Seaweed Drying Process Using Tray Dryer with Dehumidified Air System to Increase Efficiency of Energy and Quality Product

G B Pradana(1), K B Prabowo(1), R P Hastuti(2)*, M Djaeni(3) and A Prasetyaningrum(3)

1 Undergraduated in Department of Chemical Engineering, Faculty of Engineering, University of Diponegoro, Jl. Prof. Soedarto, Tembalang, Semarang, 50239, Indonesia.
2 Master Program in the Department of Chemical Engineering, Faculty of Engineering, University of Diponegoro, Jl. Prof. Soedarto, Tembalang, Semarang, 50239, Indonesia.
3 Department of Chemical Engineering, Faculty of Engineering, University of Diponegoro, Jl. Prof. Soedarto, Tembalang, Semarang, 50239, Indonesia.

Corresponding author: ririnpujihastuti75@gmail.com

Abstract: Seaweed, one of the marine resources has a high economic value but easily damaged in fresh condition. Drying method using air dehumidification system is an effort to decrease moisture content to prevent using high drying temperature which causes degrading quality. The process of drying seaweed with air dehumidification system using silica gel adsorbent becomes an option to decrease efficiently drying process. The purpose of this study was to examine the drying time and temperature of the moisture content, the rate of drying, energy efficiency, and the physiological properties of the dry product. Seaweed is dried in a tray dryer at 40°C, 50°C, 60°C, and 70°C for 2, 3, and 4 hours. The water content in seaweed is measured every 30 minutes. Seaweed water content according to SNI is obtained at drying for 4 hours at 50°C, 4 hours at 60°C, and 7 hours 40°C and 70°C for 2, 3, and 4 hours. The water content in seaweed is measured every 30 minutes. Seaweed water content according to SNI is obtained at drying for 4 hours at 50°C, 4 hours at 60°C, and 4 hours at 70°C. The increase in drying temperature is directly proportional to the high drying rate that occurs while over time the drying rate will decrease. At the optimum air temperature and drying time, the highest efficiency of tray dryer is obtained during drying for 4 hours at 50°C that is 91.50%. The highest swelling capacity value is owned by the dried seaweed product with a temperature of 50°C for 4 hours. Best condition in drying process of seaweed is used temperature 50°C at 4 hours.

Keyword: seaweed, drying, dehumidification, efficiency
1. Introduction

Indonesia is an archipelagic country with abundant marine resource potential, one of them is seaweed. Type of seaweed *Euchema cottoni* dan *Gracilaria sp* is widely developed and cultivated [19]. Seaweed has a high economic value in the cosmetic industry, food etc.[25]. Fresh seaweed has a high water content (75-85%), organic and mineral components (15-25%). Fresh seaweed is easily damaged and rotted, then drying is an important step before seaweed used in industrial processing[15].

Drying is a process to reduced water content from substances by using thermal energy to obtained dry product[26]. The benefit of the drying process is decreased water activity for inhibited growth microbe, maintaining a quality of product and reduced storage volume [22]. Drying with solar energy was widely used for the drying and preserving agriculture product, food, and other products in developing countries, but this process has high deficiency such as drying time, drying area, and susceptible to contamination [8].

The main problem of drying method was used a high temperature for the drying process. Seaweed contains polysaccharides, minerals, vitamins and substance of bioactive such as proteins, lipids, and polyphenols [5][4]. However, the organic component in seaweed will be damaged if exposed to high temperature and a long period of drying time [11]. The high temperature in the drying process will be damaged a lot of nutrition (crude lipid content and amino acid), decreased the physical properties, rehydration and antioxidant activity of seaweed [24]. Drying time will be shorter if used temperature under 70°C [8].

The other problem in the drying method is used energy wastefully[7]. The amount of energy can be reduced if the energy efficiency of the drying process increased. At present, the ranges of energy efficiency on the drying system are 30-60%, which means that the energy must be provided 2-3 times from the really needed. The low energy efficiency of the drying process caused an inefficient transfer mass from the material to the drying air. Especially in tropical regions has a high relative humidity (70-80%), it becomes saturated quickly when condition with high relative humidity used to dry media. At high relative humidity, the evaporation process of water will be hampered because driving force of water mass transfer from material to the air (drying media) becomes lower[2].

The process of drying seaweed with air dehumidification system using silica gel for adsorbent becomes an option to replace the drying system that has been developed[8] [21]. In this case, the air will be contacted with the absorbent (silica gel) to remove the moisture content (air dehumidification). Increasing the driving force of the drying process because of relative humidity was decreased [8]. Therefore, the process of drying seaweed will be dried at low temperature to the maintained quality of product and minimize drying energy. The purpose of this study was to examine the drying time and temperature of the moisture content, the rate of drying, energy efficiency, and the physiological properties of the dry seaweed.

