A new innovative breakthrough in the production of salt

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Research article

A new innovative breakthrough in the production of salt from bittern using a spray dryer

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ABSTRACT

Spray dryer had long been used to dry liquid materials and produce dry crystalline products. However, the drying of the bittern to produce quality salt crystals has not been widely published. Therefore, the purpose of this study was to examine the effect of drying conditions of the bittern using a spray dryer to produce salt with a high natrium chloride (NaCl) content. Drying was carried out in the hot air temperature (105–125 °C), drying air flow rate (25–45 ml/min), feed flow rate (20–30 ml/min), and concentration of maltodextrin (10–30%). The parameters were observed water content, NaCl content, yield, and mean particle diameter size (MPDS). The results showed that the inlet air temperature of 125 °C can significantly reduce the water content faster and produce higher NaCl levels than the inlet air temperature of 105 °C. The salt crystals produced at higher maltodextrin concentrations have lower water content and high NaCl content. The best-operating conditions are at a hot air temperature of 125 °C, a drying airflow rate of 45 m/s, and a maltodextrin concentration of 20% because it produces salt crystals with high NaCl content. Overall, these results indicate that the bittern can be dried using a spray dryer with potential NaCl content as a raw material for the pharmaceutical industry.

1. Introduction

Salt is one of the most needed food ingredients, both for human needs and for the industry. Salt contains sodium chloride (NaCl), water compounds, magnesium ions, calcium ions, and sulfate ions [1]. The need for salt throughout the world from year to year has increased along with the increase in population and industrial development [2]. This need for a lot of salt is an opportunity and challenge for researchers to carry out various technological innovations to improve the quality of salt production [3].

Various methods of making salt have been carried out to increase the content of natrium chloride (NaCl) [4]. The most widely applied method today is drying using direct solar evaporation [5, 6]. However, this drying method has many limitations [7, 8], such as the drying time being very long [9], the resulting product sometimes does not follow quality salt standards [10]. Efforts to increase the production and quality of salt are highly dependent on the production methods and technology used [11, 12]. Technical factors that affect salt production according to Rauf et al. [13], include raw materials for seawater, drying processes, weather conditions, evaporation containers, and methods of collecting salt.

Traditionally, salt is made by inserting bittern (seawater) into an evaporation vessel to produce salt crystals (Figure 1) [14]. The process is carried out by making plots of land in stages, so that seawater can flow by gravity into the plots. To produce salt with high NaCl content, it is made by the principle of gradual precipitation (Figure 2). Salt production business like this is only able to produce salt with a NaCl content of up to 90%, so special technology is needed to produce salt with a high NaCl content [15].

Research on the manufacture of salt has been carried out by several previous researchers, including engineering salt purification equipment using the washing method [16]. This method was able to increase the average NaCl concentration by 5.3%. Research to reduce impurities in salt can be carried out by a combination of washing and dissolving, as has been done by Dong et al. [17]. The research carried out a reaction between traditional salt with Na2CO3 and NaOH, resulting in a precipitate

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Figure 1. Conventionally salt ponds [14].

in the form of $CaCO_3$ and Mg $(OH)_2$. The results obtained indicate that the purification of salt was strongly influenced by the ratio of Ca/Mg. The ratio was too large or too small, the impurity deposition will not work properly.

The drying of the bittern into salt crystals through the heating process of the boiling and oven systems has been widely disclosed by previous researchers [18, 19]. However, producing salt with this oven system takes a long time and the level of NaCl obtained is still low [20]. Thus, there needs to be another alternative as a solution to this problem.

A spray dryer is one type of dryer that can be used to dry liquid materials [21, 22]. It tool can change the material from a liquid state into dry particles through continuous spraying in a hot drying medium [23]. The spraying process takes place at a high speed so that the material can evaporate immediately after contacting the surface with high-temperature dry air [24].

The spray drying method is generally carried out by spraying the material in the form of fine droplets into a stream of hot air [25, 26]. The drying process occurs very quickly, so this method is very suitable for heat-resistant materials at high temperatures [27]. The resulting product is in the form of powder or dry particles [28]. Three main parts play an important role in the drying process, namely the atomizer, drying chamber, and product collection container [29]. These three components must be designed in such a way as to suit the desired dry product [30]. Therefore, the development of drying equipment to produce salt with high NaCl content is necessary. Thus, the study aimed to dry concentrated seawater using a spray dryer to produce salt with high NaCl content. The technique that has been developed in this research is to use a heating system and air circulation in the spray dryer. The manufacturing method uses a hot air spray system in the drying chamber. Heat stability and relative humidity (RH) in the drying chamber are controlled as needed.

