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Optimization of elutriation device for filtration of microplastic particles from sediment

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ABSTRACT

The increasing presence of plastic pollution in marine ecosystems has become a major concern. In the environment, plastics break down into smaller and smaller pieces of microplastics. Methods of microplastic recovery are needed to reduce the dangers they can pose to a variety of organisms. An elutriation device was manufactured and optimized to achieve maximum microplastic recovery. The parameters flow rate and diameter of elutriation column were varied and their domain of variation was determined. A composite factorial experimental design was generated using MODDE 10.1 and was undergone. The optimal values of flow rate and column diameter were determined to be 385 L h^{-1} and 5.06 cm respectively, under constraints, to achieve a maximum feasible microplastics recovery percentage of 50.2%. The elutriation process can be improved through further testing, and can be tested in the field to compare its efficiency to that of manual microplastics filtration.

1. Introduction

Plastic plays an integral part in our everyday lives, from being used in shopping bags to being an essential material in infrastructure. It is widely used due to its life-span attributed to its inability to break down in the environment for many centuries. However, this is the exact reason why it is such a threat to the world's ecosystems, especially marine ecosystems (Andrady and Neal, 2009). Currently, plastic pollution has been reported in every major body of water, including the Arctic, Atlantic, Pacific, and Indian Oceans (Lebreton et al., 2012). The most common plastic pollutants found in the surface water of the South Atlantic Ocean are polyethylene (PE) and polypropylene (PP), used in everything from plastic toys to plastic containers and packaging (Morris, 1980). Due to the long duration of time which plastics take to fully revert back into inorganic substances, it remains in the environment and may disrupt wildlife in the process (Andrady, 2003). Plastic equipment, parts, bags, and toys may break down when exposed to UV light to form tiny microscopic particles which may remain in the world's oceans for centuries (Eriksen et al., 2013). This poses a risk to organisms at the bottom of the food chain which may mistake these plastic particles for food and accidentally ingest them, thereby reducing their nutrient intake. Eventually, the organisms may starve to death. The survival of the species as a whole is also put into risk because the organisms' ability to reproduce is also affected (Ryan, 1988). Another possible consequence of the proliferation of tiny plastic particles in the world's water systems is their accumulation of organic toxins (Rios et al. 2010). Upon ingestion of these plastic pieces, animals may also be at risk of not only dying but passing these toxins to their predators, resulting in the biomagnification of toxins (Sheavly and Register, 2007). Although more research needs to be done on this topic, it is clear that these plastic pellets can prove to be very deadly and that potential methods of sampling and retrieving these particles should be investigated. Elutriation is a microplastics sampling device developed by Claessens et al. (2013). The process separates plastic particles from sediment using the density differences between the two substances (Claessens et al., 2013). This device has been applied in plastic sampling. However, little effort to optimize the device was reported. In this paper, the elutriation device was optimized to determine its maximum percent recovery of microplastic particles.

2. Experimental set-up

Microplastic filtration was carried out using an elutriation device, similar to the one used by Claessens et al. (2013) for microplastic particle sampling (Fig. 1a). Their column was 1678 mm long and 150 mm in diameter. They also included a 1 mm sieve on top of the column and a 38 μm sieve for collecting microplastic particles. The column was connected to a hose at the bottom which supplied the water flow. Three large air stones (50 × 25 × 25 mm)

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were also placed at the bottom of the column for aeration and efficient separation of the microplastics from sediment. The authors experimentally determined that 300 L h^{-1} flow rate would maximize plastic collection while minimizing contamination with sediment particles. However, they did not show whether that value for flow rate would maximize plastic collection irrespective of the amount of sediment collected. They also did not show their method of optimization or any evidence of optimization of other variables related to the elutriation process (Claessens et al., 2013).

Our device was based off of the elutriation column of Claessens et al. (2013) (Fig. 1b). The length of our device was fixed at 50 cm. The column was made of PVC and the rubber hose was connected to the column at the bottom via a bronze hose connector piece fastened to the column using epoxy. A 100 × 20 × 20 mm air stone was placed at the bottom of the column for aeration and efficient microplastics retrieval. Microplastics were collected using a 3 mm sieve placed adjacent to the opening of the elutriation column. The water emerging from the top of the column drained into the sieve, and any plastic pieces and sediment were collected in the sieve. Time of filtration was set at 10 min.

