

The Drying Rate of *Chlorella pyrenoidosa* Using an Oven in Bioethanol Production

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ABSTRACT

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The production of bioethanol from microalgae goes through several stages, including cultivation, harvesting, drying, storage, and conversion to bioethanol. Nearly 40% of the total energy consumed in the bioethanol production from microalgae is from drying. This research aims to study the drying rate model of *Chlorella pyrenoidosa* using an oven. The drying is carried out at the temperatures of 50, 60, and 70 °C. The initial moisture content of *Chlorella pyrenoidosa* was 317.798% dry weight. The results showed that at the temperatures of 50, 60, and 70 °C, the critical moisture content was 9.108, 7.583, and 6.93% dry weight, while the equilibrium moisture content was 3.172, 3.158, and 3.109% dry weight. The most optimal drying is at 70 °C and the drying rate gets faster as the temperature does too. The Page model is better at describing the drying rate of *Chlorella pyrenoidosa* using an oven than the Newton model. The drying speed constants (k) were 0.00056, 0.00061, and 0.00208, at 50, 60, and 70 °C, respectively.

Keywords:

Chlorella pyrenoidosa; Drying rate;
Newton model; Oven; Page model

1. Introduction

The rapid global economic growth as well as population growth have led to an increase in energy demand [1]. The energy needs at this time are mostly met from fossil energy, which is not renewable (unrenewable fuels) and its availability is very limited [2]. As a result of this scarcity, new and renewable energy sources is needed. Biofuels, like biodiesel and bioethanol, are the answer to this problem [3].

The microalgae have good prospects to be developed as a raw material for biofuels production. Some of the biofuels that can be produced from them are biodiesel, bioethanol, and biogas [4]. They have the ability to grow quickly and do not require a large area for production activities, do not compete with foodstuffs and can grow in sea water, fresh water, or wastewater [5].

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The bioethanol production from the microalgae has several stages; they are cultivating and harvesting, drying, storing, and conversing to bioethanol [6]. Drying is process of removal water content. During drying process, heat is transferred from hot air to a product. Generally, on the same method, different product has their different drying rate and drying duration [7]. The drying process is important, because the energy conversion is very high. The post-harvested *Chlorella pyrenoidosa* contains 80-480% moisture content, so microalgae must be dried to 10% before being processed [8,9]. The drying process can also open the microalgae's cell walls [10,11].

This research studied the equilibrium moisture content, critical moisture content, and drying rate of *Chlorella pyrenoidosa* using an oven. In the previous studies, the drying was carried out at the temperatures of 40, 60, 80, 100, 120, and 140 °C. The result showed that the drying at 60 and 80 °C can maintain the characteristics of the microalgae [12]. Using too low or too high temperature will affect the color, structure, carbohydrate and lipid composition [13]. Therefore, in this study, drying was carried out at temperatures of 50, 60, and 70 °C. One important aspect in drying is the mathematical modeling of the drying process. There are several mathematical models for drying kinetics called Newton, Henderson and Pabis, Page, Modified Page, Logarithmic, Two-term Model, Two-term Exponential, Wang and Singh [14]. The purpose of mathematical modeling is to make it easier to choose the most suitable operating conditions. In addition, drying kinetics parameters can also be used to calculate drying speed, drying time, energy requirements, and designing drying systems on an industrial scale [8].

2. Methodology

The *Chlorella pyrenoidosa* slurry was obtained at UGO Plant Shop, Purworejo, Central Java. Before being used, it was stored in a refrigerator at 30 °C. Before the drying, it (± 50 g) was filtered using a filter paper (twice) and let stand for 15 minutes until a wet powder was obtained. The drying was done with 2 g of microalgae in a weighing bottle using an oven (Memmert, un 55). Every 5 minutes, the weight was observed using a digital scale (OHAUS PA214) and stopped after a constant weight was met. This drying was carried out at temperature variations of 50, 60 and 70 °C.

