Performance Validation and Scaling of a Capillary Membrane Solid-Liquid Separation System

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Algaeventure systems · Ohio University

Abstract

Algaeventure Systems (AVS) has previously demonstrated an innovative technology for dewatering algae slurries that dramatically reduces energy consumption by utilizing surface physics and capillary action. Funded by a $6M ARPA-E award, transforming the original Harvesting, Dewatering and Drying (HDD) prototype machine into a commercially viable technology has required significant attention to material performance, integration of sensors and control systems, and especially addressing scaling issues that would allow processing extreme volumes of algal cultivation media/slurry. Decoupling the harvesting, dewatering and drying processes, and addressing the rate limiting steps for each of the individual steps has allowed for the development individual technologies that may be tailored to the specific needs of various cultivation systems.

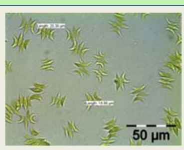
The primary performance metric used by AVS to assess the economic viability of its Solid-Liquid Separation (SLS) dewatering technology is algae mass production rate as a function of power consumption (cost), cake solids/moisture content, and solids capture efficiency. An associated secondary performance metric is algae mass loading rate which is dependent on hydraulic loading rate, area-specific hydraulic processing capacity (gpm/in^2), filter:capillary belt contact area, and influent algae concentration. The system is capable of dewatering 4 g/L (0.4%) algae streams to solids concentrations up to 30% with capture efficiencies of 80+%, however mass production is highly dependent on average cell size (which determines filter mesh size and percent open area).

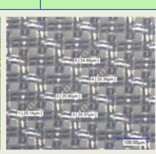
This paper will present data detailing the scaling efforts to date. Characterization and performance data for novel membranes, as well as optimization of off-the-shelf filter materials will be examined. Third party validation from Ohio University on performance and operating cost, as well as design modification suggestions will be discussed. Extrapolation of current productivities will be used to suggest a design for integration into commercial-scale production.

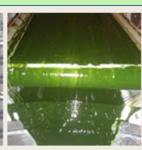
Performance Metrics

Primary Performance Metrics	Performance Dependent Physical & Operational Parameters
• Algae Mass Production Rate − power consumption (cost) − cake solids/moisture content − capture efficiency	• well geometry • well operational level (water depth) • belt speed • belt tension (longitudinal and lateral) • ambient environment temperature • ambient environment humidity • blower speed • system hygiene demands
Secondary Performance Metrics	
• Algae Mass Loading Rate − hydraulic loading rate − area-specific hydraulic processing capacity (gpm/in^2) − influent algae concentration	

Tertiary Performance Metrics	Performance Dependent Physical Parameters	
• Belt Properties − wicking rate − water holding capacity − water expulsion rate − recovery	• % open area • pore size • pore shape • porosity • permeability • capillarity • hydrophobicity	• thickness • strength • flexibility • elasticity • durability • chem. resistance • cake release
• Algae Cake Properties − thickness − release efficiency	• algae morphology • algae-web adhesion properties • algae cell surface properties • algae species distribution	







AVS

Algaeventure Systems conducted performance characterization testing of the Lab model SLS in October of 2011 for baseline evaluation. Independent variables included influent algae concentrations of 1, 2, 3, 4, 5, 6 and 7 g/L for *Scenedesmus dimorphus*; filter meshes 6/5, 10/3, 12/6, 15/9, 18/13 and 25/20; and filter belt speeds of 0.84, 16.76 and 31.25 ft/min. Performance metrics evaluated included capture efficiency (inverse of pass through), processing rate (time to process 10 L), mass productivity, mass productivity per unit area, energy consumed per unit mass produced, and dewatered algae solids content. Full factorial tests are planned for the Lab model, and similar optimization tests are planned for the Production Models at collaborator sites using pilot-scale cultivation facilities or full-scale natural environments to qualitatively demonstrate scaling efforts by AVS. Finally, recent scaling prototypes will be evaluated, and a final Production Model developed for commercial deployment.

