

## An Optimal Harvesting and Dewatering System Mechanism for Microalgae

**Patricio VALDIVIA-LEFORT**

University of Arizona, Department of Agricultura and Biosystem Engineering,  
Shantz Bldg. 440 Tucson, Az 85718 - USA  
pvl@email.arizona.edu

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**Abstract:** The use and production of renewable energies is a very relevant topic for all countries because it has been established as a priority in the last few years. The recent droughts that have severely impacted the hydro-energy-dependent countries, the projected increase in prices of oil, uranium and natural gas due to global shortage, the negative impact on the environment due the consumption of fossil fuels (Hill 2006), have made that authorities focus their attention on these aspects, encouraging research and development of new and alternatives energies, specially biofuels from microalgae. The microalgae harvesting mechanisms currently used, such as centrifugation, sedimentation and flocculation are efficient, but at the same time expensive, representing more than 35% of the total biofuels production cost. The objective of this work is to show the different methods that have been used to harvest microalgae and to show the features that an optimal, inexpensive and versatile harvesting and dewatering system should have in order to reduce biofuels production costs and make those competitive with conventional fuels.

**Key words:** Bio-energy, microalgae, harvesting dewatering techniques

### INTRODUCTION

Algae have demonstrated to be an efficient bio-energy source (Chisti, 2007) because in contrast to sugarcane, soybean, canola and oil palm, algae are not edible, they are less expensive to produce, grow faster, allow higher yield and production rate per hectare (Sivakumar et al., 2010), do not require clean water to grow, and have the potential of reducing carbon emission (Danquah et al., 2009). This is the reason why developed countries have turned to algae as an efficient and adequate choice for the global energy crisis.

The current microalgae harvesting mechanisms worldwide used, such as centrifugation, sedimentation and flocculation (Shelef et al., 1984), have shown to be efficient, but at the same time are expensive, representing between 35 % to 50 % of the total production cost (Molina et al., 2002); consequently, the benefits associated to a new, inexpensive and versatile harvester are to reduce biofuels production costs and to make these achievable and competitive with conventional fuels (FAO, 2010). This research shows the features that an optimal harvesting and dewatering system mechanism for microalgae should have.

### METHODS

Different literature in the field was reviewed in order to determine the main characteristics, and then compare capabilities of different harvesting methods used for microalgae. Approximately 20 studies were reviewed for this purpose. Also, preliminary description of a developing pilot project is presented as example of an efficient harvester.

### RESULTS

According to the literature reviewed, the following correspond to the harvesting methods used for microalgae:

- Gravity Sedimentation: This is a simple and inexpensive process that requires different density liquid-solid media (Shelef et al., 1984). Frequently, this technique requires the utilization of flocculation previously for higher reliability. For this reason, this technique has low throughput rate. Gravity Sedimentation has not high efficiency due to loss in oil sediment.
- Centrifugal Sedimentation: It is one of the most popular, widely used and reliable method, this

technique is ideal for large volumes of biomass where high throughput rate is achieved, Centrifugation works under the physic principle of Stoke's law, creating a force proportional to the density liquid-solid difference of high value products (Shelef et al., 1984). This method is not only used for harvesting algae, but also it is used for bio-lipid extraction and chemical separation in biodiesel. The power demanding for centrifugation changes from 0,3 to 8 kWh/m<sup>3</sup> depending on the operation mode (Molina et al., 2002). In order to achieve highest efficiencies, higher centrifugation forces must be applied; consequently, higher power is demanded. The efficiency of this technique may go up to 95% at the centrifugation force of 13000 g, while decreasing centrifugation force to 1300 g reduces the efficiency to 40%. Other factors on which the efficiency relies are: the biomass settling rate, the biomass residence time, and the biomass settling distance (Richmond, 2004). The main disadvantage of this technique is the high energy requirement, which may cause cell damage, resulting in loss of biomass during the harvesting process.

- Bioflocculation: Flocculation is achieved changing the pH of the algal broth by adding bioflocculants (Molina et al., 2002), such as inorganic agent, polymeric organic flocculants, etc. The process is effective in low biomass concentration. The type of flocculants and the biomass removal efficiency depend on the type of biomass (Oh et al., 2001). One of disadvantage of this technique is inducement of flucculant contamination during the process. Bioflocculation has demonstrated to be efficient for *Chlorella vulgaris*.
- Chemical Flocculation: Similar to Bioflocculation; the negative algae charge could be reduced by adding flocculants (Millamenaet al., 1990), 90% effectiveness in *Chaetoceros Tctrasahnis* was observed when using Aluminum as flocculant. According to Richmond (2004), the flocculation effectiveness is not only a function of biomass concentration and hydrodynamics characteristics of the algae culture, but also a function of molecular weight, charge density and dose of the flocculant. Although chemical flocculation has become the harvesting method utilized in waste

treatment ponds, this technique requires high costs, induces flocculant toxicity and is non-feasible scalable up (Richmond, 2004).

