



Research article

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

Ansar Ansar^{a,*}, Ahmad Naim Ahmad Yahaya^{b,**}, Anton Abdulbasah Kamil^c, Rahmat Sabani^a, Murad Murad^a, Siti Aisyah^d^a Department of Agricultural Engineering, Faculty of Food Technology and Agroindustry University of Mataram, Mataram, Indonesia^b Malaysian Institute of Chemical and Bioengineering Technology, University of Kuala Lumpur, Alor Gajah 78000, Melaka, Malaysia^c Faculty of Economics, Administrative and Social Sciences, University of Istanbul Gelisim, Turkey^d Department of Graphic Engineering, Creative Media State Polytechnic, Indonesia

ARTICLE INFO

Keywords:

Bittern
Drying air flow rate
Inlet air temperature
Natrium chloride
Pharmaceutical industry

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 25% 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

* Corresponding author.

** Corresponding author.

E-mail addresses: ansar72@unram.ac.id (A. Ansar), ahmadnaim@unikl.edu.my (A.N. Ahmad Yahaya).



Figure 1. Conventionally salt ponds [14].

in the form of CaCO_3 and $\text{Mg}(\text{OH})_2$. 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 Paremas 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]:

$$MC = (b - c) / (b - a) \times 100\% \tag{1}$$

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 sodium chloride (NaCl) from drying was calculated using Eq. (2) below [33]:

$$\text{NaCl} = (V \times N \times \text{fp} \times 58.5) / W \times 100\% \tag{2}$$

where, V = volume of AgNO_3 required for titration (ml), N = normality of AgNO_3 (N) Fp = diluent factor, and W = weight of test sample (mg).

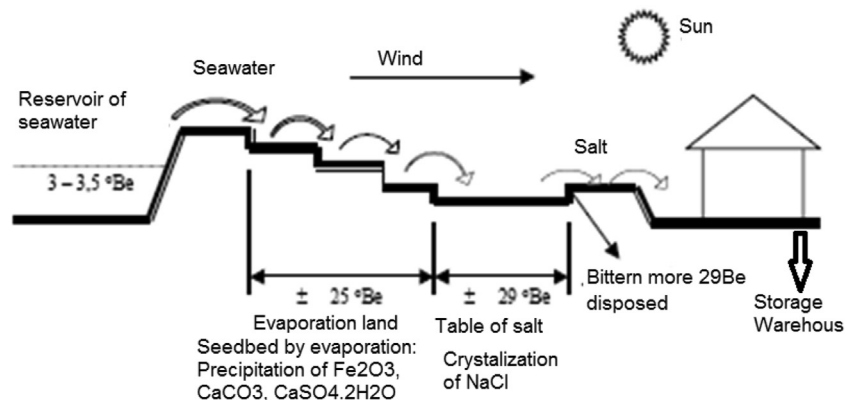


Figure 2. Gradual deposition system salt production [15].



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

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

$$Y = (P \cdot S_p) / (L \cdot S_f) \times 100\% \quad (3)$$

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.

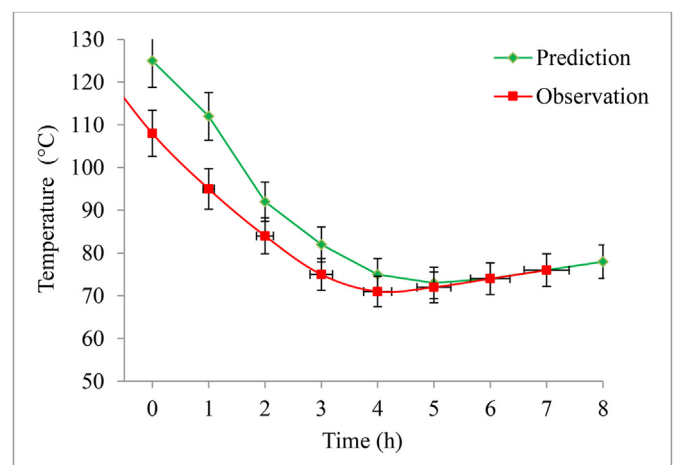


Figure 4. Profile of the hot air temperature as a result of observations and predictions.

