Innovative Technology for Algae Dewatering

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ABSTRACT

This paper describes a novel technology for dewatering of algae for biofuel production and other applications. This hydrodynamic separation (HDS) technology uses customized fluid flow patterns in a curved channel to focus suspended particles into a concentrated band near one channel wall. A splitter at the end of the channel divides the flow into a dilute and a concentrate stream. The particle focusing is caused purely by hydrodynamic forces, which are proportional to the size of the particles, but independent of their density. This technology enables the concentration of particles with densities equal or close to that of the surrounding fluid without the need of a physical barrier, making it especially attractive for the dewatering of algae. Other advantages of this technology over conventional practice include: small foot print, low energy requirement, rapid process, and continuous flow operation. Added benefits include no moving parts, high scalability, high modularity in construction, and low cost in materials and TCO. This technology has been tested on many raw water matrices.

Keywords: Hydrodynamic separation, algae dewatering, bio fuels

1 INTRODUCTION

Algae as a feed for biofuel production have regained research interest as the global energy uncertainty escalates. Typically cultivated at a concentration of 0.02-0.06% total suspended solids, microalgal culture requires dewatering to reach a concentration of 5-25% TSS depending on target process objective [1]. This dewatering step adds a significant portion to the cost of entire process, often as high as 25-40%, due to the vast amount of water that needs to be treated. Centrifugation is energy intensive, but also dissolved air flotation (DAF) requires significant amount of energy for aeration plus cost of chemicals. A less energy intensive alternative technology for dewatering is highly desirable.

The Palo Alto Research Center (PARC) has invented, tested and demonstrated at the laboratory scale a novel, low-cost, hydrodynamic separation technology to remove small inorganic and organic particles from multiple water matrices [2-5]. Besides using this technology directly to remove already existing larger suspended particles from a liquid stream, it can be used in combination with a flocculation stage to grow smaller particles into larger aggregates for separation.

In the following sections we provide a more detailed description of this novel separation technology followed by three specific application examples for removal of selected algae samples.

2 HYDRODYNAMIC SEPARATION

An innovative dewatering technology, which is purely based on fluidic interactions, is used to dewater algae in a contiunuous flow process. This hydrodynamic separator (HDS) uses centrifugal force to create transverse fluid flow patterns that generate a combination of drag and lift forces that sweep suspensions to a force equilibrium position near one of the side walls (Figure 1).

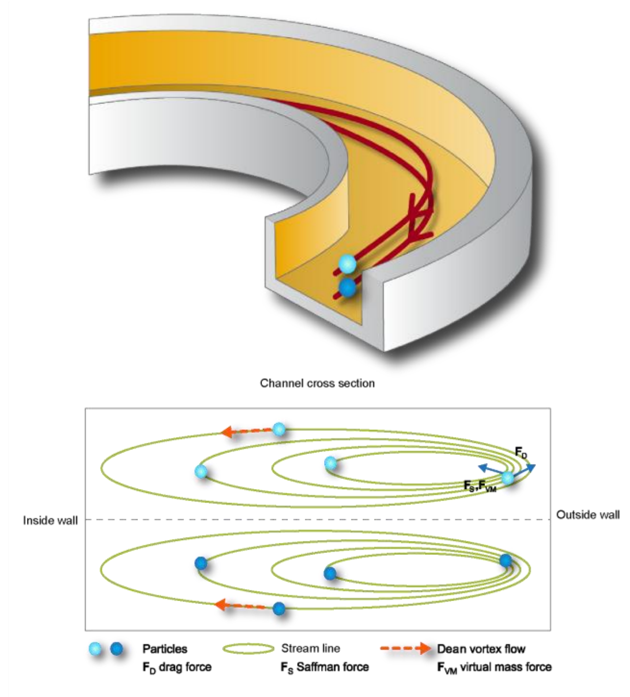

Figure 1: Schematic drawing of separator channel with relevant forces: Centrifugal force on the water creates a transverse flow pattern, which manifests itself as a pair of Dean vortices; a combination of drag and shear forces move the suspended particles to an equilibrium positions close to the channel outside wall.

This use of centrifugal force is different from that in traditional hydrocyclones and centrifuges where particles of different density from the liquid are moved relative to the liquid using very high (1000s) relative centrifugal force (RCF). In contrast, the PARC hydrodynamic separator uses hydrodynamic forces to move suspensions, requiring very low (single digit) RCF. The flow patterns in the separation channel sweep particles in the transverse direction so that they relocate to a force equilibrium positions where they concentrate into a band. This equilibrium position can be either close to the inside or the ouside wall depending on the flow conditions.

