Evaluation of food drying with air dehumidification system: a short review

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Evaluation of food drying with air dehumidification system: a short review

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Abstract. Energy efficient drying for food and agriculture products resulting high quality products has been an important issue. Currently, about 50% of total energy for postharvest treatment was used for drying. This paper presents the evaluation of new approach namely air dehumidification system with zeolite for food drying. Zeolite is a material having affinity to water in which reduced the moisture in air. With low moisture content and relative humidity, the air can improve driving force for drying even at low temperature. Thus, the energy efficiency can be potentially enhanced and the product quality can be well retained. For proving the hypothesis, the paddy and onion have been dried using dehumidified air. As performance indicators, the drying time, product quality, and heat efficiency were evaluated. Results indicated that the drying with zeolite improved the performances significantly. At operating temperature ranging 50 – 60°C, the efficiency of drying system can reach 75% with reasonable product quality.

Keywords: *efficiency, dehumidified, humidity, quality, zeolite*

1. Introduction

The main challenge in global food demand is how to obtain high quality dry food products in efficient processing. The dry food or its extract can be a good option due to the long life storage and consumer convenience. To realize this preference, drying process offers the major role corresponding to the moisture removal from wet product. In general, the agriculture and food products with high moisture content (vegetables, herbs, starch products) are dried at low (10°C) to moderate temperatures (50-70°C) to conserve the valuable ingredients (protein, vitamins, enzymes, oil) as well as physical appearance such as color, and texture [1,2].

Currently, a huge amount of energy was used for food drying processes. In post harvest treatment, about 60 - 70% of total energy was used for drying [1,3,4]. The efficiency of energy utilization by food dryer ranged between 30 – 60%. It means that the total of energy used was about 1.5 – 3.0 times from the theoretical load.

Meanwhile, the modern drying technology has been widely developed with attractive results in the product quality aspects. However, the efficient dryer development has been scared. For example, the energy efficiency in freeze and low temperature dryers is lower than that of a conventional convective dryer. This is due to the low value of driving force for moisture transfer and higher latent heat of moisture evaporation. Recently, the energy usage has become an important issue with respect to the limitation of fossil fuel supply. On the other hand, the availability of biomass as side product of agriculture crops has not been intensively used as renewable energy resource in drying process.

Conventional dryer with sunlight is very advantageous due to its low energy cost, and environmentally benign. The dryer has been widely used for a long time in various sectors, such as agriculture, fishery, forestry, and herbal medicine products. Unfortunately, the uses of this dryer is also restricted by main drawbacks of this dryer such as sustainability and product quality, which are rooted from its climate dependent [1].

Drying with pre-dehumidified air using zeolite as moisture sorbent has been previously discussed [5,6,7,8]. The zeolite was capable to remove moisture in the air close to 0% relative humidity [6]. Compared to the other adsorbents like silica, alumina and pillared clay, the adsorption capacity of zeolite was still higher even under low relative humidity. With the incorporation of zeolite in the dryer, the drying time was shorter, and thus save 70–75% of the total energy used by the dryer [1,9]. Furthermore, in multistage adsorption dryer design, the energy efficiency may achieve 80–90% [10]. Thus, the application of dryer with pre-dehumidified air for various food or agriculture crops drying can be an attractive option.

This research evaluates the application of air dehumidification with zeolite for food drying. Here, paddy and onion were dried using air dehumidified with zeolite [1, 11, 12]. The drying was conducted in various temperature and relative humidity. As performance indicators, the product quality and heat efficiency were evaluated. The results were also compared with a conventional drying without ari dehumidification system.

2. Materials and Methods

Based on the model and simple experimental test, the adsorption dryer with zeolite has shown attractive performances [10]. In this study, the dryer was tested in wider range application for agriculture crops drying. This work consisted of two main steps. Firstly, the two types of dryer (fluidized bed and tray dryers) were constructed in laboratory scale equipped with an air dehumidification section with zeolite. The dryers were used for different application (fluidized bed dryer for paddy drying, and tray dryer for onion drying). Secondly, the dryers performances were evaluated based on product quality, drying time, and or/ heat efficiency. The heat efficiency was estimated referring to the total heat used for evaporated water divided by the total heat introduced in the system [1,9,10]. The product quality was analyzed based on physical properties as well as important substance content.

