Lipid yields of algae dried in an enhanced solar chimney

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Abstract. This work focuses on the lipid yield of algae dried using an enhanced solar chimney dryer with the aim towards high quality biodiesel production and low energy consumption. Jaworski’s medium was chosen for the cultivation in this research project as it can provide enough nutrients to green algae of type Chlorella. Sp. Centrifugation is an effective method to harvest the algae from its medium prior to a drying process. In this project, the methods used for drying were oven drying, open-sun drying and an enhanced solar chimney drying. The moisture content was determined where the average moisture content were 82.5% for oven drying method, 81.6% for open sun drying and 82.2% for solar chimney drying. Methods were found to affect differently the algae properties in terms of the lipid yield and mineral content. The lipid yields were 23.7% for oven drying, 20.6% for open sun drying and 24.4% for enhanced solar chimney drying. While the oven drying was found to be the fastest way to dry the algae, the solar chimney drying proved best in energy saving while producing the same amount or more algae lipid within reasonable drying times.

1. Introduction
Algae based fuels are considered to be the most sustainable, renewable, effective and environment-friendly response to climate change and food security threats, as well as the only renewable energy resource that has the capacity to meet the global demand for fuels in the long term. A roadblock to harvesting of algae is the high concentration of water and it can reduce the extraction efficiency. Drying is a critical step in the production of biodiesel from algae, as it removes the water content in algae before the lipid extraction. There are many ways of drying microalgae such as oven drying, drum drying, freeze drying, spray drying, open sun drying, solar chimney drying and vacuum drying. Each method affects the properties of the algae at varying degrees such as the volume of lipid extraction yield as well as the fatty acids content in lipid, mineral content and other significant properties in algae for conversion to biodiesel.

Generally, the production of microalgae biodiesel is no different from the production of first generation biodiesel. The biomass is cultivated, then harvested for lipid extraction to undergo transesterification for conversion into FAMES (fatty acid methyl ester), or biodiesel. Unlike the oil seed plants, harvesting microalgae cells can be quite challenging. The tiny cells floating in water cannot be collected as easily as plant seeds or leaves, and accordingly oil extraction is more complicated than the cold-press procedure traditionally used for oil seeds extraction. Furthermore, algal cultures are often dilute in nature, around 1% through autotrophic growth and up to 10% by heterotrophic growth, and dewatering is necessary prior to biomass use. Thus, harvesting stages can be varied from one to several
different stages, where each stage’s operation can vary according to the final desire solid concentration. Generally, algae cultivation results in nothing more than a green slurry. In order to increase its calorific value, the slurry needs to be concentrated through the process of drying [1].

Depending on the different usage, the harvesting methods may vary. For instance, nutraceutical products require algae free from chemical contamination and still maintaining its natural characteristics, therefore physical process for harvesting is much preferred [2]. For fish feeding products, a longer shelf-life is prioritised, thus the continuous centrifugation of algae slurry is preferred. This method is highly effective and it is still the most widely used due to its efficiency and well documentation of the techniques.

One major challenge in developing a viable biodiesel production process from microalgae is finding an effectively harvest the biomass in a cost-effective manner [3]. Until recently technology development for downstream processing with low energy consumption while producing high yield is still advocated as a priority [4, 5]. The aim of this research project is to evaluate a strategy for its efficiency and cost effectiveness in harvesting microalgae. One of the factors to consider when choosing a harvesting method is the size of particles of the algae produced.

To produce biodiesel from algae economically is the primary challenge to date. After harvesting, the wet slurry of the microalgae undergoes dewatering for further processing. Drying of the harvested algal biomass which is 90% water presents an obstacle to making the algal biodiesel commercially viable, as it takes up vast amount of energy and time in order to gain dried biomass for lipid extraction. It was reported that drying of microalgae biomass by centrifugation and tangential filtration can account for 20% to 57% of the final total production costs of algae biomass [4, 6–7] which makes up the overall net energy ratio [8]. Though many researchers use freeze drying technique to dry the wet algal biomass [9], the drying method is believed to affect the phytochemical properties in algae such as the fatty acids as well as the anti-oxidant content in algae.

Sun drying has long been traditionally employed to dry crops, thus, it is not new to the area of drying research. Drying is a continuous process with simultaneous changes in the moisture content of the crop being dried and in the air humidity [10].