By placing a flow splitter at the end of the channel we obtain a dilute stream, and a concentrated particle stream (Figure 2). The HDS works for particles above a lower cut-off size. This cut-off size depends on channel geometry and flow conditions and can be designed to efficiently concentrate particles as small as 10 to 20 μm within a reasonable energy budget. Figure 3 shows separation results of a 15 μm cut-off hydrodynamic separator with a 50-50 flow split ratio. Dewatering efficiency can be increased by changing the dilute to concentrate flow rate ratio, e.g. by using an 80-20 splitter.

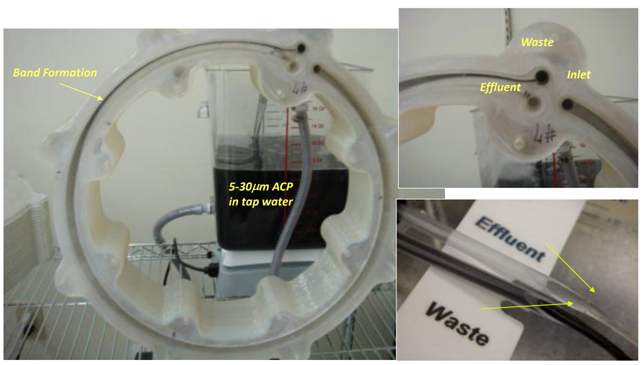

Figure 2: Picture of a demo separator using a carbon bead suspension. Particles enter the separator at the one o'clock position. By the time they reach the ten o'clock position a tight band has formed that is separated off as waste stream by a flow splitter.

The novel and innovative capability of this system is its ability to separate particles of any density, including neutrally buoyant particles such as algae and other biological and/or organic matter, from the source water without the use of a physical barrier, thus reducing any system downtime due to clogging and fouling.

This technology has been tested on many raw water matrices, including seawater, ballast water, and different types of wastewater. Based on test results with our research prototypes and technical analyses conducted to date, the technology appears compelling on a number of dimensions:

- Highly effective with neutrally buoyant material, making it highly suitable for removal of organic and biological particles as well as oil/water separation.
- Optimal performance for concentrations typically found in algae ponds up to a few weight %.
- Highly modular design allows dewatering of algae at the ponds, even for large area pond systems, without the need of pumping hugh quantities of water.
- Direct concentration of algae withiout the use of chemicals allows recycling of the clean water stream directly back into the algae ponds.

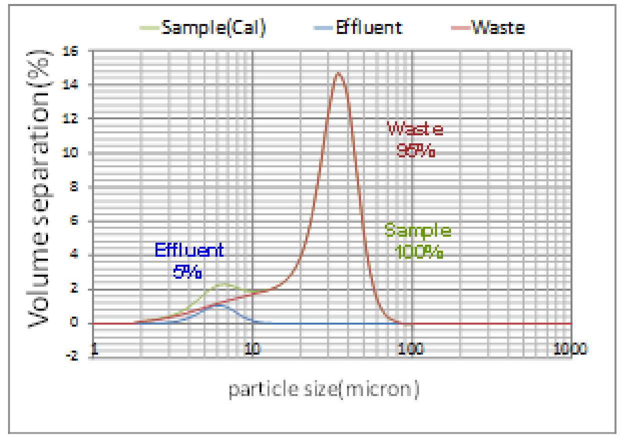

Figure 3: Particle size distributions of a water spiked with 5 μm and 30 μm carbon beads before and after separation.

3 SAMPLE RESULTS

In the laboratory, we have tested several different species of algae using HDS technology, both with and without the use of a flocculant. For the chemical free separation tests we use a HDS channel that can very efficiently remove particles down below 20 μm and we use a pressure vessel to drive the sample fluid through the separators (Figure 4).

