

## Experimental and Simulation Study of Small Scale PV Powered Photobioreactor for *Nannochloropsis oculata* Cultivation

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**Abstract**— Microalgae has become promising third generation source of biodiesel material recently. One of the methods that is used for microalgae cultivation is by using photobioreactor. The advantages in using photobioreactor to cultivate microalgae are the easiness to control optimum growth parameters and to protect culture from external contamination. However, to run a photobioreactor, considerable amount of energy is required in the form of electricity. To achieve zero emission production, renewable energy system such as PV system can be used to run the photobioreactor. In this research a PV system has been used to supply energy of a small scale photobioreactor for *Nannochloropsis oculata* cultivation. The experimental setup were operated for one cycle cultivation that takes about seven days long. 500 Wp PV panel and 400 Ah battery capacity of 12V PV system were used. It is shown that the system can supply the required energy during the cultivation time. Yet, the SoC of battery shown decreasing level during operation. It is revealed that the system that is used for experiment need to be redesign and simulation using TRNSYS is used to test the recommended system setup.

**Keywords**— Microalgae, TRNSYS, system design, renewable energy.

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### I. INTRODUCTION

To overcome energy crisis that is threaten our future, energy diversification is important especially from renewable energy resources. Biomass energy sources such as briquet, biogas, bioethanol, and biodiesel are potentially replaced fossil fuel. Biodiesel could replace liquid fossil fuel particularly diesel fuel that is greatly used in transportation. Since the properties of Biodiesel that is resembled diesel fuel, it can be used with less machine modification [1].

Not all species of microalgae appropriate for biodiesel production, it is depend on the type and amount of oil that is produced by it [2]. Total lipid percentage such as neutral lipid, glycolipid, and phospholipid are vary for each species of microalgae [3]. From several species listed in Table 1, *Nannochloropsis* sp. are categorized as microalgae with high content of oil. Furthermore, *Nannochloropsis* sp. can be growth with high cell density (50 and 27.5 g/L) in an autotrophic growth condition and produce high lipid content (52% and 46%) [4].

Microalgae can be cultivated through open system such as open pond or closed system such as photobioreactor [5]. Open pond cultivation system are generally used nowadays since the cost to build it relatively cheaper than other system. Even though the cost of making open pond system is cheaper, contamination from other species of algae or even

bacteria are likely occurs. Other disadvantages of open pond system is the area needed will be wider since the depth of the water should be limited so sunlight can pass through the water and evenly distributed. Cultivation with closed system (without light) only suitable for several species of microalgae (heterotrophic microorganism) and not as efficient as photosynthetic process (photoautotrophic). Microalgae cultivation system using photobioreactor has several advantages i.e. the ability to control optimum growth parameters, protection from culture contamination, and area efficiency by using vertical system. However, installation and operational cost might be more expensive.

In photobioreactor operation power supply are needed to supply energy for pump, monitoring and control system, and other required supporting devices. If this kind of energy source are come from conventional grid electricity it would not be a pure renewable energy production system. The use of solar energy (photovoltaic) to supply photobioreactor system is one of the solution to achieve production system that is purely come from renewable energy. From this research it is expected that data related to load profile of small scale photobioreactor can be obtained especially for operation in tropical country climate (Indonesia). In addition, the data that is obtained from this research hopefully would be used as input data for photovoltaic (PV) power system sizing for photobioreactor operation and for system simulation. It is expected from this research PV

powered photobioreactor model can be used to predict and observe the behavior of the real system so it can simulate the real condition to achieve reliable system. Model that is developed in this research are validated using experimental data for small scale photobioreactor system.

## II. MATERIALS AND METHOD

### A. PV System design using PSH Method

To design standalone PV system using PSH method, firstly, solar energy potential for the location and daily electricity load need to be known. Photobioreactor prototype that was used in this research using a water pump with 60Watt power and operational time of 24 hours. From this data total daily electricity power ( $P_{total}$ ) for the prototype is about 1440 Wh/day. Solar energy potential for East Java area can be found on global solar radiation map, i.e. about 4.5 kWh/day, this value equal to 4.5 PSH.