2.1. Paddy Drying

The paddy drying system was designed as a fluidized bed dryer [11]. The dryer was equipped with a blower to deliver air for the fluidization process (see Figure 1). Initially, ambient air at a relative humidity (RH) of 70 - 80% and temperature about 30°C was flown to the heater at a velocity of 4.0 $m.s^{-1}$. The air was heated up to dryer temperature (designed as 40°C). The air was then used for paddy drying with initial moisture content of about 25% (w/w). To speed up the process, paddy was mixed with zeolite in a certain percentage (pre-determined as 20% (w/w) of 200 grams total mixture). The hot air evaporated moisture from paddy using sensible heat. At the same time, zeolite simultaneously adsorbed moisture from the air. So, relative humidity of air can be kept low from that improved the driving force for moisture transfer. In addition, the exothermic adsorption of vapour by zeolite released adsorption heat, which can increase the sensible heat of air. Hence, the heat was used for moisture evaporation from paddy surface [11].

The moisture in paddy was measured every 10 minutes using Krisbow KW06-404 Grain Moisture Meter until the moisture content in paddy close to 12%. The process was repeated for the inlet air temperature of 50 and 60°C, and the zeolite percentage in the mixture of 0 and 40%. The data were used to evaluate the drying rate and time. Meanwhile, the paddy quality was evaluated based on the swelling power [11].

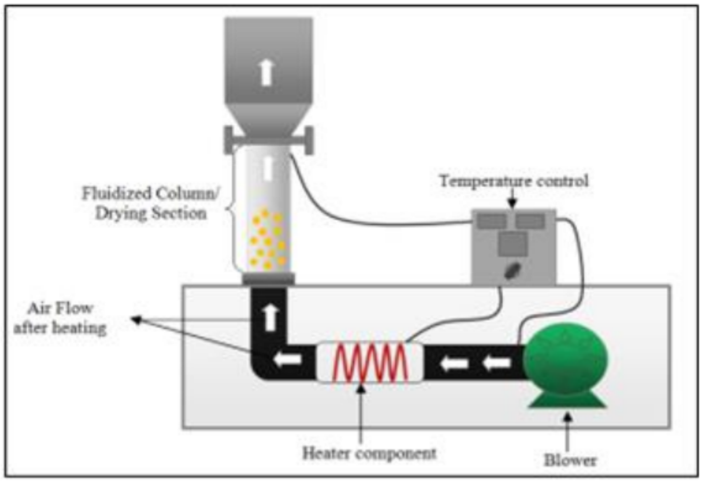

Figure 1. The schematic of fluidized bed dryer with incorporation of zeolite [1,11].

2.2. Onion Drying

Generally, onion was harvested from a farm with 88 - 92% moisture content. After drying, the average moisture content in the onion was desired to be 80 - 85% [1]. The onion drying was conducted in tray dryer completed with zeolite, as presented in Figure 2. The fresh air was heated up to 50°C by an electric heater. The air was used for onion drying with addition of a zeolite pack [1]. After evaporating the moisture from wet onion, the hot-wet air was dehumidified by zeolite. The moisture content in onion versus time was gravimetrically observed. With the data, the drying rate of moisture from onion can be developed with the model as previously published [12]. The validated model was used to find drying time for onion. The steps were repeated for different air temperature and air velocity. For comparison purpose, the onion drying without zeolite was also conducted.

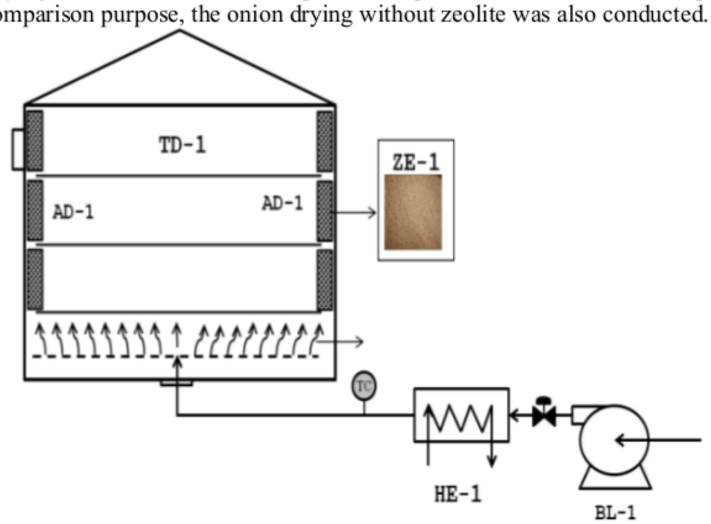

Figure 2. Onion drying with zeolite. Note: TD-1: Tray Dryer, AD-1: Adsorption Box, ZE-1: zeolite, HE-1: Air Heater, BL-1: Blower. The tray dryer dimension was 0.6x0.4x0.6 m [1]

