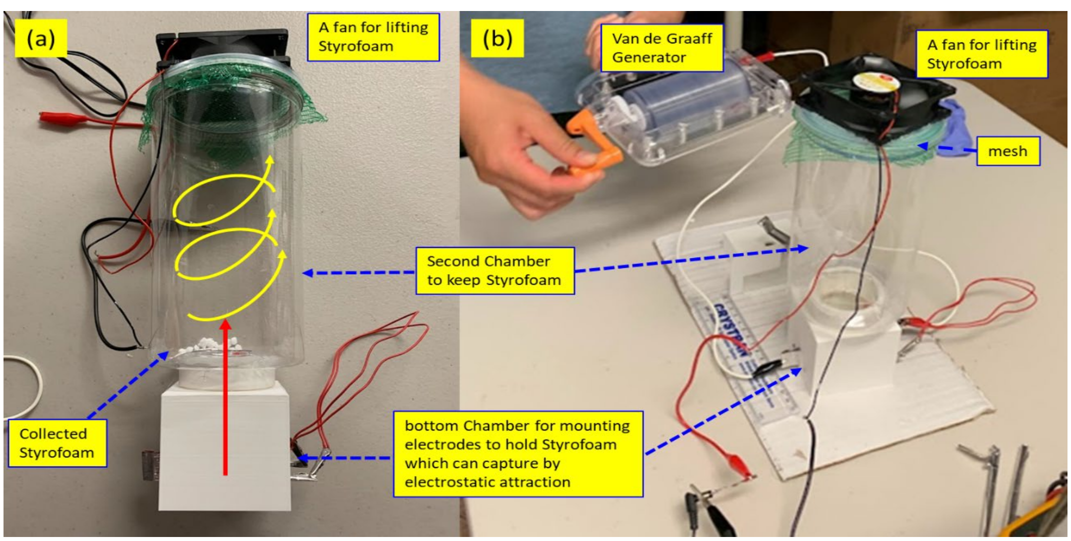

Figure 10. (Figure 10a) a photo showing an assembled mini-styrofoam particle collector, and (Figure 10b) showing the demonstration of the device which includes a Van de Graaff generator, an electric fan, a bottom chamber made by a 3D printer, a second chamber which is a transparent tube, and a sheet of mesh preventing styrofoam particles from going through the electric fan. One can find the collected styrofoam particles in the bottom of the second chamber.

Based on the experimental data and analysis as explained in **Figure 4, 7** and **8**, a prototype mini-styrofoam particle collector is designed using a 3D modeling program, called Tinkercad[18] as shown in **Figure 9a** and a 3-D printing system (Ender-3 Pro 3D Printer) which is commercially available as shown in **Figure 9b**. **Figure 9** shows one of the main components of the mini-styrofoam particle collector that is used to accommodate two sets of electrodes (two aluminum plates and two aluminum bars). One can notice that as a result of the discussion from **Figure 7** and **8**, the separation distance between the aluminum metal plate and bar is set to be *1cm* apart in order to make a compact and mini-styrofoam particle collector.

Figure 10 shows an assembled mini-styrofoam particle collector which is composed of a Van de Graaff generator, a fan, a sheet of mesh, a bottom chamber (made using a 3D printer), and a second transparent chamber which is used for collecting the styrofoam particles within the chamber. The aluminum metal electrodes mounted in the bottom chamber induces an electrostatic attraction with enough force to cause the styrofoam to stick to the electrodes. After the electrodes capture the styrofoam particles, the fan is then turned on. This will propel the styrofoam particles to spiral upwards towards the second chamber, and will ultimately be deposited in the bottom edges of the second chamber. The driving force is the fan that propels just enough air to ensure that the electrostatic interactions between the styrofoam particles and the electrodes are broken.

As illustrated in **Figure 11**, the assembled mini-styrofoam particle collector is successfully operable and was able to collect the styrofoam particles effectively in the second chamber. Interestingly, styrofoam particles are attracted to both metal electrodes as evidenced in **Figure 11d**. However, major portions of the styrofoam particles are negatively charged and attracted to positive polarity. Only small portions of the styrofoam particles are attached to the negative electrodes, which are the aluminum plates. Therefore, it is, once again, confirmed that the styrofoam particles can be charged either to be positive or negative depending on their situation when the electrostatic field is applied. It is also clear that the styrofoam particles are being captured in the second chamber due to the spiral movement with help from the fan as shown in **Figure 11f**, meaning that the proposed mini-styrofoam particle collector is operational.