By using the above data PV panel and battery capacity can be calculated using the following equation:

$$P_{PV} = \frac{P_{load}}{PSH \times \eta_{system}} \quad (1)$$

$$C_{bat} = \frac{P_{load} \times N_a}{DoD \times V_{system} \times \eta_{system}} \quad (2)$$

- $P_{PV}$  = PV panel capacity (Wp)
- $P_{load}$  = Daily electricity load
- $PSH$  = Peak Sun Hour
- $\eta_{system}$  = System efficiency
- $C_{bat}$  = Battery capacity
- $DoD$  = Depth of Discharge
- $N_a$  = Autonomy day number
- $V_{system}$  = System voltage

Other parameters such as system efficiency, system voltage and DoD are presented in Table 1.

TABLE I  
PARAMETERS VALUE FOR CALCULATION

No.	Parameters	Value	Unit
1	System efficiency	90	%
2	System Voltage	12	Volt
3	DoD	50	%

The value of system efficiency parameter is the total efficiency include energy lost because of cable connection, dust factor, inverter efficiency and charging efficiency. System voltage of 12V was chosen for small scale system (under 1 kWp), while for DoD, the "sweet spot" value of 50% was used for a trade off between optimum energy consumption and battery age [6]. From the calculation and sizing curve of PV panel and battery capacity it can be found for 1440Wh daily electricity load and PSH of 4, the suitable PV system configuration consist of 457Wp PV panel and 1028Ah battery capacity for 12V system. The value of PV panel and battery capacity then adjusted by rounding the number up or down so the capacity meet the available PV

panel in the market. It is recommended to round the number up so the capacity would not be under-design. Finally, the recommended configuration are 500Wp PV panel with 1000Ah battery for 12V system.

### B. Experimental Setup (Photobioreactor, PV System, and Culture)

For this research case, electricity load is electricity energy that is needed by photobioreactor system. Photobioreactor electricity load actually consist of circulation system power (pump), monitoring and control, and also supporting devices. However in this research, small scale photobioreactor that only needed circulation and aeration system are used. So, operational characteristic of photobioreactor electricity load depend on pump operation. Fig.1 shows experimental set up for PV powered small scale vertical photobioreactor.

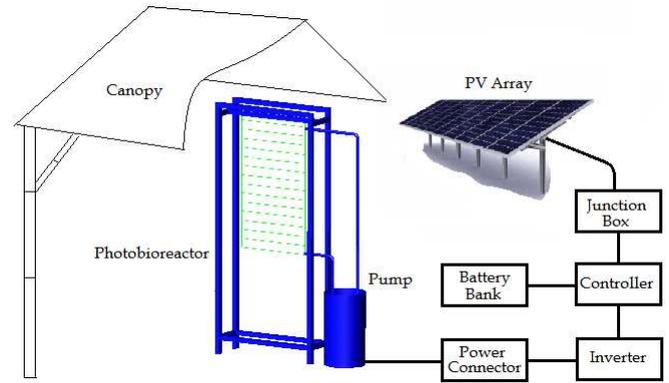


Fig. 1 Experimental setup

PV system are installed to supply power of aerator and pump. PV system specification for the experiment are presented as follow:

TABLE II  
PV SYSTEM SPECIFICATION

No.	Item	Specification
1.	PV Panel	400 Wp (minimum)
2.	Battery	400 Ah, 12V (minimum)
3.	Controller	30A
4.	Inverter	500W

Small scale vertical photobioreactor has been developed with PE plastic as the material. This photobioreactor has been tested to cultivate *Nannochloropsis oculata* with grid electricity as the power source [7]. This photobioreactor was operated outdoor with canopy to avoid direct sunlight that can induce *photoinhibition*. This photobioreactor use 60 Watt pump with 24 hours daily operation time. Total energy used for this photobioreactor prototype ( $P_{total}$ ) is about 1440 Wh per-day.

Microalgae seeds used in this research are *Nannochloropsis oculata* pure culture. 1 mL Walne fertilizer are used for each Liter of culture. N. Oculata culture preparation consist of several steps: Sealed plastic are hanged on steel frame as shown in Fig.1; water are circulated through pipe and photobioreactor plastic by using submerged pump; sterilized drum with submerged pump inside are filled with sea water; 1 mL Walne fertilizer are

mixed with 1 Liter of sea water and left  $\pm$  5 minutes until homogen culture are obtained.

### C. System model in TRNSYS

To produce reliable PV system in supplying required energy for photobioreactor, PV components sizing are required. Sizing method using Peak Sun Hour (PSH) can be used for instant design. The result of this design then can be tested using PV model simulation in TRNSYS software.