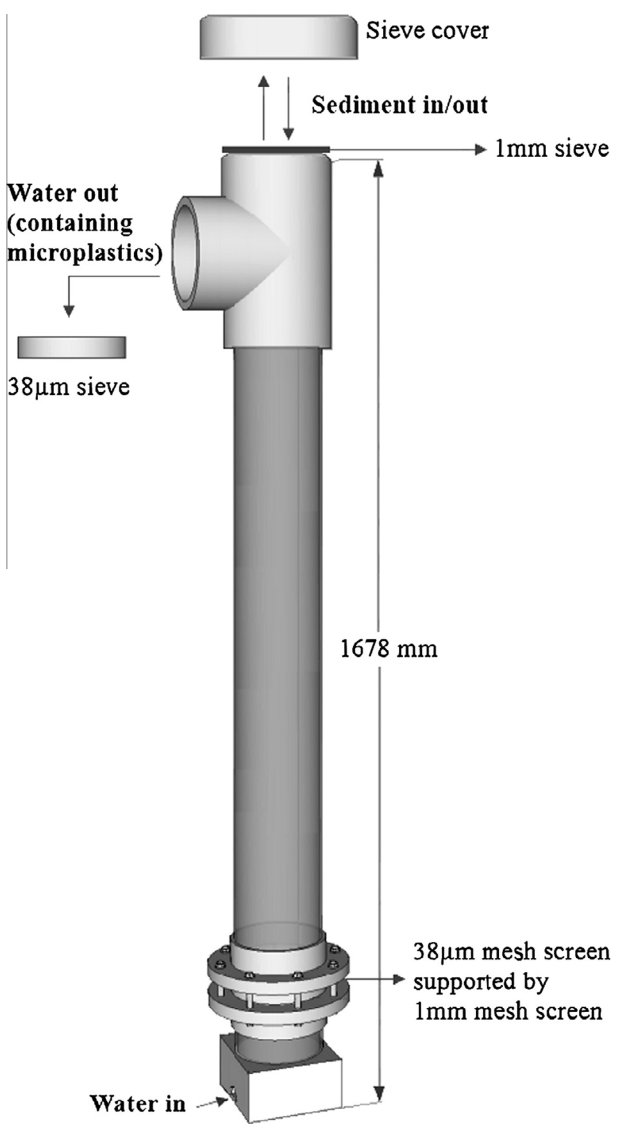

Fig. 1. Schematic representation of the elutriation device used by Claessens et al. (2013) for microplastics sampling.

3. Materials and methods

The plastic-sediment sample used in the optimization experiments consisted of 500 mL of sand collected from a Toronto beach and 50 pieces of 5 × 5 mm of plastic obtained from plastic water bottles.

The recovered microplastic amount was reported in percentage.

$$\text{Microplastics recovered} = \#\ \text{pieces of microplastics recovered}/(50\ \text{pieces of microplastics}) * 100\%$$

MODDE 10.1 was used to optimize two variables of the elutriation process: flow rate and diameter of elutriation column. Flow rate was measured using the formula:

$$\text{Flow rate} = \frac{1}{4}\pi\ (\text{diameter of hose})^2\text{velocity}$$

Practice generating the desired flow rate was undergone.

All other dimensions of the column and variables were kept constant. A quadratic model can be obtained from the software by performing a composite factorial experiment (Table 3). The response variable is Percent Recovery of Microplastics (Mic). The 2 parameters are flow rate (Flo) and column diameter (Dia). The model was obtained as a function of the normalized centred values of the parameters diameter and flow rate:

$$\text{Mic} = a_0 + a_1(\text{Flo})^* + a_2(\text{Dia})^* + a_{11}(\text{Flo})^{*2} + a_{22}(\text{Dia})^{*2} + a_{12}(\text{Flo})^*(\text{Dia})^*$$

The coefficients of the mathematical model were calculated and the response contours determined. In this step, the domains of variation were determined in which the optimal values of the two parameters were likely to be found.

Table 1
Experiments to determine domain of variation of the flow rate (Flo) parameter.

Diameter (cm)	Height (cm)	Flow rate (L h^{-1})	Microplastics (%)
7.64	50	100	0
7.64	50	200	4
7.64	50	300	16
7.64	50	400	13
7.64	50	500	12

Table 2
Experiments to determine the domain of variation of the column diameter (Dia) parameter.

Diameter (cm)	Height (cm)	Flow rate (L h^{-1})	Microplastics (%)
5.06	50	200	35
7.64	50	200	4
10.16	50	200	1

Table 3
Experiments to optimize flow rate and column diameter of the elutriation process. Flow rate was measured in L h^{-1}, diameter in inches, and microplastics recovered in percent.

Exp No.	Exp name	Run order	Incl/excl	Flow rate	Diameter	Microplastics recovered
1	N1	11	Incl	200	2	35
2	N2	8	Incl	400	2	50
3	N3	4	Incl	200	4	1
4	N4	6	Incl	400	4	13
5	N5	7	Incl	200	3	4
6	N6	5	Incl	400	3	13
7	N7	3	Incl	300	2	49
8	N8	9	Incl	300	4	2
9	N9	1	Incl	300	3	14.5
10	N10	10	Incl	300	3	16.5
11	N11	2	Incl	300	3	17