Great Lakes Shoreline Algae Harvesting and Separation System

Matthew M. Kline
Department of Mechanical Engineering
Saginaw Valley State University
University Center, MI 48710
Email: mmkline@svsu.edu

Ryan J. Schulz
Department of Mechanical Engineering
Saginaw Valley State University
University Center, MI 48710
Email: rjschulz@svsu.edu

Thomas A. Mahank
Department of Mechanical Engineering
Saginaw Valley State University
University Center, MI 48710
Email: tmahank@svsu.edu

Abstract

Each year the beaches of the Great Lakes are closed for weeks at a time due to *E. coli* contamination of shoreline algal wash. The benthic algae thrive on a steady diet of phosphorus-rich agricultural runoff flowing from the streams and tributaries supplying the lakes. To alleviate beach fouling, a shoreline algae harvesting and separation system was developed with university and corporate support as a mechanical engineering senior design project, as a high-school/undergraduate student internship to promote STEM education, and as an undergraduate student-led research project. Preliminary testing of the scale-model and prototype hydrocyclones is underway. Light and heavy muck, sand, and water from the beach of the Bay City State Recreation Area were effectively extracted and separated using the prototype hydrocyclone.

Introduction

Excessive algal growth is a growing concern to the many Michigan residents who have witnessed the picturesque, sand covered beaches of the Great Lakes transformed into decaying fields of muck, as shown in Fig. 1. The green algae *Cladophora* die on the beaches each summer, having thrived in abundance on a steady diet of phosphorus-rich agricultural runoff flowing from the streams and tributaries supplying the lakes[1;2;3]. Invasive dreissenid mussels (*Dreissena polymorpha* and *Dreissena bugensis*) have been implicated in the algal growth as well, as the mussels encourage phosphorus cycling[4], and filter the water, increasing the level of sunlight reaching the algae[5]. Shoreline algal

Fig. 1. Algal decay and *E. coli* contamination of Saginaw Bay shoreline.

decay can be foul smelling to beach goers and oxygen depleting to nearshore waters, adversely affecting aquatic life[6].

Cladophora has been shown to harbor the pathogenic bacteria *Escherichia coli* (*E. coli*)[7], *Campylobacter*, *Shigella*, and *Salmonella*[8], which can be present in the deposited fecal matter of geese and gulls feeding on washed up crustaceans. Water quality standards, as prescribed by the Federal Water Pollution Control Act of 1972, Clean Water Act of 1977, and Water Quality Act of 1987, recommend *E. coli* as a marker of fecal contamination, with a single sample maximum of 235 *E. coli* CFU/100 ml. A colony forming unit (CFU) is an estimate of the number of viable bacteria. Michigan beaches are closed when *E. coli* concentrations exceed 300 CFU/100 ml.

A means to harvest algae from the Great Lakes shoreline and nearshore waters is needed to restore the shoreline to its former splendor. To alleviate beach fouling, a shoreline algae harvesting and separation system was developed.

Concept and Design

The algae harvesting and separation system was developed on several fronts, with university and corporate support, as a mechanical engineering senior design project, as a high-school/undergraduate student internship to promote STEM education, and as an undergraduate student-led research project.

The prototype, as envisioned by the mechanical engineering senior design group, consists of a rolling pre-filtering cage and hydrocyclone separation unit, as shown in Fig. 2. The pre-filtering cage is comprised of an intake manifold enclosed in a perforated stainless steel cage to allow a steady supply of muck from the shoreline but prevent the ingestion of rocks and debris which could damage the supply pump. The hydrocyclone relies on a centrifugal process to separate the light and heavy solids, as shown in Fig. 3. A high speed spiraling vortex accelerates the solids. The heavy solids

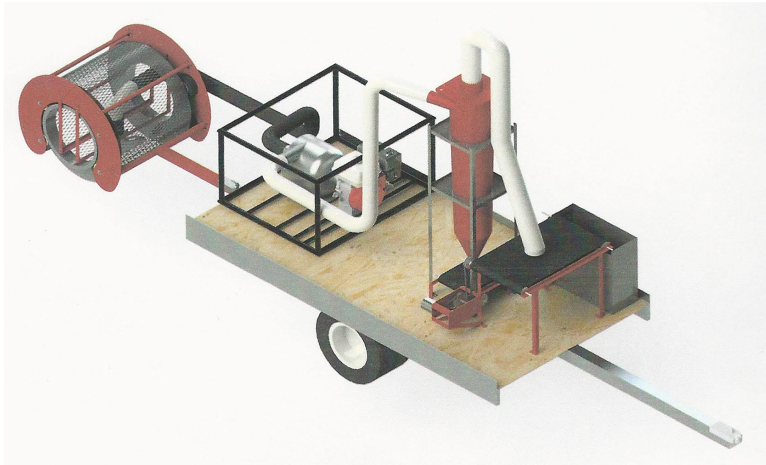

Fig. 2. The rolling pre-filtering cage (left), pump (center), and hydrocyclone separation unit (right)[9].

