A Novel Energy Efficient Adsorption Drying with Zeolite For Food Quality Product: A Case Study in Paddy and Corn Drying

Mohamad Djaeni, Nurul Aishah, Berkah Fadjar Tamtomo Kiono*, and AJB van Boxtel**

Master Program Department of Chemical Engineering
*Department of Mechanical Engineering
Faculty of Engineering Diponegoro University
Jl Prof H. Soedharto, SH, Tembalang, Semarang, Indonesia
**Agrotechnology and Food Science, Wageningen University
Bornsesteg 59, 6708 PD Wageningen, The Netherlands
Email: m.djaeni@undip.ac.id, mzaini98@yahoo.com

ABSTRACT

Nowadays, the importance of powdered food products as for example soups, sauces, dried yeasts, and herbal medicine is increasing for consumer convenience. Mostly, these products have been produced with drying process etiher, direct sunlight, conventional, or modern dryer. The direct sunlight dryer depends on the daily weather extremely both in the product drought and process continuity. Meawhile, conventional dryer results high energy consumption as well as low product quality due to the introduction of hot air. In addition, modern dryer process can improve the product quality, but the energy efficiency was fair.

This paper discusses the design and application of adsorption dryer with zeolite for food. Here, the air as drying medium was dehumidified by zeolite to enhance the driving force. Thus, the drying can be well conducted in low or medium temperature. The dryer was designed in single and multi stage system. Result showed that energy efficiency of single stage dryer was 70 - 72% (10% higher than that of conventional dryer). While in multi stage, the energy efficiency can reach 80% (for two stage) and 90% (for three stage). In corn and paddy drying, the dryer with zeolite can speed up drying time and retain the nutrition and physical quality.

1. INTRODUCTION

Nowadays, the importance of powdered food products as for example soups, sauces, dried yeasts, and herbal medicine is increasing for consumer convenience. This situation is a challenge how to provide these materials in high quality close to fresh condition. The challenge can be overcome when in drying process, the texture, nutrition, vitamin, and other active substances do not degrade. In drying physical and chemical process can occur, e.g.; browning, de-naturation of protein, shrinkage and texture change, evaporation of active component, and degradation of vitamin [1].

The term of browning in food refers to enzymatic and non-enzimatic reaction where the color of food changes to be brown [2]. Enzymatic browning is a less desirable series of reactions. It occurs in certain fruits and vegetables when phenolic compounds react with oxygen in the air, which results in brown complexes. Whereas, non-enzimatic can occurs with several probability such as Mailard reaction, cracking of carbon chain, and caramelization, or de-naturation of protein. The caramelization is a process when sugar or carbohydrate is heated higher than 120^{o}C at less water. The protein deterioration can occur by introducing of heat above 50^{o}C. Meanwhile, vitamin C and volatile components are sensitive with temperature change. Vitamin C can degrade above 30^{o}C, and it will be higher as temperature increase. Active valotile component can evaporate along with water evaporation during the drying process. The higher temperature and the longer process, more volatile component are losses.

The other important aspect in drying technology is the energy efficiency. A large part of the total energy usage in industry is spent in drying. For example 70% of total energy spent in the production of wood products, 50% of textile fabrics, 27% of paper, 33% of pulp production is used for drying [3]. In food and pharmaceutical industry the energy consumption for drying is around 15% of the total energy usage in this sector. Energy spent for drying varies between countries and ranges between 15-20% of the total energy consumption in industry [4].

Currently several drying methods are used, ranging from traditional to modern processing: e.g. direct sun drying, oven convective drying, microwave and infra-red drying, adsorption, freeze and vacuum drying. Based on the operation system and material to be dried, we also know about tray and cabinet, rotary, spray and fluidized bed dryers. However, current drying technology is often not efficient in terms of energy consumption and has a high environmental impact due to combustion of fossil fuel or wood as energy source [5]. Considering the limitation of sources of fossil fuel, the increase of energy price, the rise of industrial energy usage, and the global climate change issue on increase of greenhouse gas emission; the need for a sustainable industrial development with low capital and running cost especially for energy becomes more and more important. In this case the development of efficient drying methods with low energy consumption is an important issue for research in drying technology.

