Energy Efficient Dryer with Rice Husk Fuel for Agriculture Drying

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ABSTRACT: Energy usage is crucial aspect on agriculture drying process. This step spends about 70% of total energy in post harvest treatment. The design of efficient dryer with renewable energy source is urgently required due to the limitation of fossil fuel energy. This work discusses the performance of air dehumidification using rice husk fuel as heat source for onion, and paddy drying. Unlike conventional dryer, the humidity of air during the drying was dehumidified by adsorbent. Hence, the driving force of drying can be kept high. As consequences, the drying time and energy usage can be reduced. Here, the research was conducted in two step: laboratory and pilot scale tests. Results showed that the lowering air humidity with rice husk fuel has improved the energy efficiency. At operational temperature 60°C, the heat efficiency of 75% was achieved.

Keywords: adsorbent, dehumidified, heat efficiency, onion, paddy

1. Introduction

Energy efficient drying is still crucial issue on food and agriculture drying. This process requires about 70% of total energy in post harvest treatment (Kudra, 2004; Djaeni et al, 2013a; Gilmour et al, 2004). In addition, most of industrial drying used the fossil fuel as energy source that was still in-efficient for energy usage.

Currently, the energy efficiency of dryer ranged 30 – 60% which took 40 – 50% of total cost for the treatment. It means that the total energy introduced was about 1.5 – 3.0 times from real load. On the other hand, the modern drying technology has been widely developed with attractive result respecting to the product quality. However, the development of energy efficient dryer was scare. With the limitation of fossil fuel feedstock, the innovative efficient dryer with renewable energy is strongly recommended.

Conventional dryer with sunlight is really helpful in the aspect of low energy cost. It has been used for long time in almost of all areas, such as farming, fishery, forestry, and herbal medicine. However, the dryer was incovenience because of climate dependency (Djaeni et al, 2013a).

The positive result has been shown by air dehumidification with adsorbent such as zeolite (Revilla et al, 2006; Djaeni et al, 2009; Ratti, 2001; Atuonwu et al, 2011). The zeolite has high affinity to water that can remove the moisture in air up to 0.1 ppm or close to 0% relative humidity (Djaeni et al, 2013a). With zeolite, the energy efficiency of the dryer achieved 70 – 75%.Thus, the design of the dryer in a larger capacity with renewable energy source became the attractive idea.

Rice husk is a potential option as renewable energy source. This biomass can be easily found as waste after paddy harvesting. With moisture content below 15% and calor value of 15 MJ.kg^{-1}, it can be directly used for substituting fossil fuel in a furnace (Djaeni and Asiah, 2014). The heat combustion was used for heating up air as drying medium or regenerating the saturated zeolite.

This research discusses the pilot scale of dryer using air dehumidification as drying medium, and rice husk combustion as heat source. For material test, paddy and onion were dried. The energy efficiency and drying time

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are estimated and compared with conventional dryer without zeolite.

2. Materials and Methods

The research methods were done into two steps. Initially, two dryers were designed using electric heater. The first dryer was fluidised bed for paddy drying. The second one, was tray dryer utilized for onion drying. Both dryers were operated to find drying time.

After determining the effective drying time, the dryers were then scaled up using rice husk combustion as heat source. The rice husk was selected because its combustion value to 15 MJ/kg. With latent heat of water evaporation about 2.5 MJ/kg, one kilogram of rice husk can evaporate 6 kg of free moisture (Djaeni and Asiah, 2014) In the pilot scale, the heat efficiency was estimated with the following equations (Djaeni et al, 2013b; Djaeni et al, 2009).

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

Where, η is the total energy efficiency (%), Q_T is the total heat required the system for operational time (kJ), and Q_{evap} is the total heat to evaporate water from product (kJ).