The moisture content analysis of *Chlorella pyrenoidosa* drying was calculated using Eq. (1), where M_t is moisture content (% dry weight), W_t is weight at observed time (g), and W_s is dry weight (g) [15].

$$M_t = \frac{W_t - W_s}{W_s} \times 100\% \frac{\text{g total water}}{\text{g dry solid}} \quad (1)$$

The equilibrium moisture content was identified when there was no change in the water content, also the critical moisture content was an average material moisture content at the end of the constant-rate-drying period, this period occurs before the equilibrium moisture content [10]. The equilibrium moisture content was calculated using Eq. (2), where M_{eq} is the equilibrium moisture content (% dry weight) and W_{eq} is the equilibrium weight (g) [15].

$$M_{eq} = \frac{W_{eq} - W_s}{W_s} \times 100\% \frac{\text{g total water}}{\text{g dry solid}} \quad (2)$$

The main characteristic used to estimate drying performance is drying rate. The drying rate must be proportional to the difference in water content between the material to be dried and the equilibrium water content. The drying rate can be calculated using Eq. (3), where DR is the drying

rate (g/minute) and $W_{t+\Delta t}$ is the weight at $t + \Delta t$ (w/w dry), and Δt is the difference in temperature (minute).

$$DR = \frac{W_t - W_{t+\Delta t}}{\Delta t} \quad (3)$$

Several studies have mathematically modeled the drying curve with a variety of different methods. The simplest exponential model (Newton's Model) is shown as in Eq. (4), where MR = moisture ratio, M_t = moisture content at observed time (% dry weight), M_{eq} = the equilibrium moisture content (% dry weight), M_0 = initial moisture content (% dry weight), and k_1 = drying constant. The exponential model has been modified to produce Page Model like Eq. (5), where k_2 = drying constant and n = Page constant [8].

$$MR_{(cal)} = \frac{M_t - M_{eq}}{M_0 - M_{eq}} = \exp(-k_1 t) \quad (4)$$

$$MR_{(cal)} = \frac{M_t - M_{eq}}{M_0 - M_{eq}} = \exp(-k_2 t^n) \quad (5)$$

The value of each parameter (k_1 , k_2 , and n) was tested, so that the calculation results of moisture ratio (MR) approached the experimental data. For more systematic procedure, the differences in the calculation results and experimental data were calculated based on the minimum sum of squared error (SSE) as well as the R^2 from Excel software. The SSE equation is written as Eq. (6), where $MR_{(cal)}$ = moisture ration calculated result, $MR_{(d)}$ = moisture ratio data, and i = time.

$$SSE = \sum_{i=1}^{i=n} (MR_{(cal)}^2 - MR_{(d)}^2) \quad (6)$$

3. Results

3.1 The Effect of Temperature on *Chlorella pyrenoidosa* Drying using an Oven

The results of *Chlorella pyrenoidosa* drying at various temperatures (50, 60, 70 °C) can be seen in Figure 1. These curves have similar trends with drying result reported by Alimalbari *et al.*, [7]. Alimalbari *et al.*, [7] dried palm fruit using hot air-tray dryer with air temperature of 80 until 100 °C. As the temperature gets higher, the moisture content drops dramatically which then become constant. On other hand, the moisture content reduces exponentially as the drying time increased. In this research, the initially moisture content of *Chlorella pyrenoidosa* was 317.798% dry weight. After 100 minutes, the moisture content dropped to 230.5, 150.2, and 79.6% dry weight for 50, 60, and 70 °C, respectively. And after drying for 200 minutes it decreased to 163.2 and 18.8% dry weight for 50 and 60 °C, respectively. At this condition, for drying temperature of 70 °C, the moisture content of *Chlorella pyrenoidosa* was constant. However, for drying temperature of 60 °C, the moisture content was almost constant. The best drying time at 70 °C is 180 minutes, with moisture content of 1.671% dry weight.