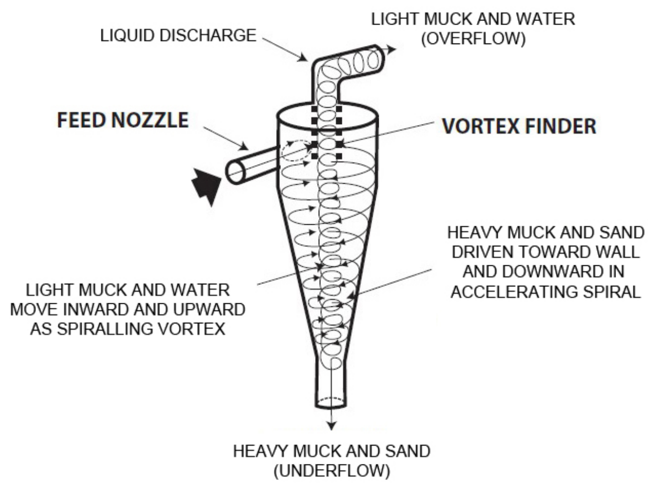

Fig. 3. The fundamentals of hydrocyclone separation.

(heavy muck and sand) are driven outward from the center toward the wall by centrifugal force and descend to the lower outlet as underflow, while the light solids (light muck) entrained in the flow ascend to the upper outlet as overflow. The vortex finder prevents the heavy solids near the feed inlet from entering the overflow stream. The length of the vortex finder can be increased to allow more time for the heavy solids to be entrained in the underflow stream, increasing the separation efficiency of the unit. The heavy muck and sand are separated by a course-mesh filtering belt upon leaving the unit, while the light muck and water are separated by a fine-mesh equivalent.

The scale-model, as envisioned by those participating in the high-school/undergraduate student internship and undergraduate student-led research project, consists of a hydrocyclone separation unit forty percent the size of the prototype, useful for studying the separation process in a laboratory setting. Both devices were designed based on the paper by Arterburn[10].

High-School / Undergraduate Student Internship

The participants of the seven week high-school/undergraduate student internship consisted of a faculty internship director, two high-school teachers, two undergraduate students, and four high-school students. The participants met Monday through Thursday from 9 a.m. to 4 p.m. in a classroom and a laboratory. The relevant scientific literature was discovered through database searches. Journal articles by Winslow et al[2], Howell et al[5], Arterburn[10], Depew et al[11], Nevers et al[12], and Show et al[13] were read, discussed, and summarized as oral and written reports by the students to gain an understanding of the topic. Solid-modeling software was explored through focused tutorials, so that components of the hydrocyclone could be visualized, designed, and dimensioned. The high-school students were introduced to a machine shop, and the system components were machined using CNC, drill press, lathe, mill, saw, and welder. The undergraduate students functioned as mentors to the high-school students throughout the project, while the faculty internship director and teachers collaborated to promote learning and develop STEM skills.

Beach Sand Collection and Measurement

The senior design and internship groups participated in field trips to a number of Saginaw Bay beaches prone to algal wash for beach sand collection. Optical microscopy was applied to determine the average size and size range of the sand grains. These measurements were needed to size the hydrocyclone, as the sand would need to be separated from the muck and redeposited on the beach during the harvesting process. The sand grains ranged in size from 1.4–2,000 μm, as shown in Table I.

TABLE I

SIZE RANGE OF SAND GRAINS COLLECTED FROM SAGINAW BAY BEACHES.

Location	Size range (μm)	Average size (μm)
Sagatoo Rd., Standish	1.4–50	8.6
Bay City State Park, Bay City	100–500	237
Linwood St., Linwood	200–750	335
Pinconning Rd., Pinconning	170–2,000	480

Hydrocyclone Theory

The overflow and underflow of a typical hydrocyclone are shown in Fig. 3. The $D50_C$ is used to size the hydrocyclone, and is defined as the particle size of which 50% reports to the overflow and 50% to the underflow[10]. The $D50_C$(base) is the particle size that a standard cyclone can achieve operating under base conditions

$$D50_C(\text{base}) = \frac{D50_C(\text{application})}{C_1 C_2 C_3} \tag{1}$$

where C_1 is the hydrocyclone feed concentration correction, C_2 is the pressure drop correction, and C_3 is the specific gravity correction

$$C_1 = \left(\frac{53 - V}{53}\right)^{-1.43} \tag{2}$$

$$C_2 = 3.27\Delta P^{-0.28} \tag{3}$$

$$C_3 = \left(\frac{1.65}{G_S - G_L}\right)^{0.5} \tag{4}$$

and where V is the percent solids by volume of hydrocyclone feed, ΔP is the pressure drop in units of kPa, G_S is the specific gravity of solids, and G_L is the specific gravity of liquid. The diameter and height of a hydrocyclone chamber (units of centimeters) can be calculated from