- Screening: it works retaining particles leaving the liquid flows. For algae harvesting microstrainers and vibrating screen filters are used (Shelef et al, 1984). *It is an inexpensive* method and is used mainly for large size algae such as *Spirulina platensis*.
- Filtration: This one of the simplest technique, based upon the Momentum Equation of fluid mechanics, or also known as the principle of pressure drop. Three filtration methods exist: vacuum, pressure and gravity. When no pump is used (Gravity), it is an inexpensive, labor-intensive and slow process; nonetheless, the throughput rate may be increased by choosing adequate porosity materials for the filter. When using pump (vacuum, pressure), filtration is an efficient, labor demanding and an energy demanding process: 0,2 – 5,9 Kwh/m<sup>3</sup> (Molina et al., 2002). In general, the filtration processes require drying process for best results and fail to recover bacterial dimensions algae.
- Pressure Filtration: Liquid pressure by pumps is used as pressure drop (Molina et al., 2002). Pressure filtration is inexpensive, but it is an energy demanding, relatively slow and labor-intensive technique; very effective for large size microalgae, such as *Coelastrum proboscideu*, *Spirulina platensis*, but it fails to recover bacterial dimensions (e.g., *Scenedesmus*, *Dunaliella*, *Chlorella*).
- Vacuum Filtration: It is similar to the Pressure Filtration method, but the difference is this technique uses suction in the media side as pressure drop (Molina et al., 2002).
- Ultrasonic Separation: The cells migrate to the pressure node under low ultrasound energy (Bosma et al., 2003). This method has achieved efficiency for low biomass concentrations, up to 90% for *Monodus subterraneus*. High energy is required; the lower the flow in the going rate, the better the efficiency.
- Magnetic Separation: Based upon suspension of magnetic particles in the solution (Shelef G. et al, 1984). High algae recovery (90% in some cases), but this mechanism requires high energy.

- Electro Flotation: Fine gas bubbles are formed by electrolysis (Shelef G. et al, 1984) with this technique. It has very good reliability and should be operated conjunctly with chemical flocculation. However, it is very energy demanding and the differential potential required to maintain the necessary current density for bubble generation depends on the electrical conductivity of the feed suspension.
- Flotation (dissolved and dispersed air flotation): Is based on the higher solubility of air in water as pressure increases. Flotation is a gravity separation process which uses the attachment of air or gas bubbles to solid particles, which are produced by agitation combined with air injection. The success of flotation depends on the instability of the suspended particles (Shelef G. et al, 1984).
- Light-Harvesting Antenna complex: Generation of reactive oxygen species from the action of light-harvesting antenna complexes causes increase in photo-oxidative stress, reduction of photosynthetic efficiency, and damage the photosynthetic apparatus (Sivakumar et al., 2010). This method has been successful with *Clamydomonas reinhardtii*.
- Algae Ventura: It is a thermo mechanical design, at prototype scale that uses a membrane to screen and dewater algae; low energy for dewatering is required and it is versatile to multiple algae species (<http://www.algaevs.com/>).

## DISCUSSION

From the literature reviewed we can conclude that the harvesting process chosen strongly depends on the algal specie: for filamentous or large cell size algae, such as *Spirulina platensis*, *Micractinium sp.* or *Scenedemus sp.* it is highly recommended to use some of the filtration methods stated before, such as Vacuum, Pressure or Gravity filtration, due to its low cost and high efficiency achievable for those specie strains. However, for small cell size or particles that are compressible or display some plasticity, such as *Chlorella sp.* or *Oocystis* (Becker, 2008) because of their capability to easily block the pores of the belts or filters, it is recommended to carry out one of the alternatives between centrifugation or flocculation method described before, depending on what level of

energy is available and what level of chemical contamination is acceptable.

The parameters to pay attention during a harvesting process correspond to percentage of the biomass concentration (%), energy per volume consumed (kWh/m<sup>3</sup>), and production rate or throughput rate or efficiency, expressed in (m<sup>3</sup>/h). Becker (2008) asserted that in case of using belt gravity filtration as harvesting method to obtain a complete recovery of the biomass, a throughput rate up to 17 m<sup>3</sup>/h was achieved when used a belt of 12 µm pore size at 22 of belt speed. In fact, it was determined that the higher the belt speed, the higher the throughput rate; however, the algal slurry solid concentration decreases when the belt speed increases. The same researcher suggests, that in order to harvest small size cells, the belt pore size may be reduced to 5 µm, but the throughput rate falls substantially to 2-3 m<sup>3</sup>/h. Using Vacuum filtration method is an alternative for small size cells, but very slow throughput rate are achieved again restricting, consequently, bacterial scale size algae to Flocculation or Centrifugation methods.