2.3. Heat Efficiency Estimation

The paddy and onion drying were continued with rice husk combustion as a heat source. The rice husk with combustion heat value up to 15 MJ.kg^{-1} was obtained as a side product of rice mill industries. Theoretically, with latent heat of moisture evaporation about 2.5 MJ.kg^{-1}, one kilogram of rice husk can evaporate 6 kg of free moisture. As previously published, the heat efficiency was estimated using the equations (1) [1,9].

$$\eta = 100\,\%\left(\frac{Q_{evap}}{Q_T}\right) \tag{1}$$

where η was total energy efficiency (%), Q_T was total heat for drying system (kJ) and Q_{evap} was total heat for water evaporation (kJ). Q_T can be estimated based on the total heat required for heating air to dryer and air for regenerating the saturated zeolite, eliminated by the heat recycled from exhaust air [1,9]. Meanwhile, Q_{evap} was estimated based on the amount of moisture evaporated (kg) multiplied by the latent heat of water evaporation (kJ.kg^{-1}) [1,9].

3. Results and Discussion

3.1. Paddy drying with air dehumidification

The paddy drying was conducted at different temperatures with the presence of zeolite and without zeolite [11]. As previously discussed, zeolite was used for maintaining the moisture content of the drying air to be always low. So, the difference of this value with moisture content of paddy as driving force for drying process remains high [11]. As a result, the rate of moisture transfer from paddy to drying air was faster. The result was comparable with the dyer using the other solid adsorbents. For example, Revilla et al. showed that the drying with adsorbent such as silica, pillared clay, and zeolite speed up drying time [5]. Compared with paddy drying without zeolite conducted by Witinantakit et al., this result sounds a very positive improvement [13].

Air relative humidity and temperature determines the equilibrium moisture content in paddy as formulated with GAB model [11]. With low relative humidity and/or high temperature, the equilibrium moisture content in the product can be kept low in which speeds up drying rate proportionally as seen in equation (2) [6,11].

$$\frac{dq_{w,t}}{dt} = -k(q_{w,t} - q_e) \tag{2}$$

where $q_{w,t}$ was moisture in product at time (kg.kg^{-1}), q_e was moisture at equilibrium (kg.kg^{-1}), k was constant of drying rate (minute^{-1}) and t was sampling time (minute)

Using equation (2), the drying time for paddy at various temperature and relative humidity was then predicted, as presented in Figure 3. With a lower relative humidity, the drying time can be significantly reduced especially at temperature 40 – 70°C. Upper 70°C, the effect of air dehumidification on drying time was not significant. This improvement of drying performance was significant as compared to the other methods [13,14]. For example, without air dehumidification, the drying time of paddy from 33 to 16% (wet basis) at 150°C was 53 minutes [15]. By air dehumidification, the result was comparable with the drying at 60°C with air relative humidity of 20%.

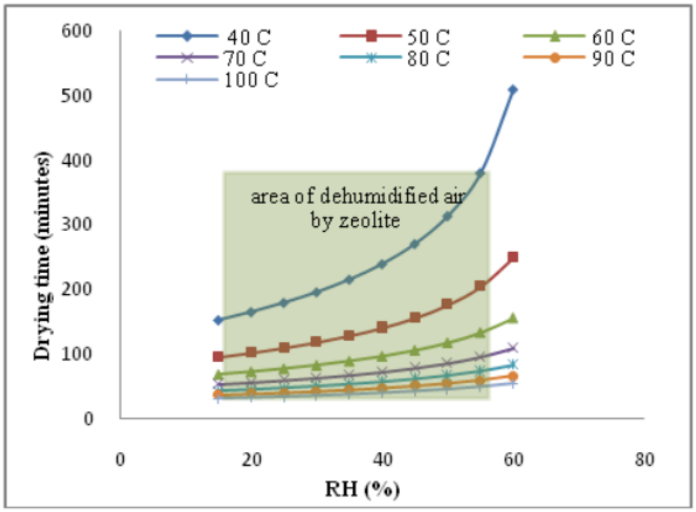

Figure 3. The drying time estimation for paddy at different temperatures and relative humidity [11].