$$D = \left[\frac{D50_C(\text{base})}{2.84}\right]^{1.515} \tag{5}$$

$$H = D \tag{6}$$

The hydrocyclone prototype was sized to produce an overflow of 98.8% while passing a particle of 45.0 μm. The $D50_C$(application) was calculated as 24.3 μm using the constants given in Table II. The pressure drop across the hydrocyclone prototype was determined to be 10 psi from Fig. 9 of Arterburn[10], by assuming a 215 GPM flow rate. The scale-model hydrocyclone was sized to produce an overflow of 80% while passing a particle of 24.3 μm. The $D50_C$(application) was calculated as 30.4 μm. The pressure drop across the scale-model hydrocyclone was determined to be 6 psi, by assuming a 20 GPM flow rate. The flow rate can be reasonably achieved in a laboratory environment by recirculating fluid through a 50 gallon storage tank with a 1.5 hp motor/pump. The design constants of the scale-model and prototype hydrocyclones are shown in Table II.

TABLE II
DESIGN CONSTANTS OF SCALE-MODEL AND PROTOTYPE HYDROCYCLONES.

Property	Scale-model	Prototype
Particle size, μm	24.3	45.0
Passing to overflow, %	80.0	98.8
Multiplier	1.25	0.54
$D50_C$(application), μm	30.4	24.3
C_1	1.15	1.03
C_2	1.30	1.00
C_3	1.62	0.99
$D50_C$(base), μm	12.6	23.8
Cylinder diameter, D, cm	9.56	25.0

The hydrocyclones were constructed in the university machine shop. The prototype was built from steel. The scale-model was formed from sheets of polycarbonate. The inlet scroll and cone were shaped by heating the polycarbonate in a convective oven and forming the material over mandrels, as shown in Fig. 4. The solid model assembly and scale-model hydrocyclone are shown in Fig. 5.

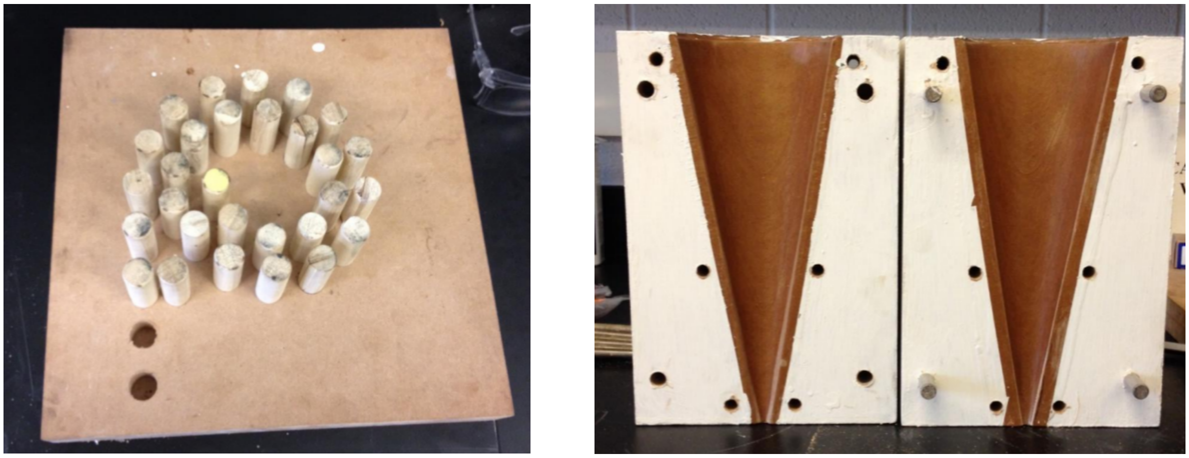

Fig. 4. The mandrels used to form the inlet scroll and cone of the scale-model hydrocyclone.

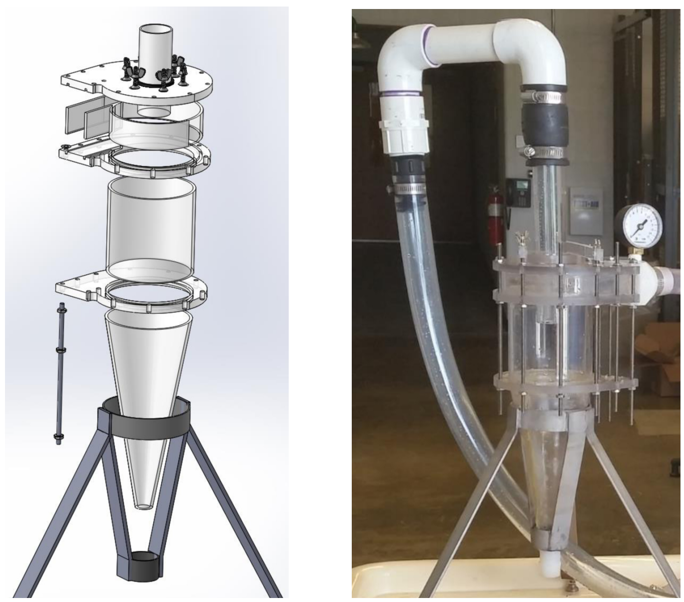

Fig. 5. The solid-model assembly and scale-model hydrocyclone.