A large range of drying methods is being applied by small and industrial users. Next consideration is just a limited review on some major drying methods. Direct sun drying is simple and doesn't need fuel fossil for energy generation, but the system needs a large drying area, long drying time (often 3-5 days), high operational cost for labor, and depends highly on the climate. Furthermore, product contamination may occur due to the open air conditions and therefore sun dried food products are not accessible for all markets [1]. Improvement of this drier type has been achieved by using for example a solar tunnel drier equipped with an electric fan to dry chilli.[6] Although, the result showed that the processing time is reduced, it is still rather long (2-3 days).

Convective drying [1,7] is more attractive than sun drying because of the shorter operational time, low product contamination, lower operational costs, no dependency on the climate, and relative limited space usage. In this dryer, the air as drying medium is heated up to desired temperature. The hot air is then used for drying. However, the disadvantage of this system is that the product quality can be affected by the operational temperature, and the high energy consumption.

Microwave dryingis an emerging technology that could be used as an alternative to the current method which most often uses heat from burning natural gas [8,9]. Microwave energy causes the molecules of the material irradiated (referred to as the "load") to vibrate more rapidly, creating friction and hence heat. Drying takes place in a different way than the current standard, with heat being generated within the molecules of the feedstock itself rather than being applied from an outside source. This method claims not only to be more energy efficient than the current method but also to do less harm to the feedstock, preserving nutritional characteristics of the product for livestock feed [8,9].

Vacuum and freeze drying systems are operated in the temperature range –20 to –0^{o}C and for pressures in the range of 0.0006 to 0.006 atm [10 - 14]. The air as drying medium is chilled below 0^{o}C to condensed the water content. The cold and dry air is then used to dry heat sensitive product by sublimation. As driving force is the different of water content between product and air. To speed up the process, the operational pressure can be reduced in vacuum condition. Sometimes, vacuum dryer can be operated in hot or warm air dryer. In this method, the air is heated up at certain temperature (suppose 40-70^{o}C), and it is then used for drying under vacuum condition.

Considerable amounts of energy are lost in the off-gas of convective drying systems. The off-gas temperatures are commonly in the range 60-90°C but may even rise till 120°C as reported for spray drying of Roselle extracts [15] and sugar-rich food products. Until now, off-gas flows with these temperatures are hardly recovered for use in other processes. As a result, the energy efficiency of drying is poor. The energy equivalent of about 1.5 kg of steam to remove 1 kg of water (i.e. 65% energy efficiency) is common for spray drying, and for low temperature drying of heat sensitive products (food and medicines) the required amount of energy exceeds 2 kg steam for 1 kg water removal (i.e. below 50% energy efficiency) [1].

Innovation and research in drying technology during the last decades resulted in reasonable improvements, but breakthrough solutions with respect to the energy efficiency are scarce. Therefore it can be noted that innovation in drying technology tends to reach a saturation level and a further significant reduction in energy consumption seems not feasible [1]. Positive results were obtained in adsorption dryer with zeolite to speed up drying rate and to improve energy efficiency, while other new developed drying processes cannot compete with traditional drying method in terms of energy efficiency and operational cost [1, 16 - 22].

This paper presents the evaluation and development of adsorption drying with zeolite. In this study, the air as drying medium is dehumified by zeolite for improving energy efficiency as well as product quality. To support the discussion, the case study of the dryer application for paddy, and corn is also discussed.

2. MATERIAL AND METHOD

2.1 Conceptual Design

In this process, the air as drying medium was dehumidified by zeolite. As a result, the driving force for water transfer from wet product to air was enhanced. So, the lowering drying temperature for heat sensitive product was possible. In addition, at the same time the air was preheated due to the release of adsorption heat. This affected the reduction of external energy introduced for drying process [1,19, 22].