2. Material and method

2.1. Materials

This research was used seaweed (*Euchema Cottoni sp.*) from Jakarta and silica gel for an adsorbent agent from Indrasari (Chemical store in Semarang, Indonesia) and try dryer for a dryer.

2.2. Sample preparation

Seaweed samples were washed and soaked in the freshwater until 3 days to the removed soil, salt and coral. The silica gel must be regenerated with thermal treatment (120°C, 3 hours). The outside air as a
heating medium is heated at a certain temperature according to the variables (40°C, 50°C, 60°C, 70°C) and the corresponding drying time of the variables are 2, 3, and 4 hours. The water content in the seaweed was measured every 30 minutes by gravimetric method until the moisture content obtained constantly. The analysis in this research will be analyzed of water content used gravimetric method AOAC 2000, energy efficiency calculation, and seawater physiochemical properties test.

2.3. Energy Efficiency

Energy efficiency depends on several characteristics of a process such as a rate evaporation of water in material, steam as an air heater and heat energy. A general definition of energy efficiency in the drying process was a total energy used to evaporated water and it was divided total energy in the process [7].

\[ \eta = \frac{Q_{\text{out}}}{Q_{\text{in}}} \times 100\% \]

Energy efficiency (\(\eta\)) was calculated baseon the amount of heat released (\(Q_{\text{out}}\)) to raised the temperature of seaweed(\(Q_{\text{ensible seaweed}}\)), raised the temperature of water in seaweed(\(Q_{\text{ensible water}}\)), evaporated water from the surface of seaweed(\(Q_{\text{latent water}}\)), raised the air of dryer and evaporated water from seaweed divided by heat energy enter in the form of hot air (\(Q_{\text{hot air}}\)). Calculation of heat value (\(Q\)) calculated by equation [23] as follows:

\[ Q = m \times C_p \times \Delta T \]
\[ Q = m \times H_v \]

Information: \(Q\) is the heat needed (J/Kg), \(C_p\) water, \(C_{pv}\) is the specific heat of air and water vapor (J/Kg \(^\circ\)C); \(\Delta T\) is the changing temperature in and out (\(^\circ\)C); \(H_v\) is a heat of evaporation (J/Kg).

3. Physico-Chemical Properties

3.1. Water Swelling Capacity (WSC)

Aquadest 10 ml was mixed with 0,5-gram seaweed powder. The mixture was stirred in a measuring cup and left for 18 hours in the room conditions. The volume of water absorbed into the sample, it will be measured as swelling volume (ml/ gram drying sample). Test of the swelling capacity was carried out three times.

4. Results and discussion

4.1. Relation of time and temperature to water content

Figure 1 shows that the diffusion process of water into the dry air occurred. The water content of seaweed was decreased by the time [1].The results of modeling drying with tray dryer are the water content decrease rapidly until the decline slows and constant. The higher drying air temperature cause the lower water contents. A decrease water content will be faster because the greater heat energy is carried and the greater difference between heating media and foodstuffs will be encouraged evaporation process of water [14]. The higher dryer air temperature, the lower
relative humidity of the air [9]. Because of decrease relative humidity, heat and mass transfer will be a greater and increase the drying kinetics rate. According to the Indonesian Nasional Standard (SNI) about Quality Standard of Dry Seaweed, the water content of seaweed to storage is 20% ± 5%. The optimum time and temperature used to obtain water content 20% ± 5% were drying process 4 hours at 50°C and 60°C, 2 hours, 3 hours and 4 hours at 70°C.

![Figure 1. Effect of time and temperature on water content during the drying process at 2 hours, 3 hours and 4 hours.](image)

4.2. Relation of Time (t) and Temperature (T) Drying Process to Drying Rate.

Analysis drying rate was obtained by the reduction weight of wet seaweed which dried in the tray dryer at various temperature and time. This analysis aimed to compare the drying rate that occurs with variations temperature and time in the drying process. Quantity evaporated of water content per unit of time (gram/minute) or decreased water content in units of time was calling drying rates. The drying rate was usually increased at the beginning of the drying process and then constant. After that, it was decreased with time and decreased the water content of the material. Drying rate was a quantity of water content in the material which evaporated by a unit of dry weight in the material and unit of time [15]. In this drying process was equipped with an air dehumidification system and silica gel for an adsorbent agent to reduced moisture in the drying air. Using air dehumidification and silica gel will improve the ability to dry air to carry out moisture although at low temperatures [12].

The drying temperature was increased proportional to the high drying rates, especially if the material still contains a lot of moisture content at the beginning of the drying time. However, drying rate was decreased after it will a constant with the time of drying process. Increasing the drying rate was affected by the rise in temperature. The drying rate was decreased because less amount of water was evaporated as time goes by drying. In the beginning, the drying rate was very high because a lot of water
on the surface area of the seaweed material evaporated. Furthermore, molecules of water were diffusion from the seaweed cells into the surface layer [18]. Time in the diffusion process was longer needed that evaporation was occurred slowly [20].