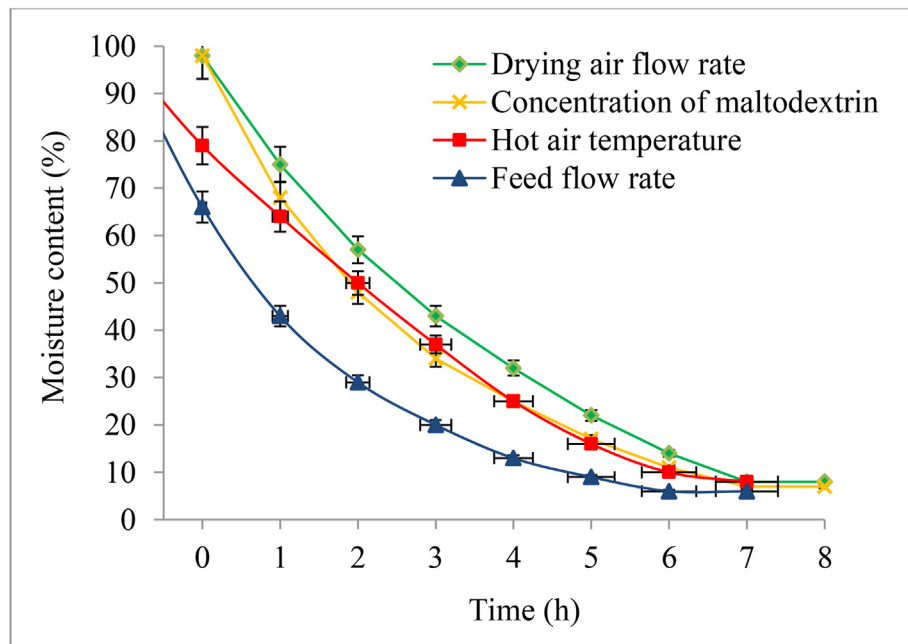


Figure 5. The effect of inlet air temperature, drying air flow rate, feed flow rate, and maltodextrin concentration on moisture content.

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 bitter 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

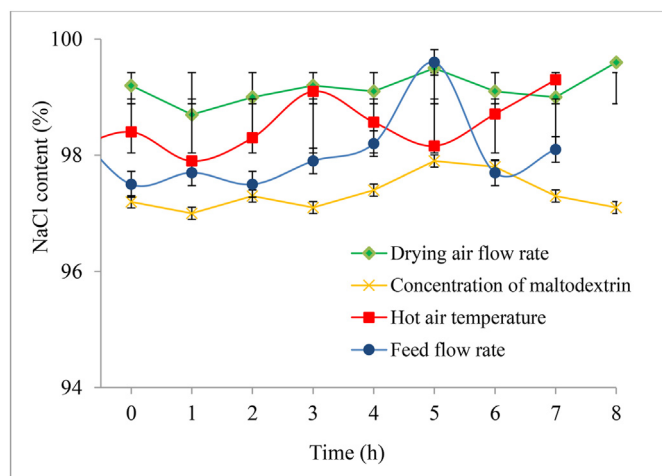


Figure 6. The effect of inlet air temperature, drying air flow rate, feed flow rate, and maltodextrin concentration on NaCl content.

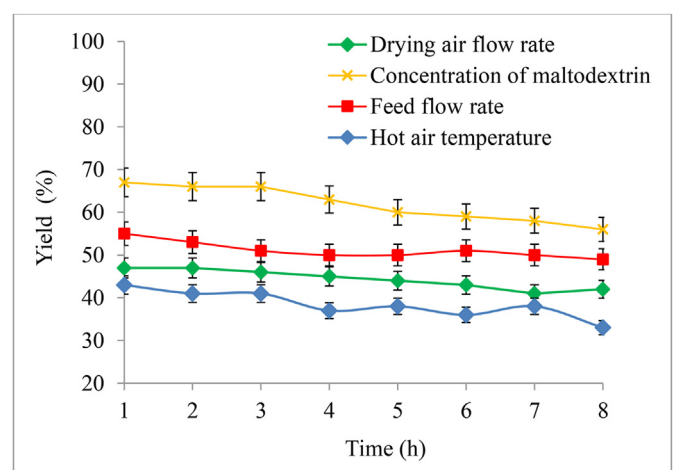


Figure 7. The effect of inlet air temperature, drying air flow rate, feed flow rate, and maltodextrin concentration on yield.

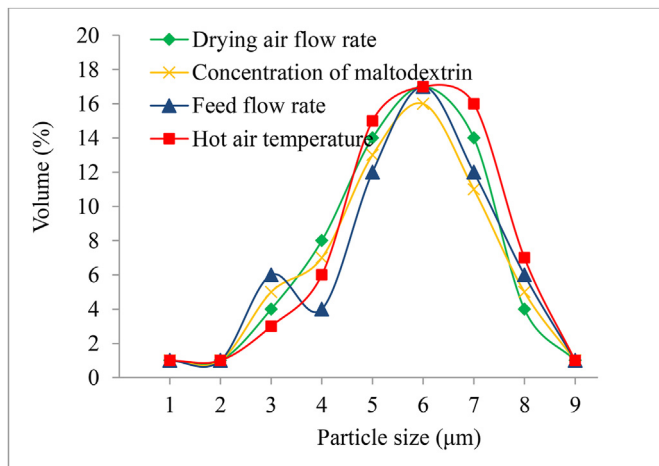


Figure 8. Effect of feed flow rate, drying air flow rate, hot air temperature, and concentration of maltodextrin on MPDS.

