

# From lab to full-scale ultrafiltration in microalgae harvesting

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**Abstract.** Ponding system is generally used for microalgae cultivation. However, selection of appropriate technology for the harvesting process is challenging due to the low cell density of cultivated microalgae from the ponding system and the large volume of water to be handled. One of the promising technologies for microalgae harvesting is ultrafiltration (UF). In this study, the performance of UF during harvesting of microalgae in a lab- and a full-scale test is investigated. The performances of both scales are compared and analyzed to provide an understanding of several aspects which affect the yield produced from lab and actual conditions. Furthermore, a unique self-standing non-modular UF is introduced in the full-scale test. The non-modular UF exhibits several advantages, such as simple piping and connection, single pump for filtration and backwashing, and smaller footprint. With those advantages, the non-modular UF could be a promising technology for microalgae harvesting in industrial-scale.

## 1. Introduction

Ponding system is still generally used for microalgae cultivation [1]. *Nannochloropsis sp.* is one of the microalgae which has high economic value and mostly cultivated due to its nutritional content and potentiality in a wide range of usage. Additionally, *Nannochloropsis sp.* is easily cultured, does not cause toxicity or damage to the ecosystem in the tub larval rearing, growing relatively fast, and contain antibiotic substances. However, low cell density resulted from the ponding system is still the main challenge. This low cell density is attributed to a low light intensity and a low CO<sub>2</sub> concentration in the water [2, 3]. The low cell density biomass and large volumes of water will become a burden on the harvesting process which is the largest cost in the production of biomass [4].

Basically, there are three main steps in the production of the biomass from microalgae which are cultivation, harvesting, and post-harvesting processes. Post-harvesting process is generally conducted after microalgae are successfully harvested and concentrated up to 10<sup>9</sup> cells/mL. Microalgae are usually harvested using the conventional process such as chemical flocculation and centrifugation. However, these conventional processes possess several disadvantages such as high chemical consumption, time-consuming, and expensive [5].

Recently, membrane technology is widely applied in almost every industrial sector due to advantages of this technology [6]. Energy efficiency, high separation capacity, selective separation, reduction in a number of unit process, and low investment cost are several advantages of membrane technology which made this technology is competitive compared to other technologies in various functions [7-18]. Ultrafiltration (UF) is a pressure-driven membrane process which is generally used in water treatment, wastewater treatment, biotechnology, food processing, etc. In microalgae harvesting, UF is the most promising techniques for concentrating microalgae [19-26]. The advantages of UF in



microalgae harvesting include less damage to cell integrity due to cross flow filtration mode, low or no chemical consumption, easy to scale up, flexible operation, and low energy consumption. However, fouling is still the main problems which result in flux decline overtime. Many strategies have been proposed to control the fouling phenomenon such as backwashing, chemically enhanced backwash, chemical cleaning, selection of appropriate operation, pretreatment, and membrane modification [13, 27-33]. By using the appropriate strategies, membrane technology could be operated effectively.

In this study, the performance of UF during harvesting of microalgae in a lab- and a full-scale test is investigated. The performances of both scales are compared and analyzed to provide an understanding of several aspects which affect the yield produced from lab and actual conditions. Furthermore, a unique self-standing non-modular UF is introduced in the full-scale test. The performance and advantages of this technique will be presented.

## 2. Materials and method

### 2.1. Lab-scale experiment

Microalgae were grown in the medium called “Walne medium”. It was made with the following composition: 100 grams of  $\text{NH}_4\text{NO}_3$ ; 20 grams  $\text{NaH}_2\text{PO}_4$ ; 33.6 grams of  $\text{H}_3\text{BO}_3$ ; 0.36 grams  $\text{MnCl}_2$ ; 1.3 grams  $\text{FeCl}_3$ ; and 45 grams of EDTA were dissolved in 1 liter of demineralized water. This solution is called pro-analyze. Then, 1 ml of trace elements is added into 1 liter of pro-analyze solution. The trace elements used were 2.1 grams of  $\text{ZnCl}_2$ ; 2 g  $\text{CoCl}_2$ ; 2 grams of  $\text{CuSO}_4$ ; and 0.9 grams of  $(\text{NH}_4)_6\text{MoO}_{25}$  which were dissolved in 100 mL of water. The medium is then sterilized if necessary. One milliliter of Walne medium was used for 1 liter of microalgae’s culture solution.