However, after used several times, the zeolite was saturated by water. The amount of heat was required to regenerate the zeolite in order to be reused as water adsorbent. For example, the release of 1 kg of water from a zeolite type 13X, required 3200 kJ [1,19,22]. It limited the improvement of the overall energy efficiency.

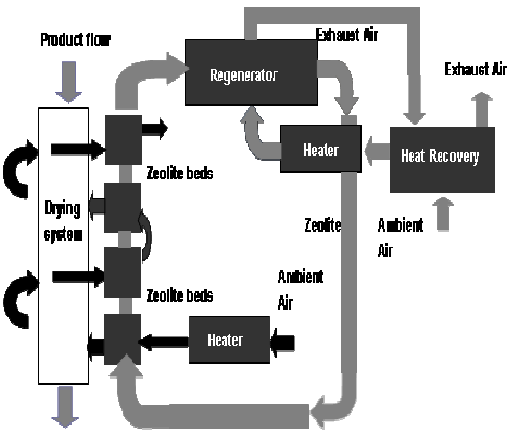

Fig. 1 Conceptual design of adsorption drying [1]

A promising alternative to improve the energy efficiency was the application of pinch technology for energy recovery system (see Fig. 1). Hence, the energy from off gas exiting regenerator can be used to pre-heat either air before entering or air for regenerating zeolite. In this case, a number of heat exchanger network was required [19].

Multistage zeolite drying has potential for further improvement of the energy efficiency. In such system product was dried in a number of succeeding stages (see Fig. 2). The product in the first stage was dried with air dehumidified by zeolite. After passing an adsorber bed with zeolite, the exhaust air from this stage was reused for product drying in a next stage. This concept was repeated several times. The system can be operated as a co-current, counter-current or cross-current system. The main benefit of the system was that the energy content of the exhaust air is reused several times. Moreover, the released adsorption heat was utilized for drying in the succeeding stages. As a consequence, product drying hardly requires heat supply. The required heat for the regeneration of zeolite was kept low by pinch technology based heat recovery [19,22].

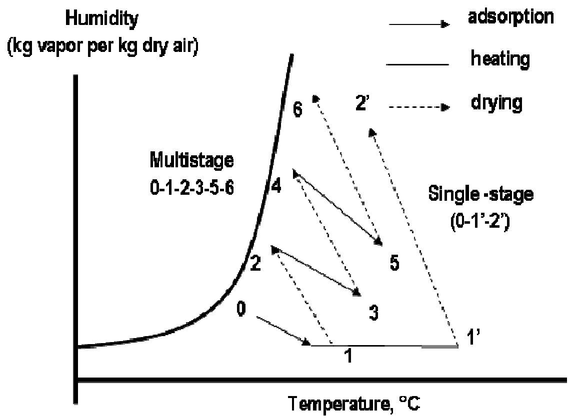

Fig. 2 Comparison of a single-stage and a multistage zeolite dryer. Fresh air is fed to the system at position 0. After adsorption and/or heating position 1 is reached for the multistage systems and 1' for the single-stage systems. From this point the multistage systems continue with drying, adsorption or heating along the path 1-2-3 etc until 6. The single-stage system continues to 2' [1]

2.2 Energy Efficiency calculation

The energy efficiency of adsorption dryer was estimated and compared with conventional dryer [19,22]. In overall, the total of energy efficiency was estimated as follows:

$$\eta = 100\%\left(\frac{Q_{evap}}{Q_{introd}}\right) \quad (1)$$

Where, η is the total energy efficiency (%), Q_{introd} is the total heat required in the system (kJ.h^{-1}), and Q_{evap} is the total heat used for evaporating water in the dryer (kJ.h^{-1}).

$Q_{int\,rod}$ can be estimated based on the total heat required for heating air to dryer, air for regerating saturated zeolite, and the heat that can be recyled from exhaust air, as expressed in equation 2

$$Q_{int\,rod} = Q_{h,a} + Q_{reg} - Q_{rec} \qquad (2)$$

Here, $Q_{h,a}$ is the total heat to heat up air for dryer (kJ.h^{-1}), Q_{reg} is heat to regenerate saturated zeolite (kJ.h-1), and Q_{rec} is the total heat recycled from exhaust air exiting from regenerator and dryer (kJ.h^{-1}). The detail model data can be seen in Djaeni et al (2007) [19] and Djaeni (2008) [1].