Q_T 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

$$Q_T = Q_d + Q_{reg} - Q_{rec} \tag{2}$$

Here, Q_d is the total heat to heating up air for dryer (kJ.h^{-1}), Q_{reg} is heat to regenerate saturated adsorbent (kJ), and Q_{rec} is the estimation of total heat recycled from exhaust air exiting from regerenator and dryer (kJ).

Meanwhile, Q_{evap} was defined as follow:

$$Q_{evap} = M_p(q_{w,0} - q_{w,f})\lambda \tag{3}$$

M_p is the mass of dry product in dryer (kg), λ is the latent heat of water evaporation (kJ.kg^{-1}), $q_{w,0}$ is the moisture in product entering dryer (kg water per kg dry product), and $q_{w,f}$ is the moisture in product exiting the dryer (kg water per kg dry product). The moisture content was measured by gravimetry.

2. 1. Paddy Drying
2.1.1 Laboratory Test

The paddy drying was performed in a fluidized bed dryer with zeolite as water adsorbent. The schematic of equipment can be seen in Fig. 1 (Djaeni et al, 2013b).

For initial, the air flow was set at 4 m.s^{-1}(25% above minimum velocity for fluidization).

Ambient air with relative humidity (RH) between 70-80% and temperature between 29-33°C was heated in the heater completed with PID controller to reach dryer temperature (supposed 40°C).

The warm air passed the dyer containing the mixture of paddy and zeolite 3A (provided by Zeochem, Switzerland). The total weight of mixture was adjusted at 200 grams with the zeolite of 40%. The water content in paddy was measured every 10 minutes by KW06-404 Grain Moisture Meter (Krisbow Indonesia). The process was operated until moisture content in paddy close to 14% (wet basis). The process was repeated for air temperature 50°C. As comparison, the drying without zeolite was also performed. All data was used to predict drying time for various relative humidity as previously formulated (Djaeni et al, 2013b).
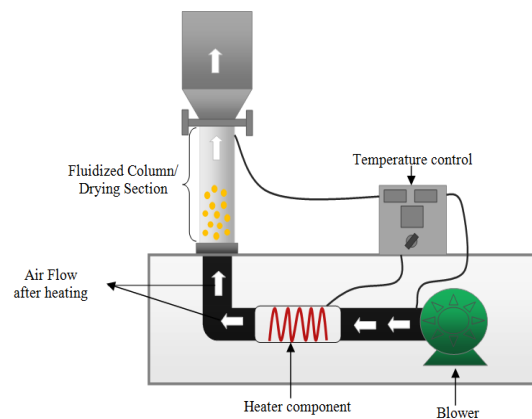

Fig. 1. Schematic of fluidized bed dryer (Djaeni et al, 2013b)

2.1.2 Pilot Test for Paddy Drying

Regarding to the laboratory test, the dryer was scaled-up in pilot test with rice husk fuel (Fig. 2). Amount of 0.5 kg of paddy was placed in fluidized bed dryer with presence of zeolite (20%). The energy efficiency was estimated based on total input and output air temperature (Djaeni et al, 2013b). The capacity was increased at various capacity up to 2.5 kg.

2.2 Onion Drying
2.2.1 Laboratory Test

The onion drying was conducted in tray dryer. The aim was to dry the outer layer and leaf of onion up to moisture content of 15 - 20%. With dry outer layer and leaf, the inside part of onion can be kept fresh before used. Normally, the raw onion harvested from farm contained one third of leaf. Both parts contained 88 - 92% water. After drying, the average of moisture was desired at 80 - 85%.