This study begins with acclimatization isolates of *Nannochloropsis sp.* in the laboratory by aerating the microalgae isolates for 2-3 days. Microalgae then cultivated in the Walne medium for about 2 weeks. Microalgae were aerated with 3 L/min compressed air and under artificial light of 2000 lux intensity. The light intensity is measured by lux meter.

Microalgae’s growth was assayed by taking a sample and then viewed under a light microscope to identify the cells. *Nannochloropsis sp.* that already reached the stationary phase will be counted the total cells using a counting chamber.

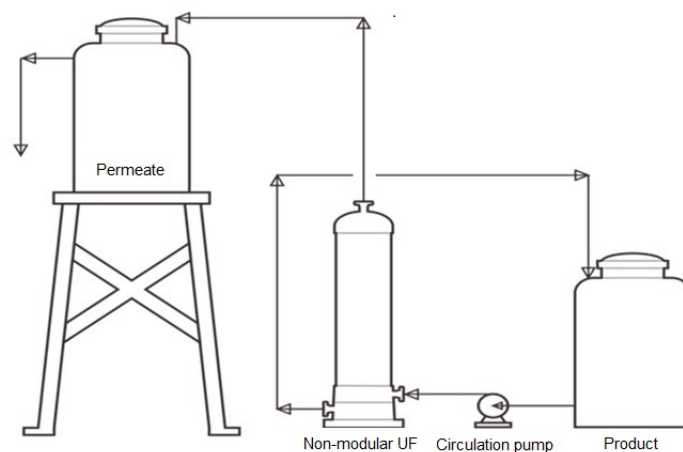
For filtration experiment, hollow fiber polypropylene ultrafiltration membrane (effective area:  $0.001 \text{ m}^2$ ) supplied by GDP Filter Indonesia was used. The UF was operated at 2 bar of trans-membrane pressure. UF process was held for about 90 minutes. Chemically enhanced backwash (CEB) was also conducted at 15 minutes duration with the interval of 30 and 45 minutes.

**Table 1.** Properties of full-scale UF membrane.

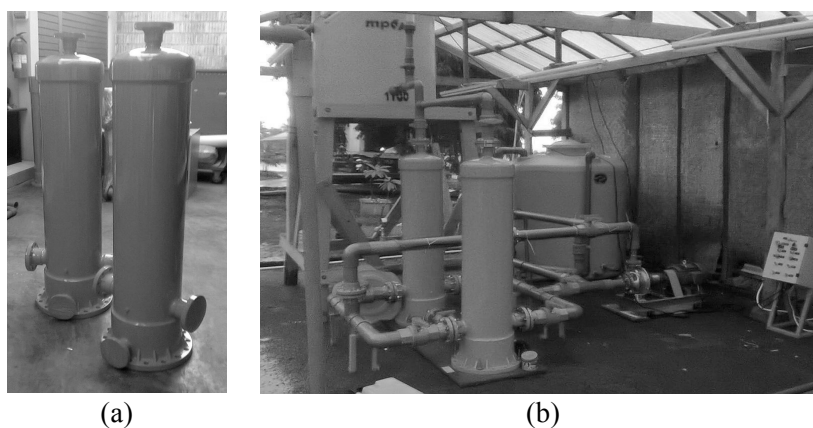
Properties	Value
Membrane material	Polypropylene
Hollow fiber OD ( $\mu\text{m}$ )	400
Membrane area ( $\text{m}^2$ )	120
Module diameter (inch)	12
Module length (m)	1,5
Feed pump type	Centrifugal
Head and impeller material	SS 316
Pump flowrate ( $\text{m}^3/\text{h}$ )	20
Pump head (m)	40
Motor power (kW)	4,5