2.3 Performing Experimental Work

This step performed the experimental procedure to apply the adsorption dryer for corn, and paddy drying where product and zeolite were mixed in a fluidized bed column. The corn and paddy were harvested from local farmer in Semarang with average initial moisture content of 28 - 30%. The drying was carried out in fluidized bed dryer presented in Fig. 3. The dryer basically consisted of a blower to supply the air flow, a fluidized column, an electric heater and an electronic temperature controller. The air velocity required was measured with an Extech Instruments Thermo-Anemometer 407113. Zeolite used in this research was Zeolite 3A provided by Zeochem, Switzerland [20,21].

The first experiment, the 150 grams of corn were taken and fluidized with air at operational temperature 40^{o}C. The air velocity of 9 m.s^{-1} was applied based on Ergun's equation (two times minimum velocity). The water content in the corn was measured every 10 minutes during the process using KW06-404 Grain Moisture Meter assembled by Krisbow Indonesia. To ensure the accuracy, the apparatus was calibrated and checked with water content analysis by gravimetric analysis. The process was terminated after water content close to 12%. The moisture content versus time was then plotted in the graph and used for estimating drying time (to find 14% water content) [20,21]. Furthermore, the corn proximate quality was also analyzed in term of protein (by Kjeldahl), carbohydrate (by Fehling Test), and fat (by AOAC gravimetric method). The process was also varied for the others process condition such as operational temperature 50^{o}C, and air velocity 11 and 13 m.s^{-1}.

The second experiment, the 150 grams of paddy was fluidised in the dryer. Because of smaller size than that of corn, the air velocity for paddy fluidization is 5 m.s^{-1}. While, the operational temperature was varied at 40 to 80^{o}C. Same with corn drying, the water content in paddy versus time was observed and drying time was estimated based on Djaeni et al (2012) [21]. At the end of step, the paddy quality involving physical and nutrition content were analyzed.

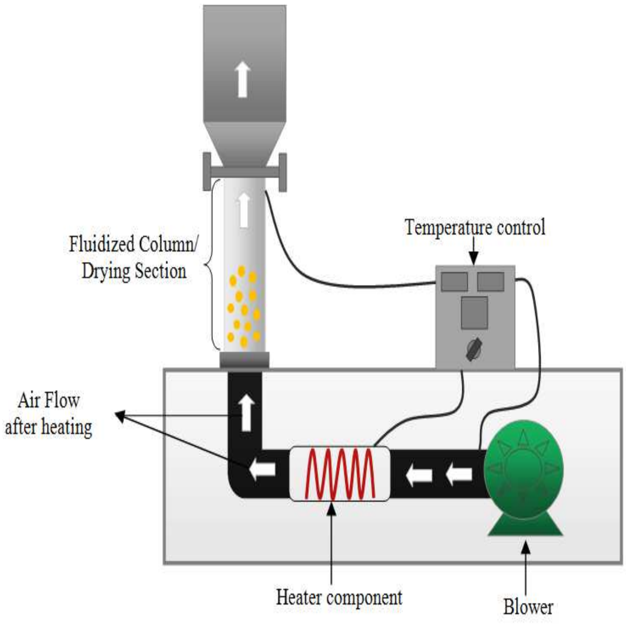

Fig. 3 Fluidized bed dryer with zeolite for paddy and corn drying

3. RESULTS AND DISCUSSION

3.1. Energy efficiency: conceptual design and validation

Table 1 presents the results for the single and multi stage adsorption drying systems indicating that the energy efficiency of adsorption dryer is higher than that of conventional dryer [1]. For all cases, extending the number of stage increased the efficiency. However, but a multistage system with 3 stages were the most applicable. Above this number the energy efficiency improvement was marginal and probably not sufficient to justify the increase of system complexity.