Fig. 2. Construction of paddy drying with rice husk

Here, the onion drying was completed by zeolite put in the side of tray (Fig. 3). So, after removing water from product, the wet air was directly dehumidified by zeolite. The air temperature and humidity were measured by KW0600561, Krisbow®, Indonesia (noted as T-RH). The air velocity was measured with an anemometer KW0600562, Krisbow ®, Indonesia (Djaeni et al, 2013b).
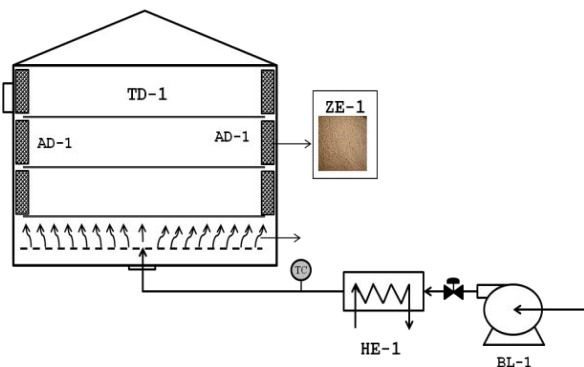

Fig. 3. Onion drying with zeolite (Note: TD-1: Tray Dryer, AD-1: Adsorber Box, ZE-1: zeolite, HE-1: Air Heater, BL-1: Blower. The tray dryer dimension was 0.6x0.4x0.6 m)

The ambient air was heated up to 50oC by electric heater. The air passed the dryer to dry 2 kg of onion. The moisture content versus time was observed as input to find effective drying time. The effective drying time can be estimated based on the previous research (Djaeni et al, 2013b). The process was repeated for different air temperature. As comparison, the onion drying without zeolite was also conducted.

2.2.2 Pilot Test for Onion Drying

The onion drying was scaled-up for capacity up to 120 kg/batch. In this test, the electric heater was replaced by rice husk furnace. Fig. 4 illustrated the schematic design of onion drying. Whereas, Fig. 5 presented the dryer construction. The energy efficiency was estimated based on the total water evaporated

divided by total energy introduced and heat for zeolite regeneration, as seen in equation 1-3 (Djaeni et al, 2009).
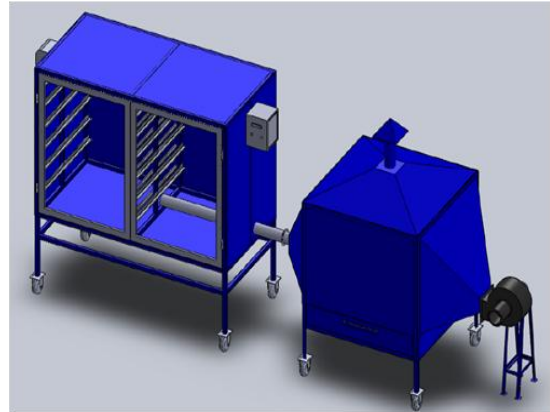

Fig. 4. The scale up design for onion drying (Note: Tray dimension was 2x1x1.6 m)

Fig. 5. The pilot scale of onion drying

3.Results and Discussion
3.1 Laboratory Test for Paddy Drying
3.1.1 The Effect of Zeolite on Paddy Drying

The paddy drying was conducted at different temperature with the presence of zeolite and without zeolite. As a response, the moisture content versus time was observed and plotted in graph as illustrated in Fig. 6 (Djaeni et al, 2013b). The zeolite adsorbed water from the air during the drying. Hence, the humidity of air can be kept low. As a result, the driving force of drying was higher as indicated in the decrease of moisture content in paddy (Revilla et al, 2006; Djaeni et al, 2009). Based on Fig. 6, the zeolite affected the moisture removal positively as compared to the literature (Witinantakit et al, 2006).

3.1.2 The Effect of Air Dehumidification

The temperature and relative humidity affected the equilibrium moisture in paddy as expressed by GAB model (Djaeni et al, 2013b).
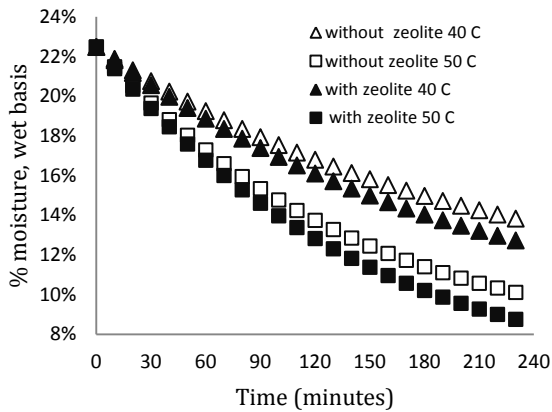
Fig. 6. Effect of zeolite on paddy drying at different temperature for air velocity 4 m.s^{-1}