Accordingly, the higher the temperature, the faster drying is [16]. This is also supported by previous research which stated that at the same time (10 minutes), the higher the power of microwave as energy source, the lower the moisture content would be [14]. Besides using an oven and microwave oven, drying of microalgae *Neochloris conjuncta* using greenhouse drying has also been studied. The moisture content was initially 70.9% w/w dry weight and after 56 h it became 21.65% w/w dry weight [17].

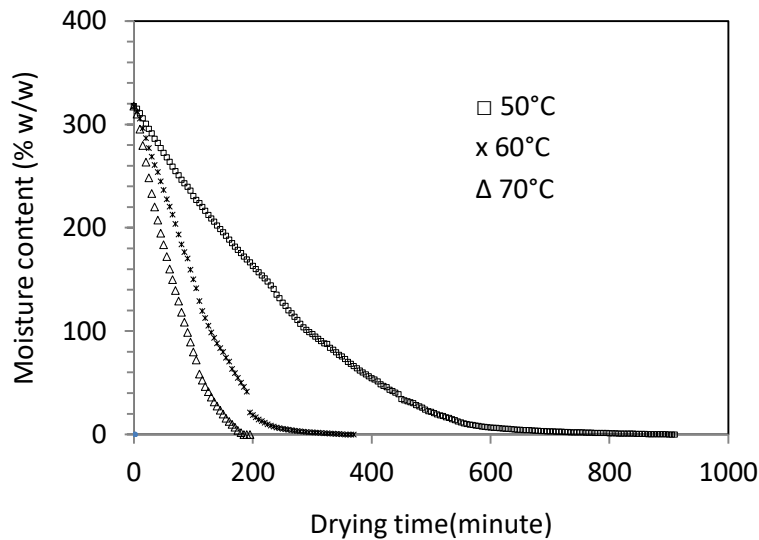


Fig. 1. The effect of temperature on *Chlorella pyrenoidosa* drying using an oven

The critical moisture content and equilibrium moisture content at each temperature variable is presented in Table 1. The values of the critical moisture content and equilibrium moisture content are different at various drying temperatures. In this research, the higher the drying temperature (50, 60, and 70 °C), the smaller critical moisture content achieved. This is due to more available energy could evaporate water at the higher temperature.

Whereas for the equilibrium moisture content, in this *Chlorella pyrenoidosa* drying, the higher the temperature, the smaller the equilibrium moisture content value will be. The equilibrium moisture contents at drying temperatures of 50 and 60 °C are still close, in which the difference is only 0.44%. However, the difference for temperatures of 60 and 70 °C is high, i.e. about 1.55%. This indicate that the drying temperature of 70 °C is very effective for *Chlorella pyrenoidosa* using an oven. This is in accordance with research conducted by Al Rey *et al.*, [14] and Hosseinizand *et al.*, [16]. They dried *Chlorella vulgaris* using oven and microwave, respectively [14,16]. It drying process of *Chlorella vulgaris* using an oven, at 40, 60, 80, 100, 120, and 140 °C, the moisture content equilibriums dropped to 16.9±2.0, 9.9±0.8, 5.1±1.4, 3.0±1.1, 2.2±0.9, and 1.3±0.3% dry weight, respectively [16]. This shows that the higher the temperature, *Chlorella vulgaris* has the drier the equilibrium moisture. In the study of Al Rey *et al.*, [14], the process drying of *Chlorella vulgaris* was carried out using a microwave, the equilibrium moisture contents at a power variation of 300, 600, and 900 W were 0.23, 0.07, and 0.001% dry weight. This shows that at a higher power, equilibrium moisture content will dramatically decrease [14]. In the drying process using microwaves as an energy source, higher power indicates a higher temperature.