Bagchi et al. [9] wrote about an oven drying protocol to improve biodiesel production for an indigenous chlorophycean microalga Scenedesmus sp. They concluded that spray and freeze drying technique are not economically feasible for microalgal biofuel production. Oven drying has become one of the common drying methods other than sun drying. Usually for research purpose, the temperatures are set to be constant at 3 different levels, namely 60, 80 and 105 °C, as recommended by the standards [11].

The objective of this research is to examine the parameters that could affect the drying process and this paper will report the best possible drying method for high lipid yield. A research at Faculty of Engineering of Universiti Malaysia Sabah on a modified solar chimney dryer [12] has found an increase of 13% in the evaporation of water, supporting the earlier results of natural convection air flowrate enhancement by the same type of chimney [13], and the solar chimney drying system was therefore adopted for this project.

2. Material and Methods
The project experiments involved 5 stages which were cultivation of algae, harvesting, drying, lipid extraction and analysis and profiling (figure 1). The species of algae used was Chlorella sp. It was decided to cultivate the algae locally using Jaworski’s medium to ensure the harvest yield is of sufficient quality and lessen quantity lost. It is usually the medium used to cultivate freshwater algae or usually for green freshwater algae.
A pyranometer was used to measure solar irradiation rate and thermocouples at various places to measure the air temperature in the ambient, in the oven and at the chimney outlet. Humidity was also measured digitally together with the air temperature.

2.1. Drying rate and Moisture Content

The weight of sample was measured according to the interval chosen. The average weight of each sample was approximately 0.5 g, in thin slices. The drying rate is usually calculated by observing the mass loss during the drying using the following equation [14–16]:

\[
Drying\ rate = \frac{Initial\ weight - Final\ weight}{Time\ Interval\ (h)}
\]  

(1)

The moisture or water content of algae is the difference of the initial weight of sample and the weight of sample after being dried in oven when all the water has been removed. Moisture content of algae is calculated using the formula given below [11]:

\[
MC = \frac{Initial\ Weight - Oven\ dry\ weight}{Initial\ Weight} \times 100\%
\]  

(2)

Centrifugation is the fastest harvesting method but is also the most expensive due to the high consumption of energy. To achieve high harvesting efficiencies, longer retention times are required for sedimentation due to the relatively low density of the cells. In these experiments the centrifuge was operated at a low flow rate of 3000 rpm for 5 minutes.

2.2. Drying

In this project the methods used were oven drying, open sun drying and solar chimney drying. Drying of sample was done for 4 runs on different days with 1 sample for each different drying method. The experiments were commenced at 8.00 a.m. and ended at about 6.00 p.m. depending on the weight measured.

Thick microalgae slurry was spread uniformly in glass petri dishes in identical manner and placed in a laboratory-scale hot air oven, in the open sun (figure 2) and in the solar chimney dryer where the water pool had been removed and replaced with the dishes (figure 3). The transparent sheet shown was made of polyethylene capable of blocking UV radiation. The oven drying temperature usually would be set at 60 °C, 80 °C and 105 °C but for this research the temperature was kept constant at 60 °C to conserve the composition and the sample was weighed at 2-hour intervals until the reading of the weight reached a constant value [8].

2.3. Lipid Extraction

There are several ways of lipid extraction, where some extraction methods do not require drying step and can be performed in the presence of water and algae. The lipid extraction method used was Bligh and Dyer method, considered to be more effective and reliable than the classical Folch’s method [16]. The Bligh and Dyer extraction method requires drying steps to remove the water. Each sample of dried microalgae was mixed with a solution of (2:1) chloroform and methanol. The ratio of extraction solvent was 2:1 of Chloroform-methanol and the total solvent was 20 mL per gram. Since only 0.5 g of sample
was used for lipid extraction so the total volume of solvent used was only 10 mL. Samples and solvent undergo homogenizing. Next, solution was filtrated to remove the non-lipid substance and any sizeable biomass debris. Instead of using water on its own, sodium chloride solution was used as the washer and centrifuged at 3000 rpm for about 5 minutes to form two layers. The upper layer was removed while the lower layer (chloroform) containing lipid was recovered.

Figure 2. Open sun and solar chimney dryer [12]. Figure 3. Solar chimney dryer dimension [12].

3. Results Analysis and Profiling
Table 1 shows the lipid yield extracted from dried chlorella sp. using the Bligh and Dyer extraction method.