3.2. Physical Properties of Paddy

After drying, the dried paddy was milled to remove the husk and obtain the rice. The physical properties including swelling power, percentage of head and broken rice, were observed (see Table 1). Results showed that at higher temperature the percentage of broken rice increased, for comparisons see also Sarker et al. [16]. It suggested that the paddy quality degraded. For example, at operational temperature 40 – 60°C, the percentage of head rice was about 60 - 80%. While at operational temperature 100°C, the percentage of head rice was 30%. At higher temperature, the moisture evaporation was faster. The hot vapour with large specific volume broke the structure of rice. Then, the dry paddy can be easily cracked during the milling.

Swelling power was also important to be discussed. As tabulated in Table 1, swelling power of the rice flour decreased at higher drying temperatures. Perhaps, at higher temperature the amylopectin in paddy degraded through heat moisture thermal degradation. Then, the affinity of rice starch to catch moisture decreased as indicated by the lower value of swelling power.

Table 1. Physical properties after drying and milling.

Drying Temperature °C	Physical properties			
	% (w/w) Moisture	% Head Rice	% Broken	Swelling power
40	12.60	80.40	19.60	4.20
60	12.30	78.70	21.30	3.86
80	12.20	29.87	70.13	3.83
100	11.00	13.43	86.57	3.62

3.3. Onion Drying

Onion dryings with and without the incorporation of zeolite were conducted at various temperatures. The result was presented and published in *Djaeni et al* [1]. In general, the moisture removal was highly affected by air temperature and relative humidity [7]. Higher air temperature will promote higher and faster moisture removal. The higher temperature accelerated the moisture movement or diffusivity in the tissue of onion. In addition, the available sensible heat of air for evaporating the moisture was higher. These two points increased the constant of drying rate value in which improved the water evaporation [17]. With the increase of air drying from 30 to 60°C, the drying times were found to be 60 - 70% shorter [17,18]. However, the some biochemical components, such as vitamin C, sugar and acidity can be potentially degraded corresponding to the increase of operating temperature.

Meanwhile, the lowering relative humidity with zeolite can enhance the driving force for mass transfer [2,5,12,17]. Removing some moisture in the air with zeolite reduced the relative humidity of air. As a result, the driving force for mass transfer can be enhanced. Under operational temperature 40°C and relative humidity 80 - 90%, the drying time for onion was around 35 hours. While, with the same operational temperature and relative humidity 10%, the drying time can be about 10 hours shorter [17]. With shorter drying time, the quality of biochemical components and appearance can be retained [19 – 22]. Thus, an acceptable onion quality was resulted. However, the effect of air dehumidification was limited at higher operational temperature [17].

3.4. Heat Efficiency Estimation

As previously published, the onion drying was conducted in capacity 120 kg per batch with the air temperature 50 - 55°C and air velocity of 0.7 $m.s^{-1}$. As a heat source, a rice husk combusted in furnace was used [1]. In this test, the average moisture content comprised moisture content in onion bulb layer and leaf. After drying, the moisture content in onion leaf should be below 20%. With 120 kg capacity of onion with initial moisture content of 90%, the total moisture evaporated was 72 kg needing total heat for evaporation of 180 MJ. In fact, about 16 kg of rice husk with total heat value of 240 MJ was required during the process. This implied that heat efficiency was about 75%. Meanwhile, the heat efficiency of onion drying without zeolite was around 66% [1]. With higher heat efficiency by air dehumidification, air recycle, or heat recovery, the total energy usage for moisture removal in drying can be saved [1,9]. The same story was also shown in paddy drying where the energy efficiency can be significantly improved with zeolite [1].

4. Conclusion

The air dehumidification with zeolite has been applied for tray and fluidized bed dryers. The dryers were used for paddy and onion drying. The zeolite as moisture adsorbent performed well. Therefore, the air can be significantly dehumidified. Based on product quality retention, drying time estimation, and heat utilization, the air dehumidification affected the drying performance positively. The fluidized bed and tray dryers were then operated with rice husk as a heat source. Results showed that the heat efficiency can achieve around 75%. This performance can be promising for sustainable food drying development.

Acknowledgements
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