PV system model that is used for simulation in this research are based on standalone PV system model that is developed by Al Riza, 2011 using TRNSYS 16. The model will also be validated using experimental data from this research. Further analysis can be carried out by using simulation with full year meteorological data.

## III. RESULTS AND DISCUSSION

### A. Photobioreactor performances: Growth of Microalgae

It is revealed from the research that flow rate of the culture affect the growth of microalgae. *N. oculata* density are decreased as increasing of flow rate as can be seen in Fig. 2. Andriyono (2001), explained that illumination periodic take an effect on synthesis process of organic material in photosynthesis since only with required energy the process will be running smoothly [9]. Flow rate also will affect the amount of sunlight received by the culture, less sunlight will cause unoptimal photosynthesis process whereas too high sunlight intensity will lead to photoinhibition phenomenon.

Hermanto *et al.* (2011) who's used flow rate of 0.6 L/minutes achieved cell density of  $3293 \times 10^4$  cell/mL for *Nannochloropsis oculata* species. The differences with this research result is suspected because of water temperature and sunlight amount during the experiment. It is also supported by Fabregas *et al.* (1986) in Sutomo (2005) explanation that salinity, pH, nutrition, temperature, carbon

source and light affect phytoplankton growth [10]. Fig. 3 shows photobioreactor during operation.



Fig. 3. Photobioreactor operation

### B. Photobioreactor performances: Water parameter dynamic

pH value during experiment are in the normal range for *Nannochloropsis oculata* growth, this microalgae species are well growth in pH range of 7.0-9.5 [11, 12, and 13]. pH value monitoring results are presented in Fig. 4. From the experiment treatment each flow rate result in different pH value. The best pH value range are obtained with 0.8 L/minutes flow rate condition. pH value obtained by this condition ranged from 7.06-8.06.

From the measurement, it is revealed that base pH condition result in lower growth rate of microalgae. This condition has also been explained by De La Noue dan De paw (1988), that pH value of the culture will affect biological ability of algae in using nutrient in the culture [14]. High pH value can reduce photosynthesis activity of microalgae. Eventhough Walne fertilizer has a complete nutrient composition, if photosynthesis process are hung up the cell growth will be halted and lead to cell mortality.