2. Research method

2.1. Materials and tools

The main raw material used is bittern with a concentration of 29 °Be. It was obtained from farmers in Pemenang Village, East Lombok, West Nusa Tenggara Province, Indonesia. The carrier materials used were maltodextrin (food grade) as a filler. The dryer was used a cylindrical spray dryer model SD-04 (Fuji Chemical Industries Co., Ltd. of Toyama, Japan) (Figure 3). Additional equipment was a type K thermocouple, viscometer (Brookfield MA 02346 USA), pycnometer (PV-Pyc 200™, USA), and oven (Hock, Indonesia).

2.2. Spray drying

The spray dryer was located in the laboratory with an air temperature around of 28–29 °C and relative humidity of 60–65%. The first step was to prepare 50 L of bittern, 10 L are used to analyze the physical and thermal properties, and the other used for drying. Prepared a spray dryer according to the conditions of the preliminary study. Drying of the bittern to form dry crystals at variations in hot air temperature of 105, 115, and 125 °C, drying air flow rate of 25, 35, and 45 ml/min, and feed flow rate of 20, 25, and 30 ml/min.

2.3. Research parameters

The measurement of the moisture content (MC) of the drying product was carried out by the oven method [31]. A sample of 2 g was heated at a temperature of 105 °C for 8 h, then cooled in a desiccator for 1 h, and then weighed. The sample was reheated for 1 h and then weighed until a constant weight of no more than 0.002 g was obtained. The water content of the product is calculated by Eq. (1) below [32]:

$$MC = (b - c) / (b - a) \times 100\% \quad (1)$$

where, MC = moisture content, a = weight of empty cup, b = weight of cup + initial sample, c = weight of cup + sample after drying.

The concentration of natrium chloride (NaCl) from drying was calculated using Eq. (2) below [33]:

$$NaCl = (V \times N \times fp \times 58.5) / W \times 100\% \quad (2)$$

where, V = volume of AgNO3 required for titration (ml), N = normality of AgNO3 (N) Fp = diluent factor, and W = weight of test sample (mg).

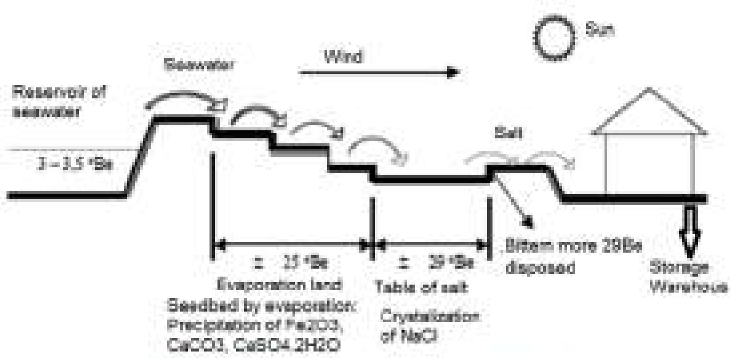

Figure 2. Gradual deposition system salt production [15].

Figure 3. Shows the spray dryer setup in the laboratory.

The yield was calculated by Eq. (3) below [34]:

$$Y = (PS_p) / (LS_f) \times 100\% \tag{3}$$

where, Y = yield (%), P = Rate of powder, Sp = Present of total solid of powder, L = Feed flow rate, Sf = Present of total solid of feed.

The particle size distribution was obtained using the Malvern Mastersizer, Coulter LS, and Aerosizer. To fairly compare the experimental data, the Mastersizer and Coulter results are re-routed into the diameter interval used by the Aerosizer.

2.4. Data analysis

Data analysis was conducted using SPSS (SPSS v21.0, Chicago, IL, USA). Observation data were analyzed using regression analysis to illustrate the relationship between hot air temperature, drying air flow rate, material flow rate, and carrier concentration on water content, NaCl content, yield, and MPDS of drying results. Prediction data were tested for validity using a two-way analysis of variance. If the F-count value is greater than the F-table, it means that there is a significant difference in effect [35].