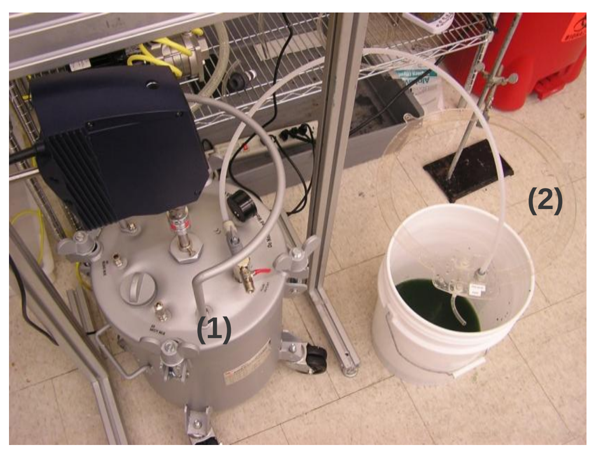

Figure 4: System setup for direct separation of algae: (1) pressure vessel; (2) separator channel.

For the characterization of the samples and to measure the efficiency of the dewatering process we used two different analytical approaches:

1. Particle size distribution (PSD). Particle sizes affect the separation efficiency of HDS and thus are carefully monitored. Horiba LA-950 is a laser-scattering based particle size analyzer and was used for all PSD measurements.
2. Total suspended solids (TSS). TSS assays are performed confirming to the gravimetric method approved in "Method 2540 D, Total Suspended Solids" by Standard Methods committee in 1997 . Sufficient amount of each sample was carefully filtered through 1.5μm glass fiber filter with house vacuum and the filter was baked at 105°C for at least one hour or until the weight change wais negligible. The net dry weight of the solids retained is divided by the volume of liquid filtered to calculate the TSS in mg/L or ppm.

Separation test were done with two different separator channels, a full-turn channel with a 345° arc length and a half-turn with a 180° arc length (both have the same radius of curvature). Both separators use the same splitter design with a flow rate ratio of 80:20 of dilute to concentrate stream. The total suspended solids (TSS) of the input sample and the two exit streams are measured and the harvesting efficiency η_H is calculated as

———————————————, (1)

which provides a measure of how much of the original algae mass is contained in the concentrate stream.

3.1 Spirulina algae

Spirulina has a cork-screw-like shape with a diameter of 30-50 μm and can be as long as 200-300 μm (Figure 5). Despite its odd shape it is separated very well with the hydrodynamic separator (Figure 6). Starting from a concentration of 0.8 g/l we achieved a 6-fold concentration increase to 4.6 g/l at over 97 % harvesting efficiency with a full-turn channel that has an 80:20 split ratio (Table 1). But even with a half-turn channel we still observe a harvesting efficiency above 90%, but at half the energy requirements.

	full-turn channel	half-turn channel
Sample TSS [mg/l]	791	660
Dilute stream TSS [mg/l]	32	84.5
Concentrate TSS [mg/l]	4608	4258
Pressure drop [psi]	≈20	≈10
Harvesting efficiency [%]	97.3	92.7

Table 1: Measured TSS values for spirulina algae for the different HDS input and output streams.

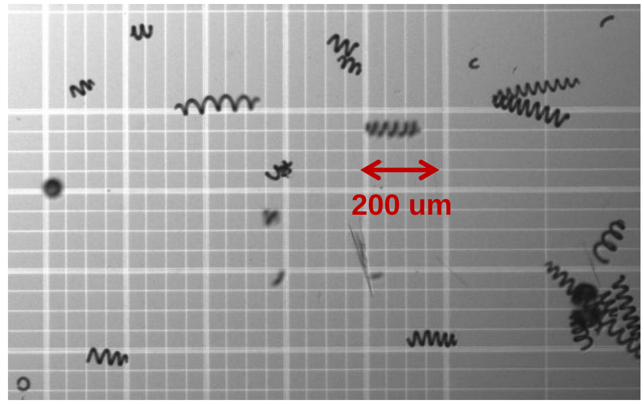

Figure 5. Micrograph of spirulina algae.

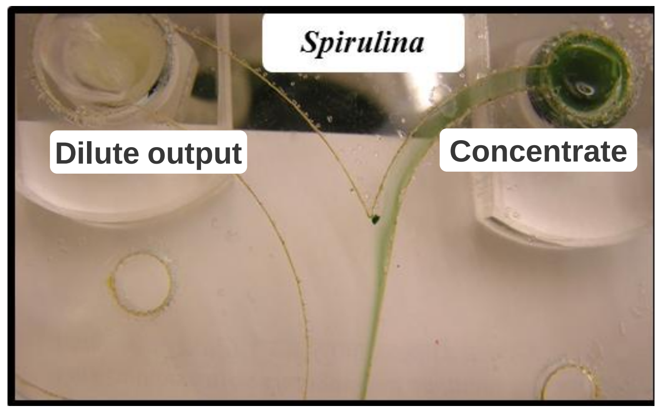

Figure 6. A concentrated stream of algae species Spirulina is being separated from bulk liquid by an HDS particle separator with an 80:20 flow split ratio.