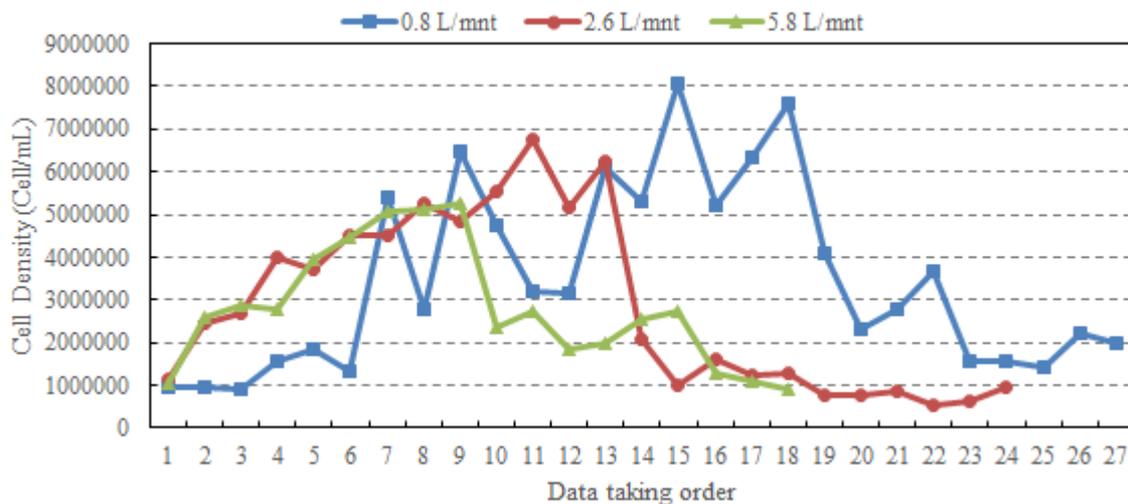


Fig. 2 *Nannochloropsis oculata* cell density during experiment

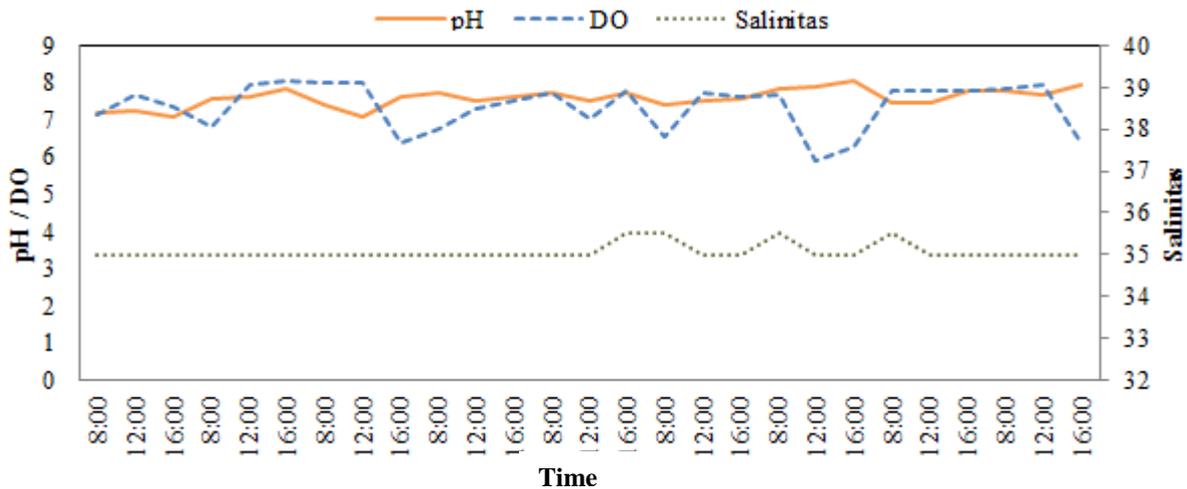


Fig. 4 pH, DO, and Salinity measured during experiment

Beside of that, Barus (2002), explained that culture condition that is too acid or too base are not good for microalgae growth since metabolism and respiration process will be disturbed [15].

Dissolved oxygen value as can be seen in Fig. 4 are relatively in the stable range between 6.17-8.23 mg/L. It is found that oxygen received and released by the culture relatively in normal condition. Oxygen diffusion process are maintained by using aerator. Salinity value during experiment also found to be stable about 35-35.5 o/oo for 0.8 L/minutes treatment and 35 o/oo for 2.6, 5.8 L/minutes dan control condition. It means that evaporation of the culture is minimum since it is a closed system that is placed under a canopy. Evaporation can be occurred due to heat of lamp during night (artificial lighting) or sunlight. Evaporation will reduce the amount of water in the culture and increase the salinity value [16]. Optimum salinity range value for *Nannochloropsis oculata* are between 25-35 ppt [17].

It is revealed that salinity and pH value of the culture are correlated, high pH value affect microalgae photosynthesis activity. So, the microalgae growth rate are affected by pH value of nutrient that lead to limitation of microalgae ability in using culture nutrient in their metabolism. The amount of nutrient that is unused during the process and organic metabolism residue give rise to salinity value. Higher pH value cause increasing of salinity as microalgae growing. The microalgae are growth for about 8 days, until it reach constant growth phase or even mortal phase.

### C. Energy balance analysis of the system

Fig. 5 shows the results of PV system power measurement during experiment. The input energy available during the day and there are no energy input during night whilst the energy output for pump and aerator occurs full day. Electricity load constantly used for 24 hours per day with

total power of 60 Watt. It can be seen that output energy during the night relatively constant. Load profile changes in the graphic estimated related with sensor accuracy and pump rotation load that is little bit fluctuated. During the day there are energy input from solar irradiation and output for electricity load, it is shown that there are surplus energy during the day that will be stored in the battery to supply energy for the system during the night. So beside supplying energy for the load the PV system also charging the battery that used to save energy for night.

It can be seen in Fig. 6 that battery voltages are vary in accordance with the energy level condition and state of charging and discharging. Battery voltage can be used as an indicator for state of charge (SOC) of the battery. During the night, battery in the condition of discharging so battery voltage constantly decreasing. Battery decreasing slope are depend on the amount of load In this experiment, since the electricity load are constant, the decreasing rate of battery voltage (slope) also found to be constant.