Table 1. Comparison of conventional and adsorption dryer with zeolite

Options	**Number of stages**	**Energy efficiency (%)**
Conventional dryer	1	60
Adsorption Dryer		
Single stage	1	72
Counter-current Multistage	2	80
	3	88
	4	90

The experiment was conducted to prove the concept [22]. Initially, the adsorption dryer with zeolite was constructed in single stage system with adsorption-regeneration working in shift (see Fig 4). In this case, column A was used as air dehumidification. After saturated (suppose 1 hour), the dehumidification process was moved to column B and column A was regenerated.

This was repeated several time until water content of product in the dryer (D01) fully dried. The results showed the energy efficiency was close to that of the concept. The energy efficiency increased corresponding to the increase of the ratio between the air flow for drying and air flow for regeneration. At a ratio 4:1 the efficiency was 70-72% which was similar to the calculations results in the previous study using a steady-state model [1,22].

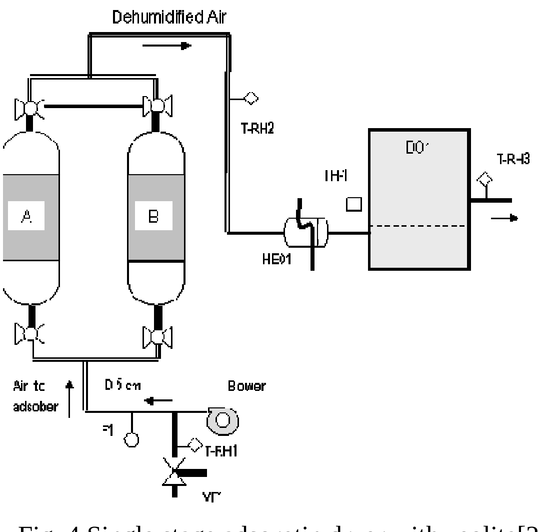

Fig. 4 Single stage adsorptin dryer with zeolite[22]

The research was also continued for two-stage adsorption dryer (see Fig. 5). In this research the air exiting first dryer was dehumidified by zeolite. With heat recovery system, the total energy efficiency was 82% in which closes to conceptual approach [22].

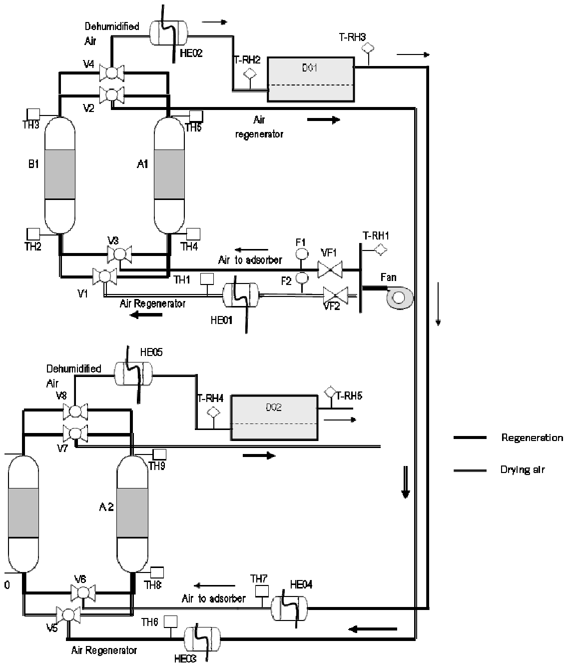

Fig. 5 Multistage adsorption dryer with zeolite[22]

3.2 Drying Time and Prodcut Quality Aspects

a. Corn Drying

The effect of zeolite in the corn drying was presented in Fig. 6. The corn drying with zeolite required shorter time compared to the that of without zeolite (conventional fluidized bed dryer). For example, the drying time to reach 0.12 gr water/gr dry corn or 14% moisture (wet basis) was about 70 minutes. In contrast, the corn drying without zeolite needed 150 minutes for same level moisture content. Compare with literatures, the drying with zeolite performed in this method can shorten drying time 0.75 – 1.0 hours [23,24]. The same positive effect for drying with zeolite also indicated in Revilla et al (2006) [18] and Alikhan et al (1992) [17].