3. Results and discussion

3.1. Hot air temperature profile

Hot air temperature data from observations and predictions on various treatments during drying are shown in Figure 4. In Figure 4, it can be seen that the observation and prediction data almost coincide. At the beginning of drying the air temperature decreases rapidly and towards the end of drying the air temperature decreases slowly.

At the inlet temperature treatment of 105 °C, the outlet temperature varied between 91.5–94.4 °C. Similarly, the inlet temperature treatment of 115 and 125 °C resulted in outlet temperatures of 97.5–99.4 °C and 117.5–119.3 °C, respectively. This data also shows that the greater the inlet temperature, the greater the outlet temperature. Thus, the heat energy required for drying has been met at the inlet temperature of 105 °C. The same thing has been reported by Wardhani et al. [36] that the temperature used for the drying process was almost the same even though the drying air flow rate was different.

In Figure 4 it can also be seen that at the beginning of drying the hot air temperature increased rapidly, then remained constant and fell again. These results are following the report of Das and Timothy [37] that the hot air temperature at the beginning of drying is very high because the mass and heat transfer processes take place quickly. Ferrari et al. [38] have also reported that the high hot air temperature at the beginning of the drying process is caused by the presence of free water on the surface of the volatile material which is then carried away by the drying air, while the bound water remaining on the material is very difficult to evaporate. As a result, the temperature of the hot air decreases. According to Ozdikicierler et al. [39], free water tends to evaporate more easily, while bound water was very difficult to evaporate, as a result, the drying rate decreases.

3.2. Moisture content

The moisture content in various treatments of hot air temperature, drying air flow rate, feed flow rate, and maltodextrin concentration are shown in Figure 5. Information from Figure 5 shows that the water content is influenced by the hot air temperature and the drying air flow rate. Water content decreases with increasing hot air temperature. Another phenomenon was that a high drying air flow rate can lead to a faster drying time. This shows that the high initial temperature of the drying air causes the heat transfer process from the drying air medium to the droplet surface to also increase. A similar phenomenon has been reported by Jubaer et al. [40] that the hot air temperature has a significant effect on the evaporation of the water content of the material.

At high feed flow rates, the drying process can take place quickly because the moisture content was more easily evaporated by the drying air. The same thing has been reported by Furuta and Neoh [41] that the drying process can proceed rapidly with increasing feed flow rate. According to Petersen et al. [42], a high feed flow rate can easily evaporate the moisture content, so the mass transfer process from the material to the environment can take place quickly.

The water content of this research is 8.34% lower than the maximum requirement for raw materials for the pharmaceutical salt industry, which is 9.00% (SNI 01-4435-2000). Thus, the water content of the results of this study has met the quality requirements as raw materials for the pharmaceutical industry.

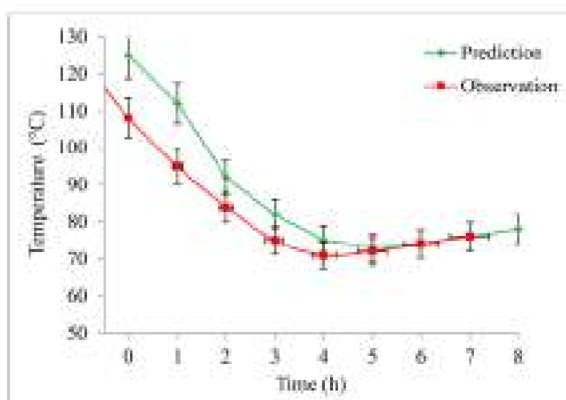

Figure 4. Profile of the hot air temperature as a result of observations and predictions.