4.3. Relation of Time (t) and Temperature (T) Drying Process about Energy Efficiency.

At the beginning of the drying process, the efficiency of tray dryer was high and decreased over time. During the longer drying time, the water content in the seaweed will be lower because the amount of the water will be less evaporated and the efficiency of the drying process decreases. Calculation of energy efficiency (η) was calculated based on the amount of heat to evaporated the water from the material (Qevap) divided by total heat requirements to regenerated the absorber and increase the air temperature (Qintr) [9]. The higher the drying temperature, the higher the heat to evaporate the water and the evaporation process of water will decrease. Because of using high temperature, efficiency drying process was higher at the beginning of drying seaweed. From the calculation of data, the average efficiency value of each variable was obtained as follows:

| Temperature | Efficiency (%) |
|-------------|----------------|
| 40 °C       | 90,768          |
| 50 °C       | 91,040          |
| 60 °C       | 91,485          |
| 70 °C       | 91,328          |

Based on the data, the optimum conditions were obtained when drying time and temperature at 4 hours 50°C, 4 hours 60°C, 2 hours, 3 hours and 4 hours 70°C. From these optimum conditions, the highest efficiency value was obtained during the drying process at 4 hours 50°C which was 91.506%.

4.4. Analysis of Physiochemical Properties of Seaweed Dry Products with Swelling Capacity Test

Swelling capacity test in the dried seaweed was obtained from the optimum condition in the several variables of the drying process. Result the swelling capacity test of seaweed follows by table. This research was conducted by the amount of water that absorbed into the dry seaweed from drying process using tray dryer. The most optimum variable was obtained from comparison selected variables (energy efficiency and quality of seaweed products). Swelling Capacity was absorbed the amount of water in the dry material every unit of weight dry [16]. Physiochemical properties such as swelling capacity can describe the fiber content in seaweed, as well as the polysaccharides, alginate, uronic acid, carrageenan, and proteins in the wall cell [27][3]. Characteristic of swelling will very important, especially for ingredients of the dietary food. Because of ability fiber to absorb and retain water, fiber can maintain health of colon and facilitate defecation process [13].

Based on Table 2, the highest swelling capacity was obtained by a variable of drying process at 4 hours 50°C. Swelling capacity tends to decrease when the drying process take a long time and high
temperatures. A high temperature in the drying process will damaged organic compounds in the ingredients of food because many polysaccharide chains will damage [12].

Table 2. Swelling capacity from the optimum condition

| Selected variable | Swelling Capacity (ml/g dry sample) |
|-------------------|-----------------------------------|
| Drying temperature (°C) | Drying time (hours) |
| 50                | 4                              | 10.85          |
| 60                | 4                              | 9.62           |
| 70                | 2                              | 10.01          |
| 70                | 3                              | 9.37           |
| 70                | 4                              | 8.99           |

5. Conclusion

In this research, increasing drying temperature was directly proportional to the high drying rate while the drying rate will decrease at over time. The water content of seaweed was obtained during at 4 hours 50°C, 4 hours 60°C, 2 hours, 3 hours and 4 hours 70°C in accordance with SNI. Efficiency drying was higher at the beginning of drying process before, constant and decreased at over time. The highest swelling capacity and tray dryer efficiency were obtained when drying at 4 hours 50°C, which was 10.85 ml / g dry sample for swelling capacity and 91.50% for the efficiency of tray dryer. Best condition in drying process of seaweed is used temperature 50°C at 4 hours.

References

[1] Agarry S E, Ajani A O and M O 2013 Thin Layer Drying Kinetics of Pineapple: Effect of Blanching Temperature – Time Combination Nigerian Journal of Basic and Applied Science 21(1):1-10
[2] Asiah N and Daeni M 2015 Multi Layer Onion Drying: Study of Mass and Heat Transfer Mechanism and Quality Evaluation AIP Conference Proceeding 1699
[3] Carvalho A F U, Portela M C C, Sousa M B, Martins F S, Rocha F C, Farias D F, and Feitosa J P A 2009 Physiological and Physico-Chemical Characterization of Dietary Fibre from The Green Seaweed Ulva Fasciata Delile. Brazilian Journal of Biology vol 69 p 969
[4] Chan P T and Matanjun P 2017 Chemical Composition and Physicochemical Properties of Tropical Red Seaweed J. Food Chemistry vol 221 p 302.
[5] Chandini S K, Ganesan P, and Bhaskar N 2008 In vitro antioxidant activities of three selected brown seaweeds of India. JFood Chemistry vol 107 p 707
[6] Djaeni M, Bartels P V, Sanders J P M, Straten G V, and Boxtel A J B 2008 Computational Fluid Dynamics for Multistage Adsorption Dryer Design J Drying Technology vol 26
[7] Djaeni M and Boxtel A J B V 2009 Energy Efficient Multistage Zeolite Drying For Heat-Sensitive Products J Drying Technology vol 27 p 721
[8] Djaeni M and Sari D A 2015 Low-Temperature Seaweed Drying Using Dehumidified Air. Procedia Environmental Sciences vol 23 p 2
[9] Djaeni M, Prasetyaningrum A, and Mahayana A 2012 Pengeringan Karaginan dari Rumput Laut Euchenna Cottoni pada Spray Dryer menggunakan Udara yang Didehumidifikasi dengan Zeolit Alam. Momentum p 28
[10] Djaeni M, Tryastuti M S, Utari F, Annisa A N, Novita D A 2016 *The Sappanwood Extract Drying With Carrier Agent Under Air Dehumidification*. IPTEK The Journal for Technology and Science vol 26