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

Ansar, 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 Sabani: Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper.

Funding statement

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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.

References

- [1] G. Delgado-Pando, E. Fischer, P. Allen, J.P. Kerry, M.G. O'Sullivan, R.M. Hamil, Salt content and minimum acceptable levels in whole-muscle cured meat products, *Meat Sci.* 139 (2018) 179–186.
- [2] M. Haldimann, M. Bochud, M. Burnier, F. Paccaud, V. Dudler, Prevalence of iodine inadequacy in Switzerland assessed by the estimated average requirement cut-point method in relation to the impact of iodized salt, *Publ. Health Nutr.* 18 (8) (2015) 1333–1342.
- [3] I. Bae, J.H. Park, H.Y. Choi, H.K. Jung, Emerging innovations to reduce the salt content in cheese; effects of salt on flavor, texture, and shelf life of cheese; and current salt usage: a Review, *Korean J. Food Sci. Anim. Resour* 37 (6) (2017) 793–798.
- [4] T. Sulistyansih Jumaeri, D. Alighiri, Quality monitoring of salt produced in Indonesia through seawater evaporation on HDPE geomembrane lined ponds, *J. Phys. Conf.* 983 (2018), 012166.
- [5] A.M. Khader, Viable engineering Options to Enhance the NaCl quality from the dead sea in Jordan, *J. Clean. Prod.* 15 (2) (2014) 145–153.
- [6] R. Jirayucharoenak, K. Khuenpet, W. Jittanit, S. Sirisansaneeyakul, Physical and chemical properties of powder produced from spray drying of inulin component extracted from Jerusalem artichoke tuber powder, *Dry. Technol.* 37 (10) (2019) 1215–1227.
- [7] M. Castoldi, M.F. Zotarelli, A. Durigon, B.M. Carciofi, J.B. Laurindo, Production of tomato powder by refractance window drying, *Dry. Technol.* 33 (12) (2014) 1463–1473.
- [8] M. Camci, Thermodynamic analysis of a novel integration of a spray dryer and solar collectors: a case study of a milk powder drying system, *Dry. Technol.* 38 (3) (2020) 350–360.