PSH value from first day to the last day of experiment are 4.3, 4.5, 3.5, 4.8, 3.0, 4.8, 1.5, and 4.5 consecutively. On the 3<sup>rd</sup>, 5<sup>th</sup>, and 7<sup>th</sup> day can be seen that solar irradiation are low with PSH value under the designed PSH value. This condition cause system can not supply and charge battery to reach the initial state of charge level. This lead to the decreasing of battery voltage during the experiment. Battery voltage which indicate the energy level of the battery will increase if there are energy surplus of the system which is reached under PSH value more than 4.5. However, generally, based on measurement data, PV system performance are relatively good since it can supply energy until the experiment is over. Overall system performance should be further analysed with longer time of PV-photobioreactor running. It can be done with simulation using full year meteorological data.

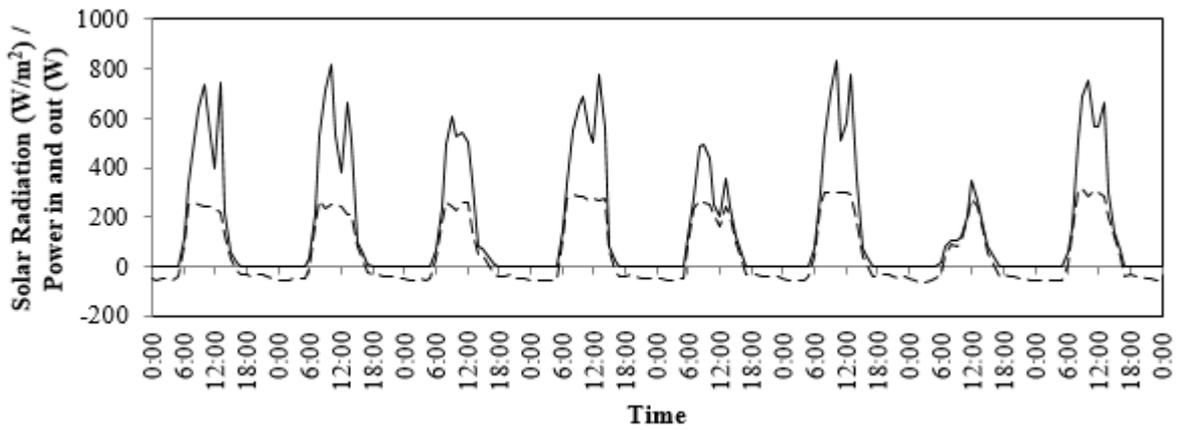


Fig. 5 Energy input and output of PV-Photobioreactor system during the experiment

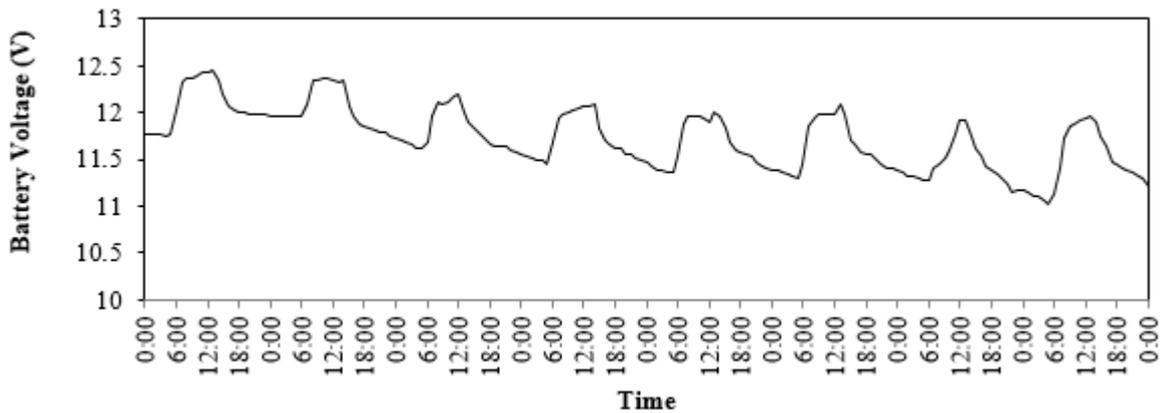


Fig. 6 Battery Voltage monitoring during the experiment

Based on observation of fat content of *Nannochloropsis oculata* during experiment, it has been found that on the last day of experiment fat content of the microalgae reach 3.56%. At the peak growth curve, fat content of the microalgae are about 17.89% with light intensity between 1000-2000 lux. Previous research relating to fat content of *Nannochloropsis oculata* is about 4.29% [16], and other research state that the fat content of *Nannochloropsis oculata* can reach value of 31-68% depend on culture conditon. Harsanto (2009) conducted *Nannochloropsis oculata* outdoor bulk culture at light intensity of 9000 lux, resulting total fat content of 36%.