Table 1

The critical moisture content and equilibrium moisture content of *Chlorella pyrenoidosa* drying using an oven

Temperature (°C)	Critical Moisture Content (% dry weight)	Equilibrium Moisture Content (% dry weight)
50	9.108	3.172
60	7.583	3.158
70	6.930	3.109

3.2 The Effect of Temperature on *Chlorella pyrenoidosa* Drying Rate using an Oven

The drying rate calculation results can be seen in Figure 2. These curves in the figure indicates that during the drying process, the drying rate is not the same. Theoretically, at the beginning of the process, the water on the surface will evaporate more easily, after which the water in the material will be difficult to get out [6]. Therefore, the drying rate will decrease during the drying. Recently, at the same drying times, the drying rate increases along with the increasing drying temperature [8]. Consequently, in this study, at 80 minutes, for 50, 60, and 70 °C, the drying rate was 0.492, 0.367, and 0.233 g/minute, respectively. From the figure, it can be seen that the achieved optimum drying rate of *Chlorella pyrenoidosa* using an oven is at 70 °C. Accordingly, at higher temperatures the relative humidity of the drying air was less compared to drying air at lower temperatures. Because of this, the higher temperature drying, the higher difference in the partial vapour pressure between material and the surrounding air environment will be. Hence, the moisture transfer rate was more with higher temperature drying air [7].

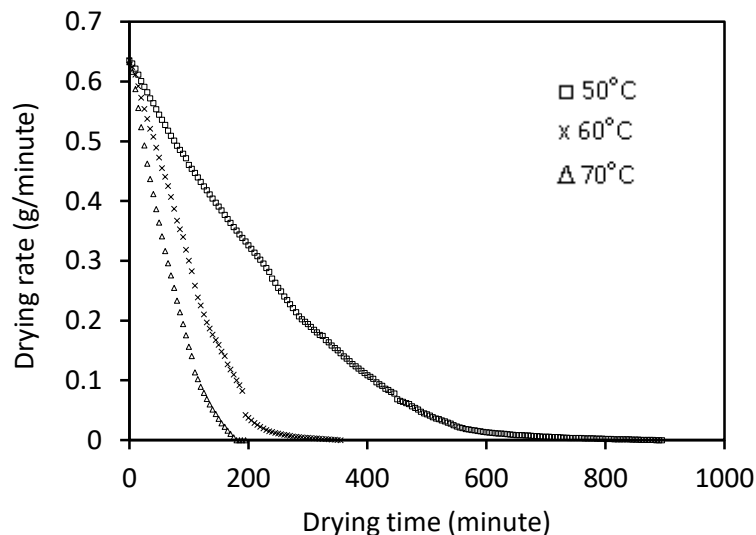


Fig. 2. The effect of temperature on the *Chlorella pyrenoidosa* drying rate using an oven

3.3 The Drying Models of *Chlorella pyrenoidosa* using an Oven

In this study, the drying models used are the Newton and Page Model. The calculation result for Newton Model can be seen in Figure 3. This figure shows that the Newton model cannot quantitatively describe the drying of microalgae *Chlorella pyrenoidosa* well. The values of the drying constant (k_1) are about 0.0041, 0.0092, and 0.014 1/minute for the drying temperature of 50, 60, and 70 °C. In addition, this model yielded the SSE and R^2 values of 0.0038 and 0.8529, respectively.

Figure 4 shows the drying kinetic using Page model. This figure indicates that the Page model is more suitable for the *Chlorella pyrenoidosa* drying, because it has a lower SSE value and higher R^2 compared to the Newton model, i.e. about 0.000428 and 0.856, respectively. This is in accordance with research conducted by Viswanathan *et al.*, [8]. In Page Model, the drying rate constants (k_2) are 0.00056, 0.00061, and 0.00208 min^{-1} as well as the Page constants (n) are 1.35, 1.56, and 1.43 at 50, 60 and 70 °C, respectively. The data comparison and the calculation results of the moisture ratio using the Page Model is presented in Figure 5 to Figure 7. These figures show that the calculation

results are close to the data, that is, approaching the diagonal line. Based on these three figures, the Page Model is suitable for *Chlorella pyrenoidosa* drying [18].