The protein in the corn and other heat sensitive materials will degrade at temperature upper 60^{o}C. The corn drying at 40^{o}C and 50^{o}C were recommended for grain material. Table 2 proved that the corn drying with zeolite conducted under 60^{o}C retained proximate (carbohydrater, protein, and fat). Based on that data, the increase of air temperature from 40 to 50^{o}C changed the proximate slighty. On the other hand, the increase of air velocity did not affect the proximate (see tabel 2).

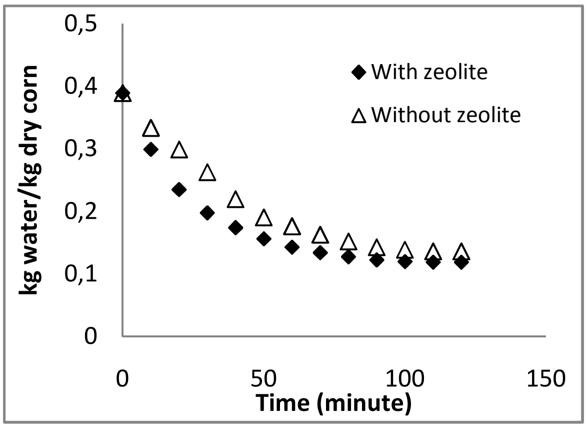

Fig. 6 Adsorption Dryer With Zeolite and Without Zeoite (0:1) for 50°C air velocity 9 m.s^{-1}

Table 2. The proximate content after drying

Input change	Protein (%)	Carbohydrate (%)	Fat (%)
Temperature (^{0}C) at air velocity 9 m.s^{-1}			
40	0,73	7,5	0,20
50	0,70	7,4	0,21
Air velocity (m.s^{-1}) at operational temperature 40°C			
9	0,73	7,5	0,20
11	0,75	7,6	0,20
13	0,75	7,7	0,21

b. Paddy Drying

The two different methods were compared namely paddy drying with zeolite and without zeolite at operational temperature 40°C and air velocity 5 m.s^{-1}. As a response, the moisture content versus time was observed and plotted in graph as illustrated in Fig.7.

The zeolite adsorbs water from the air during the drying process. Hence, the humidity of air can be kept low. As a result, the driving force of drying is higher as indicated in the decrease of moisture content in paddy. As shown in Fig. 7, the zeolite gave positive effect on paddy drying significantly. The paddy drying with zeolite resulted lower moisture content. It indicated that much water was removed from the paddy [25]. Here, paddy drying with zeolite can speed up drying time 5 – 10% faster than the drying without zeolite. The result is in line with the previous data cited from other application of zeolite in dryer where the drying with zeolite gives the positive effect both in drying rate as well as product quality [12,21,26].

Meanwhile, the paddy quality was measured in amylose, amylopectin, and protein content. The result depicted in Table 3 indicated that with the increase of temperature, the amylopection and protein degraded significantly due to the protein de-naturation. In addition, the nutrition degradation affected the physical properties of paddy (see table 4). At milling test, the total of head rice as well as swelling power decreased with the increase of temperature (see table 4). Beside, that with the increase of air temperature the whiteness and transparancy of rice tend to decrease which indicated browning due to the Mailard reaction occurs. It can be recommended that for paddy drying the operational temperature 60°C or below was favorable.

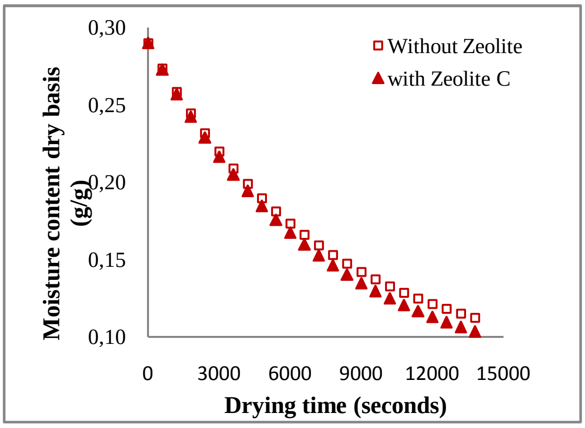

Fig. 7 The moisture content versus time in the paddy drying with zeolite and without zeolite at 40°C and air velocity 5 m.s^{-1}