- [9] S. Cheng, W. Su, L. Yuan, M. Tan, Recent developments of drying techniques for aquatic products: with emphasis on drying process monitoring with innovative methods, *Drying Technol.* (2021) 1–18.
- [10] S. Yetgin, D. Balkose, Morphology of sodium salt of calf thymus DNA on mica, alumina, and silica surfaces: effect of solvent and drying method, *Dry. Technol.* 35 (8) (2017) 1007–1019.
- [11] A. Ozarslan, Large-scale hydrogen energy storage in salt caverns, *Int. J. Hydrogen Energy* 37 (19) (2012) 14265–14277.
- [12] R. PerezAlvarez, A. Acostalborra, D. Santana, Thermal and mechanical stresses in bayonet tubes of solar central receivers working with molten salt and liquid sodium, *Res. Eng.* 5 (2020), 100073.
- [13] A.R. Rauf, A. Hasanuddin, R. Rosedi, Production improvement strategy of community-based salt in Palu Bay, *AGROLAND The Agricul. Sci. J.* 3 (1) (2016) 31–40.
- [14] D. Dwiyoitno, M.T. Sturm, H.I. Januar, K. Schuhen, Influence of various production methods on the microplastic contamination of sea salt produced in Java, Indonesia, *Environ. Sci. Pollut. Control Ser.* 28 (2021) 30409–30413.
- [15] A. Panagopoulos, Techno-economic evaluation of a solar multi-effect distillation/thermal vapor compression hybrid system for brine treatment and salt recovery, *Chem. Eng. Proc.* 152 (2020), 107934.
- [16] K.G. Nayar, J. Fernandes, R.K. McGovern, K.P. Dominguez, A. McCance, B.S. Al-Anzi, J.H. Lienhard, Cost and energy requirements of hybrid RO and ED brine concentration systems for salt production, *Desalination* 456 (2019) 97–120.
- [17] Y. Dong, T. Slade, M.J. Stolt, L. Li, S.N. Girard, L. Mai, S. Jin, Low-temperature molten-salt production of silicon nanowires by the electrochemical reduction of CaSiO₃, *Angew. Chem.* 129 (46) (2017) 14645–14649.
- [18] X. Dong, Q. Bi, J. Jiang, Y. Hou, X. Lei, Experimental investigation on the heat transfer characteristics of molten salt to subcooled boiling water, *Int. J. Heat Mass Tran.* 159 (2020), 120120.
- [19] J. Gu, Y. Wu, G. Tang, Q. Wang, J. Lyu, Experimental study of heat transfer and bubble behaviors of NaCl solutions during nucleate flow boiling, *Exp. Therm. Fluid Sci.* 109 (2019), 109907.
- [20] D.G. Akridge, Methods for calculating brine evaporation rates during salt production, *J. Archaeol. Sci.* 35 (6) (2008) 1453–1462.
- [21] S. Huang, S. Mejean, H. Rabah, A. Dolivet, Y.L. Loir, X.D. Chen, G. Jan, R. Jeantet, P. Schuck, Double use of concentrated sweet whey for growth and spray drying of probiotics: towards maximal viability in pilot scale spray dryer, *J. Food Eng.* 196 (2017) 11–17.
- [22] Y. Wei, M.W. Woo, C. Selomulya, W.D. Wu, J. Xiao, X.D. Chen, Numerical simulation of mono-disperse droplet spray dryer under the influence of nozzle motion, *Powder Technol.* 355 (2019) 93–105.
- [23] S.K. Patel, M.H. Bade, Energy targeting and process integration of spray dryer with heat recovery systems, *Energy Convers. Manag.* 221 (2020), 113148.
- [24] B. Golman, W. Julklang, Simulation of exhaust gas heat recovery from a spray dryer, *Appl. Therm. Eng.* 73 (1) (2014) 899–913.
- [25] Sukmawaty Ansar, M. Ulfa Murad, A.D. Azis, Using of exhaust gas heat from a condenser to increase the vacuum freeze-drying rate, *Res. Eng.* 13 (1) (2022), 100317.
- [26] A. Manickavasagan, K. Thangavel, S.S. Dev, D.A. Delfiya, E. Nambi, V. Orsat, G.V. Raghavan, Physicochemical characteristics of date powder produced in a pilot-scale spray dryer, *Dry. Technol.* 33 (9) (2015) 1114–1123.
- [27] A.F. McDonagh, L. Tajber, The control of paracetamol particle size and surface morphology through crystallisation in a spray dryer, *Adv. Powder Technol.* 31 (1) (2020) 287–299.
- [28] Y. Wang, W. Liu, X.D. Chen, C. Selomulya, Micro-encapsulation and stabilization of DHA containing fish oil in protein-based emulsion through mono-disperse droplet spray dryer, *J. Food Eng.* 175 (2016) 74–84.
- [29] L.N. Petersen, N.K. Poulsen, H.H. Niemann, C. Utzen, J.B. Jorgensen, Comparison of three control strategies for optimization of spray dryer operation, *J. Process Control* 57 (2017) 1–14.
- [30] T.G. Langrish, J. Harrington, X. Huang, C. Zhong, Using CFD Simulations to Guide the development of a new spray dryer design, *Processes* 8 (8) (2020) 932.
- [31] Ansar, Nazaruddin, A.D. Azis, Effect of vacuum freeze-drying condition and maltodextrin on the physical and sensory characteristics of passion fruit (*Passiflora edulis Sims*) extract, in: *IOP Conference Series: Earth and Environmental Science*, 2019.
- [32] Ansar, Nazaruddin, A.D. Azis, New frozen product development from strawberries (*Fragaria Ananassa Duch.*), *Heliyon* 6 (9) (2020), e05118.