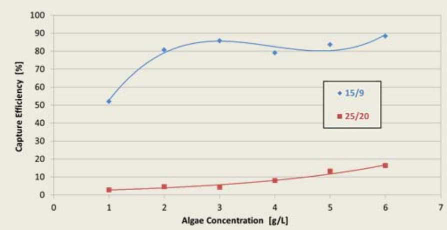


Figure 1. Capture efficiency as a function of algae concentration for the 15/9 and 25/20 filter belts

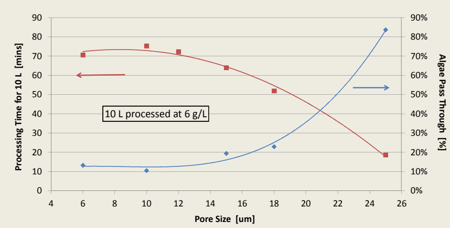


Figure 2. Processing time and algae pass through as a function of filter membrane pore size

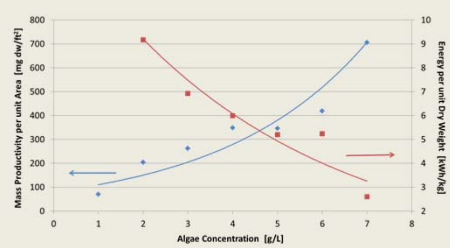


Figure 3. Mass productivity/area and energy/dry weight as a function of influent algae concentration

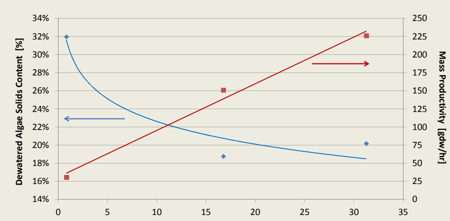


Figure 4. Solids content and mass productivity as a function of filter belt speed for 15/9 membrane

Ohio University

Ohio University developed a modified harvester prototype designed to increase system flow rate and lower energy consumption per unit mass of algae harvested when compared to the AVS pilot unit. Capture efficiency, power consumption per unit mass, and system flow rate were measured as a function of filter membrane speed for both harvesters. Five filter belt speeds were selected and a test was conducted at each speed on for both harvester systems. Each test consisted of a 3.0 g/l *Scenedesmus dimorphus* culture at a controlled volume of 5 gallons. Power consumption was measured in real time using a PLC data acquisition system and a power transducer. This allowed the average electrical consumption to be calculated once the system reached steady state. A membrane filter, with an average pore size diameter of 25µm was used on both harvester units, which was slightly larger than the average cell diameter of the *Scenedesmus dimorphus* (22.6 µm). The results from these tests are demonstrated below.

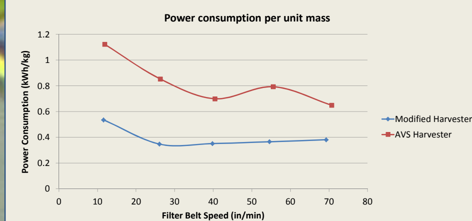


Figure 5. Power consumption per unit mass for the AVS and modified harvester units

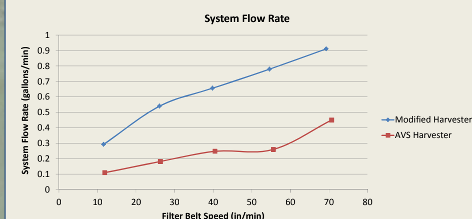


Figure 6. System flow rate for the AVS and modified harvester units

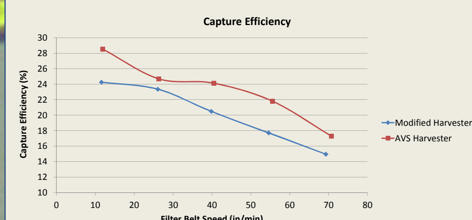


Figure 7. Capture efficiency for the AVS and modified harvester units

Results from the tests demonstrated that system flow rate and capture efficiency were linearly dependent on membrane filter speed, however, they were inversely proportional to each other. Power consumption per unit mass remained nearly constant at the higher membrane speeds. When comparing the two harvesters, the modified harvester had an average decrease in power consumption per unit mass of 108.5% with an average flow rate increase of 61.7%. The modified harvester capture efficiency was an average of 3.1% lower than the AVS pilot model, which is likely caused by the higher flow rates experienced.

Because of the average decrease in electrical consumption per unit mass, and increase in flow rate, the modified harvester unit was scaled from the 8" wide harvester well section to a 30" wide well section on the SuperSeparator modified harvester. The goal of this harvester unit is to be able to process a larger volume of microalgae culture and consume even less energy per unit mass than its predecessors. A similar study of membrane speed will be conducted once the unit is complete to determine the scaling factor for this well design.

Harvester Design Timeline - Multiple Patents and/or Patents Pending