### 2.2. Full-scale UF plant

The full-scale UF plant uses a unique self-standing non-modular UF membrane which is fabricated by GDP Filter Indonesia. The properties of the membrane are listed in table 1. Schematic diagram of full-scale UF plant for microalgae harvesting and the photograph of the plant are shown in figure 1 and 2, respectively. The plant consists of concentration tank (product tank) with capacity of 2.5 m<sup>3</sup> wherein cultivated microalgae from the pond will be concentrated, feed pump for pumping microalgae to UF module and backwashing of UF module when single batch of concentration cycle is completed, UF module, and permeate tank with capacity of 1 m<sup>3</sup> for storing permeate water which is used for backwash. In the operation, cultivated microalgae from the pond are pumped to product tank then it is fed to UF membrane using UF circulating pump where permeate is stored in permeate tank while concentrate is recirculated until desired cell concentration is obtained. This system utilizes a single pump for circulation and backwash. Backwash is conducted at the end of concentration cycle using a suction action of circulation pump which draws pure water from permeate tank through UF module. Air scouring is also employed during backwash.



**Figure 1.** Schematic of the full-scale UF plant



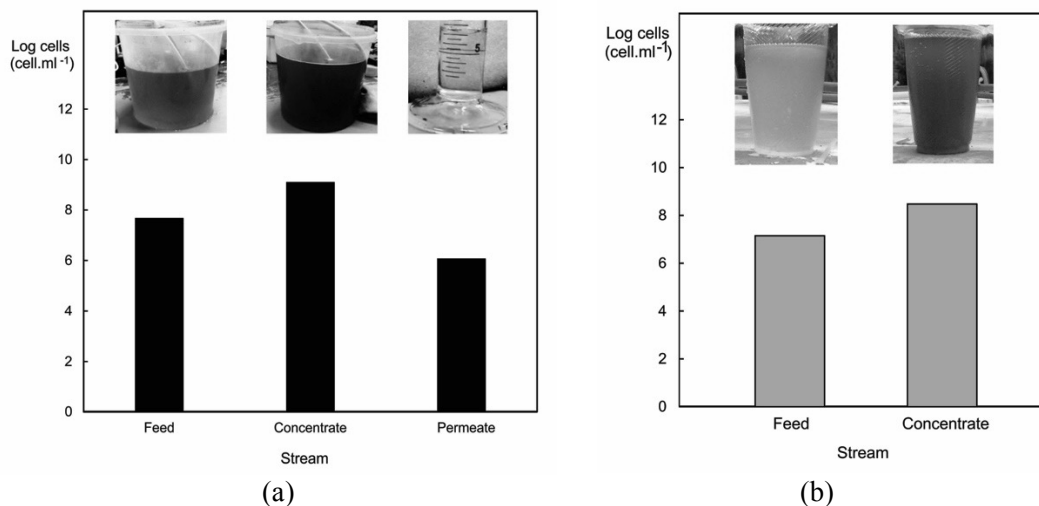
**Figure 2.** Full-scale UF: (a) Self-standing non-modular UF (12 inch in diameter) and (b) UF plant

### 3. Results and discussion

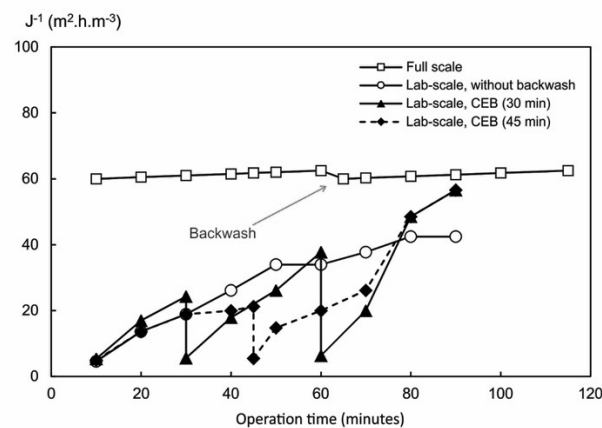
The performance of lab-scale UF in microalgae harvesting process is illustrated in figure 3 and 4. Figure 3 shows that UF is able to concentrate microalgae cells up to  $1 \times 10^9$  cells/ml from the cultivated