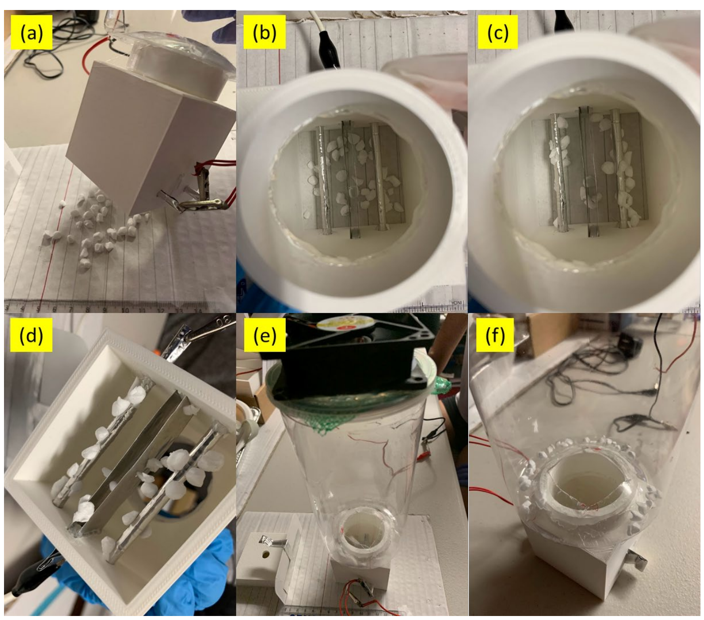

Figure 11. (Figure 11a) The mini-styrofoam particle collector before placing it over styrofoam particles, (Figure 11b) top view of the styrofoam particles which are randomly distributed, (Figure 11c) the styrofoam particles are electrostatically attracted to the metal electrodes when the electrostatic force is applied, (Figure 11d) bottom view showing styrofoam particles attached to the metal electrodes, (Figure 11e) the mini-styrofoam collector under fan operation, and (Figure 11f) a photo showing styrofoam particles being collected in the second chamber via the fan. One can find that the styrofoam can be attracted to either positive or negative metal electrodes as shown in Figure 11d.

Conclusion

In this research, an affordable mini-electrostatic styrofoam particle collector for the cleanup of styrofoam particles distributed in coastal areas has been proposed, designed, and developed using a 3D modeling software and a 3D printer. The proposed working mechanism was experimentally examined by a series of experiments that are based on the Coulombic attraction of particles and their electrostatic fields. Some interesting findings and details of the mini-styrofoam particle collector made in this research are highlighted as follows:

- The proposed working principle of an electrostatic styrofoam particle collector is validated by the experiments performed in this research. The device has two electrodes in the form of a metal plate (negative) and a metal bar (positive). It is identified that styrofoam particles used here can be charged positively or negatively.
- The metal electrode configuration that effectively collects styrofoam particles was examined in order to determine an optimal separation distance. It turned out that the styrofoam collection efficiency appeared to be the same regardless of the following parameters: (1) the distance between the metal plate and the metal bar, and (2) the orientation of the bar.
- Based on the experimental observation and analysis, the distance between the metal plate and metal bar was selected to be 1cm apart for constructing a mini-electrostatic styrofoam particle collector that was designed using a 3D modeling software and manufactured using a 3D printer.
- The assembled mini-electrostatic styrofoam particle collector was successfully operated and confirmed to be capable of collecting styrofoam particles under the lab-experimental conditions.

Since this mini-electrostatic styrofoam particle collector has been successfully operated, I believe that it can be scaled up in size and can be applicable to effectively collect certain pollutants like plastic particles such as styrofoam from the coastal area of Long Beach, CA. This proposed idea is simple and innovative and can be easily constructed without significant cost.

Limitations

Throughout the course of the design and experiment, there were a few limitations that may have impacted the outcome of the mini-styrofoam particle collector. For example, this research only focused on small styrofoam particles that can be electrostatically collected. If the size of the styrofoam particles are larger than what was tested, then the particle collection efficiency will be negatively impacted. However, depending on the design of the mini-styrofoam collector, such as the capacity of the Van de Graaff generator and the fan, this issue can be mitigated. Another limitation to this research includes an issue on the fan size of the second chamber. During the course of the experiment, I did not calculate for any optimal fan size, and I instead opted to use a fan that was readily available. In addition to the fan size, the opening sizes of the base and top of the bottom chamber should be carefully designed since the particle collection efficiency can be affected by the amount of incoming air caused by varying opening sizes. The collection efficiency will most likely increase when optimal airflow is achieved.

Future Directions

Since the mini-styrofoam particle collector has been successfully designed and operated, the suggested future research will be focused on scaling up the device. Through a careful scale up, the mini-styrofoam particle collector will provide a more efficient collection method that can be directly applied to the styrofoam (plastic) particles mingled in the sand on the coast.

Acknowledgements

Without Dr. Jeunghun Park's assistance, this would not have been possible. This idea came to me when I participated in the coastal cleanup day held at Long Beach, California. Dr. Jeunghun Park, a Scientist at Princeton University, guided me for about a year during my research process. During my research, my parents and Dr. Jeunghun Park funded this project and gave their time, effort, and support. I would also like to express my gratitude towards my mentors, who helped me by expending their time to advise and guide preparations for this paper.

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