- [33] M.V. Popa, P. Drob, E. Vasilescu, J.C. Mirza-Rosca, A.S. Lopez, C. Vasilescu, S.I. Drob, The pigment influence on the anticorrosive performance of some alkyl films, *Mater. Chem. Phys.* 100 (2) (2006) 296–303.
- [34] G.R. Chegini, B. Ghobadian, Spray dryer parameters for fruit juice drying, *World J. Agric. Sci.* 3 (2) (2007) 230–236.
- [35] Nazaruddin Ansar, A.D. Azis, A. Fudholi, Enhancement of bioethanol production from palm sap (*Arenga pinnata (Wurmb) Merr*) through optimization of *Saccharomyces cerevisiae* as an inoculum, *J. Mater. Res. Technol.* 14 (2021) 548–554.
- [36] D.H. Wardhani, I.N. Wardana, H.N. Ulya, H. Cahyono, A.C. Kumoro, N. Aryanti, The effect of spray-drying inlet conditions on iron encapsulation using hydrolysed glucumannan as a matrix, *Food Bioprod. Process.* 123 (2020) 72–79.
- [37] D. Das, A.G. Timothy, Combined crystallization and drying in a pilot-scale spray dryer, *Dry. Technol.* 30 (9) (2012) 998–1007.
- [38] C.C. Ferrari, S.M. Germer, J.M. de Aguirre, Effects of spray-drying conditions on the physicochemical properties of Blackberry powder, *Dry. Technol.* 30 (2) (2012) 154–163.
- [39] O. Ozdikiclerler, S.N. Dirim, F. Pazir, The effects of spray drying process parameters on the characteristic process indices and rheological powder properties of microencapsulated plant (*Gypsophila*) extract powder, *Powder Technol.* 253 (2014) 474–480.
- [40] H. Jubaer, S. Afshar, G.L. Maout, S. Mejean, C. Selomulya, J. Xiao, X.D. Chen, R. Jeantet, M.W. Woo, The impact of self-sustained oscillations on particle residence time in a commercial scale spray dryer, *Powder Technol.* 360 (2020) 1177–1191.
- [41] T. Furuta, T.L. Neoh, "Microencapsulation of food bioactive components by spray drying: a review," *Drying Technol.* (2021).
- [42] L.N. Petersen, N.K. Poulsen, H.H. Niemann, C. Utzen, J.B. Jorgensen, Comparison of three control strategies for optimization of spray dryer operation, *J. Process Control* 57 (2017) 1–14.
- [43] S. Fadhil, Q.F. Alsahy, H.F. Makki, R.R. Figueroa, T. Marino, A. Criuoli, F. Macedonio, L. Giorno, E. Drioli, A. Figoli, Seawater desalination using PVDF-HFP membrane in DCMD process: assessment of operating condition by response surface method, *Chem. Eng. Commun.* 206 (2) (2019) 237–246.
- [44] N. Chindapan, C. Niamnuay, S. Devahastin, Physical properties, morphology and saltiness of salt particles as affected by spray drying conditions and potassium chloride substitution, *Powder Technol.* 326 (2018) 265–271.
- [45] M. Jayasundera, B. Adhikari, R. Adhikari, P. Aldred, The effect of protein types and low molecular weight surfactants on spray drying of sugar-rich foods, *Food Hydrocolloids* 25 (2011) 459–469.
- [46] A.D. Moghaddam, M. Pero, G.R. Askari, Optimizing spray drying conditions of sour cherry juice based on physicochemical properties, using response surface methodology (RSM), *J. Food Sci. Technol.* 54 (2017) 174–184.
- [47] P. Mishra, S. Mishra, C.L. Mahanta, Effect of maltodextrin concentration and inlet temperature during spray drying on physicochemical and antioxidant properties of amla (*Emblica officinalis*) juice powder, *Food Bioprod. Process.* 92 (3) (2014) 252–258.
- [48] J. Du, Z. Ge, Z. Xu, B. Zou, Y. Zhang, C.M. Li, Comparison of the efficiency of five different drying carriers on the spray drying of persimmon pulp powders, *Dry. Technol.* 32 (10) (2014) 1157–1166.
- [49] A. Can Karaca, O. Guzel, M.M. Ak, Effects of processing conditions and formulation on spray drying of sour cherry juice concentrate, *J. Sci. Food Agric.* 96 (2016) 449–455.
- [50] H.S. Nadeem, M. Torun, F. Ozdemir, Spray drying of the mountain tea (*Sideritis stricta*) water extract by using different hydrocolloid carriers, *LWT—Food Sci. Technol.* 44 (2011) 1626–1635.
- [51] I. Tontul, A. Topuz, Spray-drying of fruit and vegetable juices: effect of drying conditions on the product yield and physical properties, *Trends Food Sci. Technol.* 63 (2017) 91–102.
- [52] F.E. Bastan, G. Erdogan, T. Moskalewicz, F. Ustel, Spray drying of hydroxyapatite powders: the effect of spray drying parameters and heat treatment on the particle size and morphology, *J. Alloys Compd.* 724 (2017) 586–596.
- [53] E.V. Hein, The particle-size distribution in soils: problems of the methods of study, interpretation of the results, and classification, *Eurasian Soil Sc* 42 (2009) 284–291.
- [54] W. Damayanti, M. Liao, Y. Xu, P. Jing, S. Jiao, Pre-drying Effect and Quality Change of Rough Rice under Hot Air-Assisted Radio Frequency Disinfection Treatment, *American Society of Agricultural and Biological Engineers*, 2021.