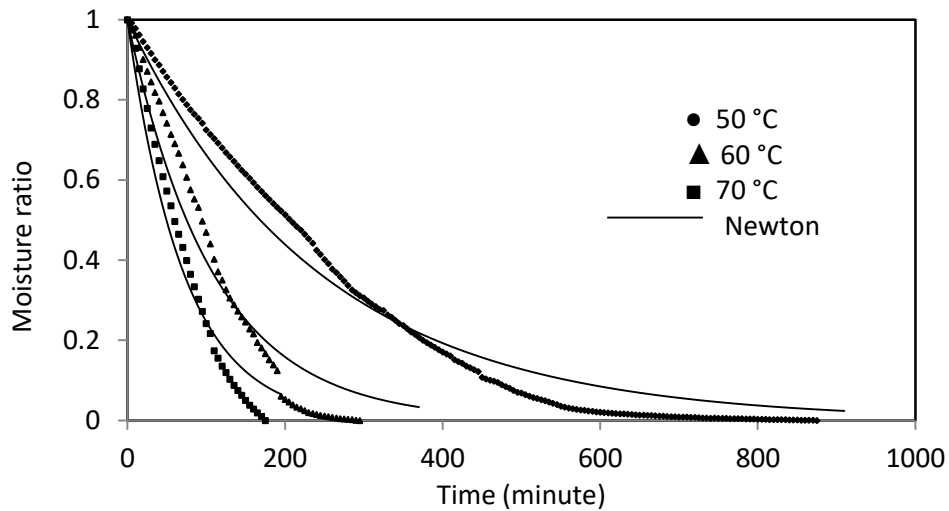


Fig. 3. The data comparison and moisture ratio calculation results of *Chlorella pyrenoidosa* drying using an oven (The Newton Model)

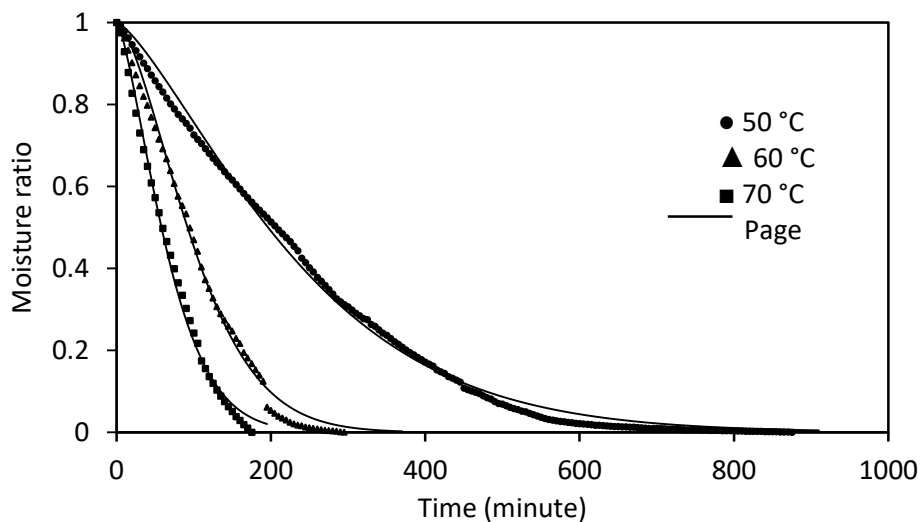


Fig. 4. The data comparison and moisture ratio calculation results of *Chlorella pyrenoidosa* drying using an oven (The Page Model)