A further increase in concentration can be obtained with a second HDS stage connected in series to further reduce the total concentrate volume to less than 5 % of the input volume and increase the concentrate to above 1 – 2 % by weight.

This separation was done without the addition of any extra chemicals, allowing the direct recycling of the dilute stream back to the algae pond.

3.2 S. dimorphus algae

For algae that are too small for direct separation with HDS, a polymer may be used to promote flocculation into larger aggregates. For a test with the algae species *S. dimorphus*, which is less than 10 μm in size, we used a bio-degradable flocculant (Chitosan [6]) to promote growth to larger aggregates. Figure 7 shows particle size distributions of the raw and flocculated sample and of the two output streams. With the addition of the flocculant aggregates of about 100 μm in size form. To avoid potential floc break-up we used a low pressure (low shear) separator (1.1 psi) to concentrate the aggregates.

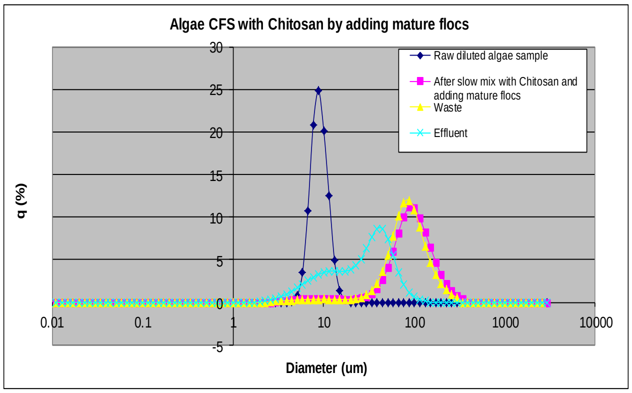

Figure 7: Particle size distribution (PSD) curves of S. dimorphus algae: blue: raw sample; pink: after flocculent addition; yellow: concentrate stream; cyan: dilute stream.

The separator used for the experiment had a 50:50 flow splitter, resulting in a doubling of the algae concentration, while only a few percent of the algae where lost with the dilute stream (Figure 8). The smaller aggregates that are left with the dilute stream grow further as can be seen by the peak at about 50 μm from the PSD measurement in Figure 7. A higher concentration factor may be achieved by using a more optimized splitter design and by cascading multiple HDS in series. In an experiment for flocculated produced water, we had successfully concentrated soft flocs up to 4% by weight by iterating the concentrate stream through an HDS floc separator with a 50:50 split ratio.

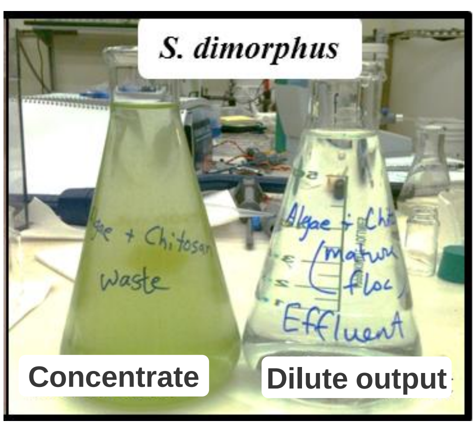

Figure 8: An algae species with a size smaller than HDS cutoff was flocculated with addition of Chitosan and subsequently separated with an HDS floc separator; the concentrate and dilute streams collected as shown

4 CONCLUSIONS

This paper describes a novel approach for the removal of suspended solids from many water matrices. Uisng purely hydrodynamic forces this technology efficiently removes suspensions by concentrating them into a narrow band that is split off the main stream without the need for physical filtration. Because this is a size and not density dependent particle concentration method it is ideally suited for the dewatering of algae from concentrations typically found in algae ponds up to a few weight %. Depending on the size of the algae separation can be achieved without the extra addition of any chemicals, allowing the direct recycling of the dilute stream back into the algae ponds. Added benefits include no moving parts, high scalability, high modularity in construction, and low cost in materials and TCO. In addition, this technology can be used for water treatment processes such as activated sludge reccyling in a waste water plant.

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