Although Flocculation may introduce some contamination to the biomass, this technique has demonstrated to be efficient for many small algal size, low in concentration factor, and reliable for algae sedimentable under specific flocculants, e.g., *Chlorella vulgaris*, *Chaetoceros Tctrasahnis*, achieving up to 90% efficiency for *Chlorella vulgaris* (Oh, Lee, Park, et al 2001).

In the case of centrifugation, even though this is a versatile mechanism for almost all algae species, achieving high efficiency for almost all of them, its initial economical investment and their operational costs associated to this method, make doubtful its implementation; nevertheless, Centrifugation has one of the most promising future scaling up at industrial harvesting level due to scale economies. In a study conducted by Becker (2008), he suggested that by comparing Centrifugation with Flocculation, there was no significant economical difference between both.

According to the studies described above and the literature reviewed, a summary of the main features and parameters of the most used harvesting methods is shown in table 1.

Table 1. Main features for different harvesting methods.

Technique	Specie recommended	Power	Efficiency (% of recovery or m <sup>3</sup> /h)
<b>Centrifugal Sedimentation</b>	Versatile to almost all algae species.	0,3 to 8 kWh/m <sup>3</sup> (1)	Up to 95% when using a centrifugation force of 13000 g. (2)
<b>Flocculation (bioflocculation, chemical)</b>	Reliable for algae sedimentable under flocculants, e.g. <i>Chlorella vulgaris</i> , <i>Chaetoceros Tctrasahnis</i> .	-	Up to 90% in <i>Chaetoceros Tctrasahnis</i> (2)
<b>Filtration (Vacuum, Pressure, Gravity)</b>	Reliable only for large scale size, >30 $\mu$ m, e.g. <i>Spirulina platensis</i> . (3)	0,2 – 5,9 kWh/m <sup>3</sup> (1)	Up to 17 m <sup>3</sup> /h (4)

(1) (Molina et al., 2002), (2) (Richmond, 2004), (3) (Shelef et al., 1984), (4) (Becker, 2008).

Even though a unique and versatile harvester for all algal specie does not exist yet, experience has demonstrated that for all algae strains it is possible to develop an appropriate and economic mechanism of recovery (Richmond, 2004). Various authors suggest an economically operation during harvesting, developing multi-stage processes or pre-concentrations phases. Richmond (2004) suggested developing a primary concentration step through natural gravity sedimentations, followed by a pre-concentration stage through Flocculation, and finishing the process in a centrifugation phase to ensure a high concentration factor of the biomass ready to initiate a drying and dehydration process.

According to the discussion stated before and the literature reviewed, the main effects to be considered in an optimal and efficient harvester mechanism are: high concentration of the output biomass (%), low energy per volume consumed (kWh/m<sup>3</sup>), high production or throughput rate (m<sup>3</sup>/h) and low implementation and operational costs. The author of this research, trough the Department of Agricultural and Biosystems Engineering at University of Arizona, USA, is developing an inexpensive and novel harvester prototype whose characteristics pursue meet the features that an optimal and efficient harvester mechanism should have. The results of this prototype will be released promptly; however, some of the features of this harvester mechanism are the following: low implementation and operational cost, low energy consuming, reliable to a large range of microalgae species and size, high throughput rate and high concentration of the output biomass.

## CONCLUSIONS

The following was concluded from this research:

- The appropriate algae harvesting method to be used depends on the specific algae species and the purposes of the product to be harvested.
- A very large or filament specie, e.g. *Spirulina platensis* is easy to harvest, whereas a bacterial size cell such as *Chlorella vulgaris* is difficult. Consequently, for large cell size it is recommended to use some of the filtration methods stated; whereas, for small cell size it is recommended centrifugation or flocculation methods, depending on what level of energy is available and what level of chemical contamination is acceptable.
- Sometimes it is recommended, according to the machines available, multi-stage harvesting process, combining primary, pre and high concentration phases, ensuring a high concentration factor of the biomass at the end of the process.
- A universal and versatile harvester for all algal species does not exist, but has been demonstrated that for all algae strains it is possible to develop an appropriate recovery.
- An optimal and efficient harvester and dewatering mechanism should satisfy the following: high output biomass concentration, low energy consumption, high production rate, and low implementation and operational costs.
- The main benefit associated with a novel, inexpensive and versatile harvester design is the reduction of the biofuel production costs, helping making biofuels feasible and competitive with conventional fuels.

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