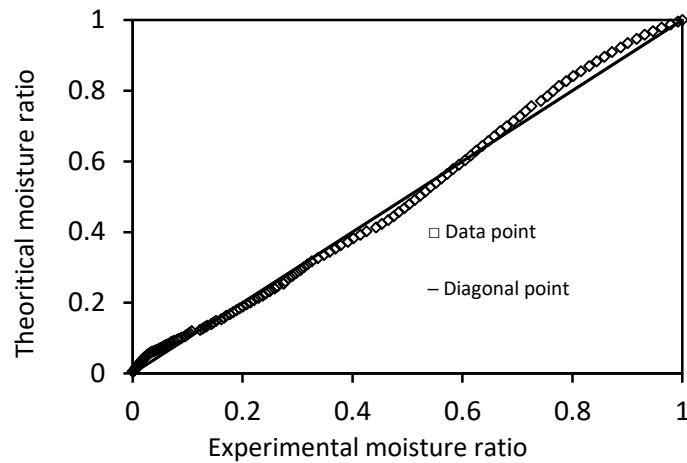


Fig. 5. The data comparison and moisture ratio calculation results of *Chlorella pyrenoidosa* drying using an oven (The Page Model at 50 °C)

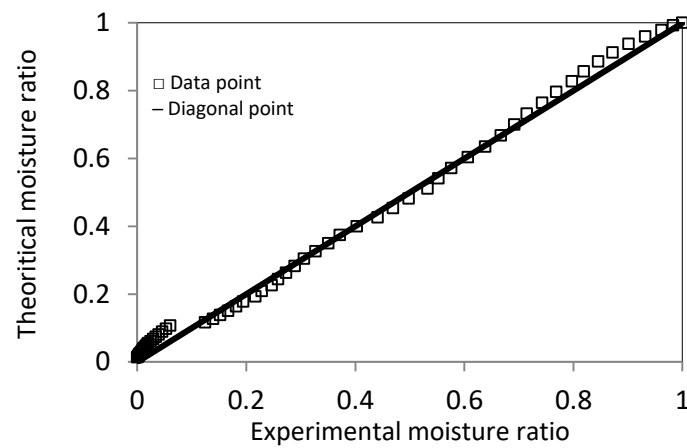


Fig. 6. The data comparison and moisture ratio calculation results of *Chlorella pyrenoidosa* drying using an oven (The Page Model at 60 °C)

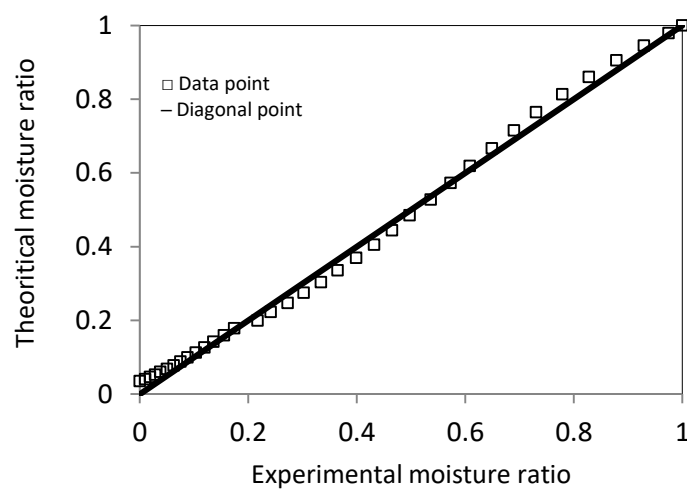


Fig. 7. The data comparison and moisture ratio calculation results of *Chlorella pyrenoidosa* drying using an oven (The Page Model at 70 °C)

4. Conclusions

In the *Chlorella pyrenoidosa* drying, as the temperature gets higher, the moisture content lessening becomes faster and the moisture content equilibrium becomes smaller. The higher the temperature, the faster the drying speed is. The optimum drying rate of *Chlorella pyrenoidosa* is at 70 °C with a drying time of 180 minutes. The appropriate drying kinetic model for *Chlorella pyrenoidosa* is the Page Model with an R^2 value of 0.856 and the drying rate constants are 0.00056, 0.00061, and 0.00208 min^{-1} for temperatures of 50, 60, and 70 °C, respectively.

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