Table 3. The proximate content in paddy drying

Temperature °C	Proximate		
	Protein	Amylose	Amilo-pection
40	9,17	19,58	60,52
60	9,16	19,57	60,51
80	9,07	19,55	60,50
Without Zeolite, 60°C	9,24	19,56	60,50

Table 4. Physical properties of milled paddy

Temperature °C	Physical Properties			
	White-ness	Transparan-cy	Head rice	Swelling power
40	45,3	1,65	80,40	4,20
60	45,9	1,31	78,70	3,86
80	45,2	1,04	29,87	3,83
Without Zeolite, 60°C	45,2	1,04	65,57	4,20

4. CONCLUSION

The drying with zeolite has been formulated to improve the energy efficiency as well as product quality. Two approaches involving conceptual design validated by experimental data have been conducted to evaluate the dryer efficiency. The results confirmed that the adsorption dryer with zeolite can enhance the energy efficiency 10 – 15% higher than that of conventional dryer. By extending the stage number, the energy efficiency increased. The positive results will boost the development of novel dryers for efficient energy usage and retaining product quality for industrial application.

The simple tests have been conducted for corn and paddy drying. Compared with conventional fluidised bed dryer, corn and paddy drying with zeolite, can speed up drying time as well as retaining the product quality. However, with the increase of temperature, the product quality decreased due to the Mailard reaction. In this case, the operational temperature 60^{o}C or below can be recommended.

ACKNOWLEDGEMENT

This paper was compiled based on the PhD thesis written by Mohamad Djaeni with several important publications. The thesis was supervised by Dr AJB van Boxtel, Agrotechnology and Food Science, Wageningen University. The data for corn and paddy drying were performed in Laboratory of Food Process and Engineering, Faculty of Engineering, Diponegoro University. The equipment for experiment was funded by KKP3N project, Agriculture Research and Development Agency, Ministry of Agriculture, Indonesia

REFERENCES

1. M. Djaeni: Energy Efficient Multistage Zeolite Drying for Heat Sensitive Products. PhD Thesis, Wageningen University, The Netherlands (2008)
2. Anonymous. http://www.food-info.net/uk/colour/browning.htm (accessed, 2nd September 2008)
3. T. Kudra, Energy aspects in drying. Drying Technology, Vol. 22 issue 5 (2004), pp. 917 - 932
4. J.E. Gilmour, T.N. Oliver, and S. Jay, Energy use for drying process: The potential benefits of airless drying. In: Energy aspects in drying; T. Kudra. Drying Technology Vol. 22 issue 5 (2004), pp. 917 - 932
5. T. Kudra, and A.S. Mujumdar: Advanced Drying Technology. Marcel Dekker Inc., New York, USA (2002)
6. G.A. Mastekbayeva, M.A. Leon, and S. Kumar, Performance evaluation of a solar tunnel dryer for chilli drying. ASEAN Seminar and Workshop on Drying Technology, Bangkok, Thailand; 3-5 June (1998)
7. C.T. Kiranoudis, Z.B. Maroulis, and D. Marinos-Kouris, Drying of solids: Selection of some continuous operation dryer types. Computer & Chem. Eng. Vol. 20, Supplement 1, (1996), pp. S177-182
8. A. Doering, and K. Hennessy, Microwave drying evaluation for wet beet pulp initiative. Sumarry report, Agriculture Utilization Research Institute, Waseca (2008)
9. J.R. Hunt, H. Gu, P. Walsh, and J.E. Winand, Development of new microwave-drying and straightening technology for low-value curved timber. National Fire Plan Research Program USDA Forest Service, USA (2005)
10. X. Hu, Y. Zhang, C.Hu, M. Tao, and S. Chen, A comparison of methods for drying seeds: vacuum freeze-drier versus silica gel. Seed Science Research, Vol. 8, (1998) paper 7
11. O.B. Ocansey, Freeze-drying in a fluidized-bed atmospheric dryer and in a vacuum dryer: Evaluation of external transfer coefficients. J. Food Engineering, Vol. 7 issue 2, (1998), pp. 127 - 146
12. C.Ratti, Hot air and freeze-drying of high-value foods: a review. Journal of Food Engineering, Vol. 49, (2001), pp. 311-319
13. Anonymous. Vacuum Drying. www.bucherguyer.ch/foodtech (accessed, August, 2009)
14. Y.Xu, M. Zhang, A.S. Mujumdar, X. Duan, and S. Jin-cai. A two stage vacuum freeze and convective air drying method for strawberries. Drying Technology, Vol. 24 issue 8, (2006), pp. 1019 - 1023
15. I.Andrade, and H. Flores, Optimization of spray drying roselle extract (Hibiscus sabdariffa l.). Proceedings of the 14th International Drying Symposium (IDS 2004), Vol. A, Sao Paulo Brazil, 22-25 August (2004), pp. 597-604
16. V.Sosle, G.S.V. Raghavan, and R. Kittler, Low-temperature drying using a versatile heat pump dehumidifier. Drying Technology, Vol. 21 issue3, (2003),pp. 539 - 554