Preliminary Results

Preliminary testing of the scale-model and prototype hydrocyclones is underway. Light and heavy muck, sand, and water from the beach of the Bay City State Recreation Area were effectively extracted and separated by the senior design group using the prototype hydrocyclone. Permission from the park as well as the Department of Natural Resources and the Department of Environmental Quality was granted to test the device. The device is shown in Fig. 6. The light muck that flowed from the overflow stream can be seen in Fig. 7. The heavy muck and sand that flowed from the underflow are shown in Fig. 8. The heavy muck was far more coarse than the light muck. The results of testing the scale-model hydrocyclone will be presented in a subsequent paper.

Fig. 6. Testing the prototype hydrocyclone on the beach of the Bay City State Recreation Area[9].

Conclusions

The fouling of Great Lakes beaches by algal wash harboring *E. coli* and other pathogenic bacteria is a public health concern. To alleviate beach fouling, an algae harvesting and separation system was developed to harvest algae from the Great Lakes shoreline and nearshore waters. An overarching goal of the project was to promote STEM education by involving high-school and undergraduate students in scientific research. This entailed the students becoming familiar with the scientific literature, learning to use solid-modeling software, and gaining experience with machine tools over the seven week high-school/undergraduate internship. Preliminary testing showed the prototype hydrocyclone was capable of separating light and heavy muck, sand, and water from the beach of the Bay City State Recreation Area. The outcome of the tests conducted on the scale-model hydrocyclone will be presented in a subsequent paper.

Further development of the system will take several paths. The system will be optimized to improve separation efficiency. This will involve studying the effect of changes to inlet velocity, inlet particle size distribution, particle concentration, and vortex finder position. The system may be redesigned to include a tractor-attached articulating arm to extend the range of the pre-filtering cage to nearshore waters, as the prototype is currently unable to harvest from these waters. An effective method for collecting the ejected muck will be pursued. And, the system could be scaled up to increase its utility.

Acknowledgments

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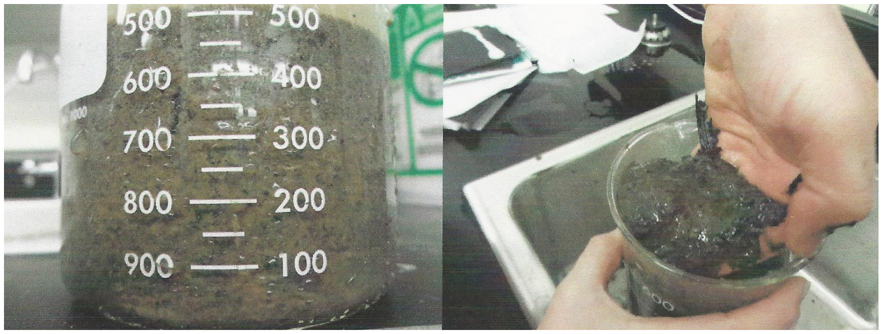

Fig. 7. Light muck from overflow stream of hydrocyclone prototype[9].

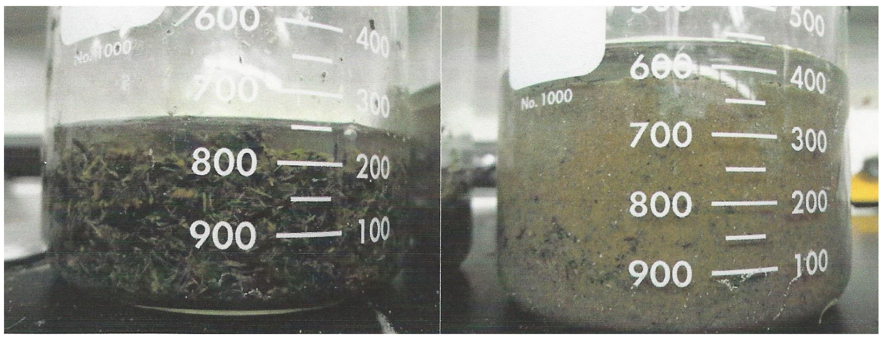

Fig. 8. Heavy muck (left) and sand (right) from underflow stream of hydrocyclone prototype[9].

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