microalgae containing  $4.6 \times 10^7$  cells/ml. Almost 98% of the microalgae cells are successfully rejected by UF membrane. However, rapid flux declining was observed during the filtration. Chemically enhanced backwash was then conducted to recover the flux. Even though the backwash successfully recovered the flux, this rapid decline would not be applicable for the full-scale since it would require an intensive chemical backwash. Another alternative way for maintaining the flux stability is by operating the membrane under a relatively low flux. Under this condition, a drag force for solute deposition on membrane surface is decreased thus the fouling formation could be reduced [34, 35]. This strategy would be preferred for a large scale test.

For energy production purpose, open ponding system is the most suitable system for large-scale microalgae cultivation. Supported by tropical weather, it is considered a simple and low cost since it uses direct sunlight intensity for growth. In this study, full-scale microalgae cultivation pond consists of 4 square ponds with dimension of  $200 \times 200 \text{ m}^2$  each. The mature pond will have  $1.4 \times 10^7$  cells/ml in average that is 3 times lower than lab cultivated culture (figure 3). Contamination from the atmosphere and lower light intensity especially at rainy season are identified as the root cause of the problem. Growth competition between microalgae and zooplankton is also noticed which negatively affects microalgae population.



**Figure 3.** Microalgae cells in (a) lab and (b) full-scale test.



**Figure 4.** UF performance during filtration of microalgae in lab-scale experiment

Apart from its disadvantages, open ponding system is still attractive from economic and operation point of view while finding best harvesting system is the main challenge. Full-scale ultrafiltration plant for microalgae harvesting process has been successfully operated to concentrate cultivated microalgae from  $1.4 \times 10^7$  cell/ml to  $3 \times 10^8$  cell/ml (figure 3). According to experience in lab scale test, low flux ( $16,67 \text{ l.m}^{-2}.\text{h}^{-1}$ ) and high turbulence ( $\text{Re} = 16,121$ ) was used in the full-scale operation to maintain performance stability while outside-in filtration mode was used to prevent fiber clogging. High degree of turbulence which is applied in this process prevent the formation of the film layer on membrane surface resulting stable permeation flux with insignificant decrease. Low flux and high turbulence operation on full-scale plant exhibit lower filtration resistance due to cake build up indicated by the lower slope of  $1/J$  vs  $t$  as shown in figure 4.

Beside superiority in performance stability, the full-scale plant suffers disadvantage attributed to high circulation rate operation. At high circulation rate, heat is continuously generated which mainly due to intensive friction between the fluid and pump head (especially when using a centrifugal pump) and accumulated to the circulation fluid thus significantly increase its temperature. A significant increase in temperature may have a negative effect on cell survival during storage. For better performance, positive displacement pump e.g. rotary screw pump is recommended since the friction is lower even at high circulation rate. According to our experience in full-scale operation, we found that there was an entrapped volume of fluid with high cell concentration inside ultrafiltration module as a dead volume at the end of concentration cycle which is proportional to module dimension. This fluid should be drained from module before backwashing UF module. To enhance draining process, pressurized air from is used to force the dead fluid out of UF module by flowing from lumen side to shell side (backwash flow).

#### 4. Conclusion

In this study, the performance of UF during harvesting of microalgae in a lab- and a full-scale test is investigated. The performances of both scales are compared and analyzed to provide an understanding of several aspects which affect the yield produced from lab and actual conditions. Furthermore, a unique self-standing non-modular UF is introduced in the full-scale test. The non-modular UF exhibits several advantages, such as simple piping and connection, single pump for filtration and backwashing, and smaller footprint. With those advantages, the non-modular UF could be a promising technology for microalgae harvesting in industrial-scale.

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