17. Z.Alikhan, G.S.V. Raghavan, and A.S. Mujumdar, Adsorption drying of corn in zeolite granules using a rotary drum. Drying Technology, Vol. 10 issue 3 (1992), pp. 783 - 797
18. G.O. Revilla, T.G. Velázquez, S.L. Cortés, and S.A. Cárdenas, Immersion drying of wheat using Al-PILC, zeolite, clay, and sand as particulate media. Drying Technology, Vol. 24 issue 8, (2006), pp.1033 - 1038
19. M. Djaeni, P. Bartels, J. Sanders, G. van Straten, and A.J.B. van Boxtel, Process integration for food drying with air dehumidified by zeolites. Drying Technology, Vol. 25 issue 1, (2007), pp. 225 - 239
20. M. Djaeni, Hargono, and L. Buchori, The effect of zeolite on drying rate of corn in mixed-adsorption dryer. 7th Asia-Pacific Drying Conference (ADC07) Tianjin, China, September 26th-28th (2011)
21. M.Djaeni, S.B. Sasongko, A. Prasetyaningrum, X. Jin, and A.J.B. van Boxtel, Carrageenan drying with dehumidified air: drying characteristics and product quality. International Journal of Food Engineering, Vol. 8 issue 3, (2012), Article 32. DOI: 10.1515/1556-3758.2682
22. M.Djaeni, P.V. Bartels, C.J. van Asselt, J.P.M. Sanders, G. van Straten, and A.J.B. van Boxtel, Assessment of a two-stage zeolite dryer for energy efficient drying. Drying Technology, Vol. 27 issue 10, (2009), pp. 1205 - 1216,
23. S. Soponronnarit, A. Pongtornkulpanich, and S. Prachayawarakorn, Drying characteristics of corn in fluidized bed dryer. Drying Technology, Vol. 15 issue 5, (1997), pp. 1603 - 1615
24. G.S. Mittal, and L. Ottern, Simulation of low temperature corn drying. Canadian Agriculture Engineering, Vol. 24 issue 2, (1982), pp. 111 – 118
25. K. Witinantakit, S. Prachayawarakom, A. Nathakaranakule, and S. Soponronnarit, Paddy drying using adsorption technique: Experiments and simulation. Drying Technology, Vol. 24 issue 5, (2006), pp. 609 - 617. DOI:10.1080/07373930600626503
26. K. Nagaya, Y. Li, Z. Jin, M. Fukumuro, Y. Ando, and A. Akaishi, Low-temperature desiccant-based food drying system with air flow and temperature control. Journal of Food Engineering, Vol. 75, (2006) pp. 71 - 77