Fat content of microalgae are increasing under condition of low nitrogen [16]. In Rizky (2010), Nitrogen source as a culture component are come from urea as a source of organic nitrogen. Nitrogen is a macro nutrient element that affect metabolism process of microalgae such as transport, catabolism, asimilation, and especially protein biosynthesis since enzymatic reaction allows the conversion of fat so indirectly Nitrogen content will affect the fat content. Low Nitrogen concentration will increase fat content, but cell concentration will be reatively low.

From the experiment data calculation total energy Input needed for the photobioreactor operation was 1.516 MJ/kg of microalgae with output energy from microalgae of 1.750 MJ/kg. This calculation means there is surplus energy produced by the system about 0.19 MJ/kg.

According to the observation photobioreactor energy demand was fully supplied during microalgae cultivation. In this experiment *Nannochloropsis oculata* reach its peak growth in about 9 days with cell density ranged from 6-8 million cell/mL.

#### D. Simulation results of the system

Fig. 7 shows simulation results of the PV-photobioreactor system with full year meteorological data. It can be seen from the fluctuation of SOC that the system can supply the energy requirement of the system throughout the year. Eventhough, during rainy season the SOC significantly decreased, so the system can not supply the energy requirement with note if the load are constantly operated throughout the year. It means that PV panel capacity design using PSH value should be increased as well as battery capacity to ensure reliability of the system.

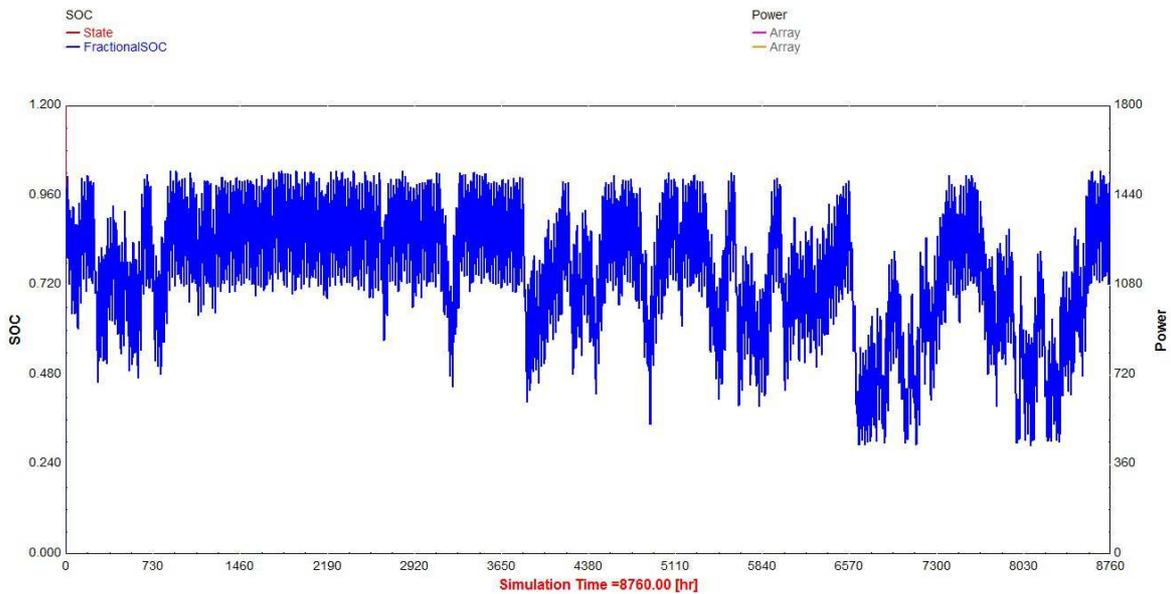


Fig. 7 SOC of battery of PV-Photobioreactor system

#### IV. CONCLUSIONS

Overall, PSH method for PV system design can be used for instant design of PV-Photobioreactor system. However, simulation results shows that if we could not predict exactly parameters value in PSH method formula the design could be under designed capacity as shown in the simulation results. Photobioreactor experiment result shows that *Nannochloropsis oculata* growth cycle reach it peak on between 10<sup>th</sup> and 11<sup>th</sup> day with fat content of 17.89% in the research. *Nannochloropsis oculata* has a potential fat content that can reach 30%. So, controlling microalgae growth parameters should be considered to achieve higher lipid content eventhough the energy requirement will be higher.

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