[11] Galaz P, Valdenegro M, Ramírez C, Nunez H, Almonacid S, and Simpson R 2017 *Effect of Drum Drying Temperature on Drying Kinetic and Polyphenol Contents in Pomegranate Peel*. J. Food Engineering p 19

[12] Gómez-Ordóñez E, Jiménez-escrig A, and Rupérez P 2010 *Dietary Fibre and Physicochemical Properties of Several Edible Seaweeds from The Northwestern Spanish Coast*. Food Research International p 2289

[13] Goni I, Gudiel-Urbano M, Bravo L, and Saura-Calixto F 2001 *Dietary Modulation of Bacterial Fermentative Capacity by Edible*. J. Agriculture and Food Chemistry vol 49 p 2663

[14] Graciafernandy, Ratnavati and Buchory L 2012 *Pengaruh Suhu Udara Pengering Dan Komposisi Zeolit 3a terhadap Lama Waktu Pengeringan Gabah Pada Fluidized Bed Dryer*. J. Momentum vol 6

[15] Gupta S, Cox S, and Abu-Ghannam N 2011 *Effect of Different Drying Temperatures on The Moisture and Phytochemical*. LWT - Food Science and Technology Elsevier vol 44 p 1266

[16] Miyagawa K, Ogawa I, and Yamano H 1995 *Calorimetric Measurements on The Swelling of Seaweed*. Thermochimica Acta vol 257 p 75

[17] Mujumdar A, and Tsotsas E 2011 *Modern Drying Technology, Volume 4: Energy Savings*. Lyon: Willey

[18] Phoungchandang S, and Saentaweesuk S 2011 *Effect of Two Stage, Tray and Heat Pump Assisted-Dehumidified Drying on Drying Characteristics and Qualities of Dried Ginger*. Food and Bioproducts Processing vol 89 p 429

[19] Sahat H J 2013 *Potensi Besar di Bisnis Rumput Laut*. In K. P. Indonesia, *Rumput Laut Indonesia* (p. 4). Jakarta: Kementrian Perdagangan Republik Indonesia

[20] Santos-Sánchez N F, Valadez-Blanco R, Gómez-Gómez M S, Pérez-Herrera A, and Salas-Coronado R 2012 *Effect of Rotating Tray Drying on Antioxidant Components, Color and Rehydration Atio of Tomato Saladette Slices*. LWT - Food Science and Technology vol 46 p 298

[21] Sappati P K, Nayak B, and Walsum G V 2017 *Effect of Glass Transition on The Shrinkage of Sugar Kelp (Saccharina Latissima) During Hot Air Convective Drying*. J. Food Engineering vol 210 p 50

[22] Shishir M R, and Chen W 2017 *Trends of Spray Drying: A critical review on drying of fruit and vegetable juices*. Trends in Food Science & Technology vol 65 p 49

[23] Smith J M and Ness V 1987 *Introduction to Chemical Engineering Thermodynamics*, 4 edition, McGraw-Hill Book Co New York

[24] Tello-Ireland C, Lemus-Mondaca R, Vega-Gálvez A, López J, and Scala K D 2011 *Influence of Hot-Air Temperature on Drying Kinetics, Functional Properties, Colour, Phycobiliproteins, Antioxidant Capacity, Texture and Agar Yield of Alga Gracilaria Chilensis*. LWT - Food Science and Technology vol 44 p 2112

[25] Wibowo L, and Fitriyani E 2012 *Pengolahan Rumput Laut (Eucheuma Cottoni) Menjadi Serbuk Minuman Instan*. 

[26] Wilhelm R L, Suter D A, and H, G 2004 *Drying and Dehydration*. In Food & Process Engineering Technology Michigan: American Society of Agricultural Engineers p 259

[27] Wong K, and Cheung P C 2000 *Nutritional Evaluation of Some Subtropical Red and Green Seaweeds*. Food Chemistry vol 71 p 475