Each sample yielded different amounts of lipid but the trend of yield for each drying method is consistent for each sample. Table 1 displays that the average lipid yields for the three different drying methods are 0.119 g for oven drying, 0.103 g for sun drying and 0.122 g for solar chimney drying. This places the solar chimney drying method at the highest position of lipid yield and shows that this drying method has negligible damaging effect on the phytochemicals content in algae. The lipid yield in terms of percentage is also tabulated where the average lipid yield for oven drying is 23.65%, sun drying is 20.6% and solar chimney drying is 24.4%. The highest yield from solar chimney drying is probably because of the lower temperature and lower exposure to solar radiation. While the oven was not exposed to the solar radiation, 60 °C is still considered a high temperature compared to the temperature in the chimney solar dryer and high temperature can cause composition deterioration. Sun drying had been exposed to an ambient temperature of about 35 °C to 45 °C, lower than that of the oven drying method, but the samples dried by sun drying were directly exposed to the UV-B radiation which could alter the DNA, proteins, lipids as well as the membranes in the algae [17] while solar chimney drying with the polyethylene plastic sheet appeared to be less affected by the UV-B radiation and also the operating temperature was lower than the oven drying.

Enamala et al. [18] compiled a large database of algae strain and the vital and required growth parameters. There were nine sources for Chlorella sp. Covering marine and fresh water habitat, and various nutrients. The maximum yield as lipid wt% of biomass, was 48%, and the minimum 4.9%, where the average yield was 22.4%, which is of the same order as the results here. Aguoru and Okibe [19] reported on the content and composition of lipid produced by Chlorella Vulgaris for biodiesel production with the average lipid production at about 28% to 32% while the research on lipid production carried out by Hussain et al. [20] by employing different drying methods and different extraction methods resulted in lipid yield in the range of 14% to 23% by using Soxhlet extraction, Halim Extraction
and Bligh and Dyer methods. It would appear that the final yield depends on both the drying and the extraction methods since different lipid yields were obtained.

| Table 1. Lipid yield in algae *Chlorella sp.* |
|---------------------------------------------|
| **No. Sample** | **Oven Drying** | **Open Sun Drying** | **Solar Chimney Drying** |
|                | Lipid Yield, g / % | Lipid Yield, g / % | Lipid Yield, g / % |
| Sample 1       | 0.132 26.0         | 0.095 19.0         | 0.112 22.4         |
| Sample 2       | 0.153 30.6         | 0.119 23.8         | 0.099 19.8         |
| Sample 3       | 0.078 15.6         | 0.064 12.8         | 0.137 27.4         |
| Sample 4       | 0.112 22.4         | 0.134 26.8         | 0.139 27.8         |
| Average        | 0.119 23.65        | 0.103 20.6         | 0.122 24.4         |
| Error          | ±0.0319 ±6.3       | ±0.0306 ±6.1       | ±0.0195 ±3.9       |

A research on the effect of ultraviolet on plant cells mentioned that the isolated or conjugated double bonds in lipids can be photo-chemically modified by UV absorbance [17]. Phospholipid and glycolipids, the main components of plant cell membranes, contain unsaturated fatty acids which are destroyed by UV-B radiation in the presence of oxygen. This research supports the common findings concerning the effect of sun drying on the lipid yield of the algae where the sun drying lipid yield was the lowest amongst the other two methods, while solar chimney dryer was better and it was close to the oven drying method in terms of production of lipid for biodiesel. Until recently oven drying has been preferred as the best method in drying applications due to its speed while solar chimney drying is still a technology under development in harnessing a natural energy source (figure 4).

![Figure 4. Graph of drying rates versus time for different drying methods.](image)

4. **Conclusion and Recommendation**

In this paper the objective of determining and comparing lipid yield extracted from the microalgae *Chlorella sp.* via three different drying methods has been achieved. The three drying methods are oven drying, open sun drying and solar chimney drying. The solar chimney drying method could yield a relatively high lipid content to that of the oven drying method and the lowest was the sun drying. The
open sun drying was found to be significantly affected by the UV-B radiation since other researchers on
the effect of ultraviolet have mentioned that UV-B light can affect the lipid content in the algae, where
high temperature can be one of the factors that reduce the lipid production. Therefore, in terms of lipid
yield, solar chimney drying with UV protection might be the best choice since it appeared to preserve
the quality of the algae and can save the usage of energy where solar energy can be the source of
renewable energy to generate hot air through the application of a stable ventilation. For future study,
research on the solar chimney drying method is recommended to be carried out on a pilot-scale to replace
the conventional ways of drying.

Acknowledgments
The authors would like to thank the Ministry of Higher Education of Malaysia for providing a
fundamental research grant under the number FRG0352-TK-1/2013 and Universiti Malaysia Sabah for
the facility and laboratory support to carry out the experimental research.

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