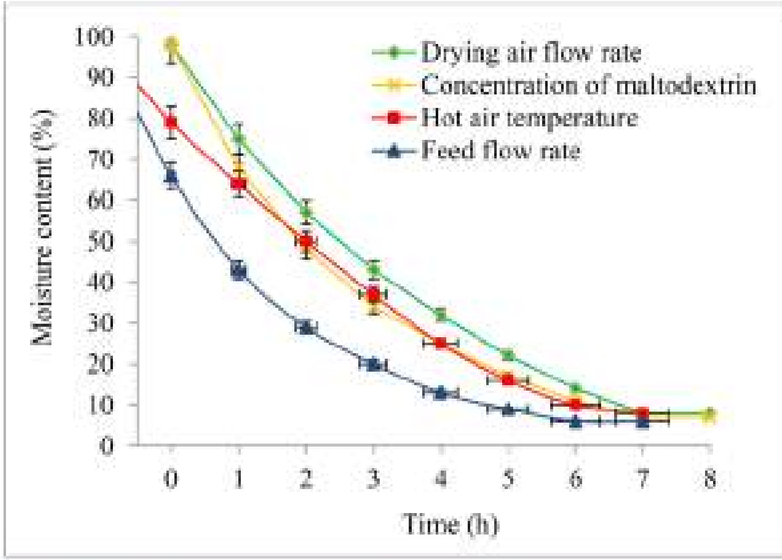

Figure 5. The effect of inlet air temperature, drying air flow rate, feed flow rate, and maltodextrin concentration on moisture content.

3.3. NaCl content

The results showed that the NaCl content obtained was 99.2%. The results it was slightly lower than the minimum of NaCl content requirement for pharmaceutical industry raw materials, which of 99.5% (SNI 01-4435-2000). The low level of NaCl is caused by the condition of the raw material for concentrated bittern which still contains a lot of mud and other impurities. According to Fadhil et al. [43], impurity factors can cause salt products to have a low NaCl content, which is less than 97%.

The use of a drying temperature of 125 °C resulted in the highest NaCl content of 99.2%, while the lowest NaCl content was obtained at a drying temperature of 115 °C which was 97.75% (Figure 6). These data indicate that the most effective for increasing the NaCl content was hot air temperature, while the relative drying air flow rate does not show a significant effect. This was presumably because the variation of the drying air flow rate used in this drying process was almost the same. The same result was reported by Chindapan et al. [44] that the hot air temperature affects the process of salt crystal formation and high air temperature can accelerate water content evaporation so that the crystallization process also takes place faster.

3.4. Yield

The indicator of the success of the drying process can be known based on the yield produced, namely the ratio between the mass of dry matter obtained after drying with the total weight of the material. The results showed that the yield of salt crystals was influenced by various factors, namely, hot air temperature, drying air flow rate, feed flow rate, and carrier concentration (Figure 7).

Informations from Figure 7 shows that the higher concentration of the carrier material, the greater the amount of product yield obtained. This happens because of the influence of the carrier material which was able to bind the material particles during drying. The use of carrier materials was also able to prevent the occurrence of product stickiness on the walls of the drying chamber. This stickiness occurs due to the influence of the glass transition temperature of each component making up the material. This prevention can be done by using additives that have a high glass

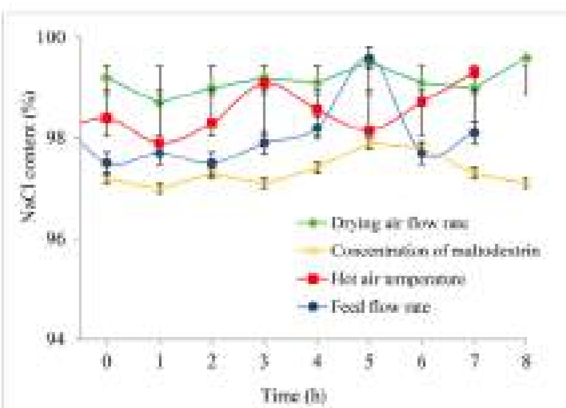

Figure 6. The effect of inlet air temperature, drying air flow rate, feed flow rate, and maltodextrin concentration on NaCl content.

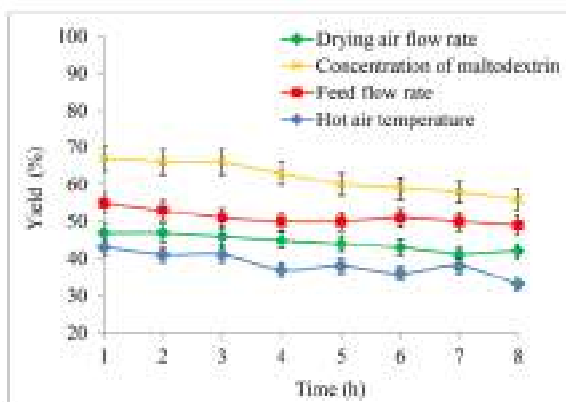

Figure 7. The effect of inlet air temperature, drying air flow rate, feed flow rate, and maltodextrin concentration on yield.

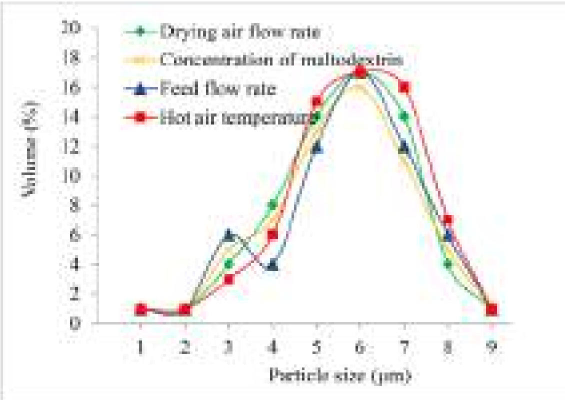

Figure 8. Effect of feed flow rate, drying air flow rate, hot air temperature, and concentration of maltodextrin on MPDS.

transition temperature, such as maltodextrin [45]. According to Moghaddam et al. [46], the use of a carrier can prevent the product from sticking to the walls of the spray drying chamber. The most commonly used carrier material is maltodextrin because it has a high glass transition temperature of 101 °C [47, 48].

The results of other studies have also reported that maltodextrin can increase the yield by 77% compared to gum arabic which was only 68% [49]. Spray drying for tea leaves has been reported by Nadeem et al. [50] that the highest product yield was obtained from maltodextrin-DE12, followed by gum arabic, maltodextrin-DE19, and cyclodextrin. High hot air temperature also plays a role in increasing the amount of yield. The results of research by Tontul and Topuz [51] have also reported that high hot air temperatures can accelerate the evaporation process of water content in a short time so the yield was also high.

3.5. Mean particle diameter size (MPDS)

The effect of material feed rate, drying air flow rate, hot air temperature, and carrier concentration on the MPDS was illustrated in Figure 8. Increasing the feed flow rate can slow down the atomization of droplets so that the MPDS becomes larger. In this case, an increase in the feed flow rate can contribute to a decrease in the MPDS. In general, it can be stated that the MPDS was directly proportional to the feed flow rate.

In this study, the maltodextrin concentration of 30% resulted in a relatively higher average particle diameter size compared to concentrations of 10 and 20%. A higher concentration of maltodextrin can increase particle size and diameter density due to a lower droplet shrinkage rate during drying. A researcher by Bastan et al. [52] also reported that the MPDS of the spray drying results was strongly influenced by the formation of the microstructure at the time of spraying the material into droplets. Hein [53] found that the concentration of 30% maltodextrin resulted in larger particle diameter sizes than the concentrations of 20 and 25%, respectively. Considering all these conditions, it was recommended to use a maltodextrin carrier material of at least 25% to have a good impact on the MPDS of the spray drying results.

The MPDS also decreased gradually with increasing hot air temperature (Figure 8). However, the MPDS slightly changed after the hot air temperature treatment of 120 °C and decreased after the hot air temperature of 125 °C. Thus, MPDS increased with hot air temperature treatment at 125 °C due to faster water vapor release. Hot air temperature can reduce the size of the particle diameter and reduce the level of porosity. Other researchers have also reported that the particle size of the powder can be decreased as a result of hot air during spray drying [54].

4. Conclusion

Hot air temperature, drying air flow rate, feed flow rate, and carrier material have a significant effect on moisture content, NaCl content, product yield, and MPDS. The use of maltodextrin as a carrier material plays an important role in increasing the yield, but the use at high concentrations causes a lot of salt crystals to stick to the walls of the drying chamber. The recommended optimum parameters are 105 °C hot air temperature, 45 mL/min drying air flow rate, 30 mL/min material feed rate, and 25% maltodextrin concentration, to produce MPDS salt according to SNI standards. The salt crystals produced from this research can be used directly as raw materials for the pharmaceutical industry salt because they have met the requirements based on SNI standards.

Declarations

Author contribution statement

Amir, Murad: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Ahmad Naim Ahmad Yahaya, Siti Aisyah: Analyzed and interpreted the data; Wrote the paper.

Anton Abdulbasah Kamil: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Rahmat Sahani: Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper.

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Data availability statement

Data will be made available on request.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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