In this step, the effect of air temperature and relative humidity on drying time were observed based on model (Djaeni et al, 2013). The results was presented in Fig. 7. Lowering relative humidity or increasing air temperature shortened the drying time significantly. This improvement was more significant as compared to the other methods published by Taweerarattanapanish et al (1999), and Witinantakit et al (2006). For example without air dehumidification, the drying time of paddy from 33 to 16% (wet basis) required 53 minutes at 150°C (Soponronnarit, 1999). This result was comparable with paddy drying by zeolite at temperature 60°C and relative humidity below 20% (Djaeni et al, 2013b).
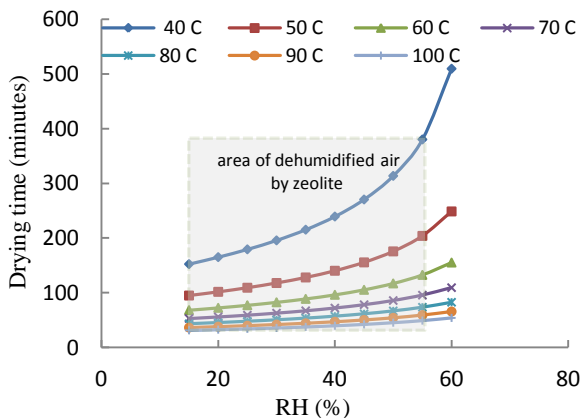

Fig. 7. The drying time for paddy at various temperatures and relative humidity for air velocity 4 m.s^{-1} (Djaeni et al, 2013b)

3.1.3. The Pilot Test for Paddy Drying

The pilot test for paddy was conducted in capacity 0.5 – 2.5 kg per batch with air temperature 60 - 70°C and velocity 10 m.s^{-1}. As heat source, the furnace with rice husk combustion was utilized. In this work, the drying time was estimated until water content close to 14% (wet basis). The heat efficiency of drying was

estimated using model cited from literature (Djaeni et al, 2009). The result was presented in Table 1 (Djaeni and Asiah, 2014).

Table 1.
Heat efficiency of paddy drying at 60 – 70°C (Djaeni and Asiah, 2014)

Capacity (kg/batch)	Drying Time (minute)	Heat efficiency (%)
0.5	25	45
1.0	30	70
2.0	40	75
2.0	60	80
2.5	80	85

Based on Table 1, the maximum efficiency 85% can be achieved. This was very significant improvement, since normally the heat efficiency of paddy drying with fluidized bed dryer was about 60%. It was also showed that higher capacity, higher heat efficiency. With higher capacity and same air flow, the residence time of air in the dryer became longer. So, more water can be evaporated. However, for higher capacity (suppose 5 kg per batch), the pressure drop in dryer was higher. Therefore, the paddy cannot be homogenously fluidized. As a consequence, the paddy was not fully dried.

3.2. Onion Drying

3.2.1 Laboratory Test for Onion Drying

The onion drying with and without zeolite were conducted in different temperature. About 2.0 kg of onion with moisture content 88% harvested from Brebes Central Java, were dried. The result was depicted in Fig. 8. In general, the water removal was affected by air temperature. Higher air temperature, higher water removal (Djaeni et al, 2013b). With higher temperature, the relative humidity of air was lower. Furthermore, the sensible heat of air for evaporating water was higher. It can enhanced the driving force for mass transfer.

Meanwhile, the zeolite for air dehumidification also affected the evaporation rate significantly (Revilla et al, 2006). With zeolite, the humidity of air reduced. Hence, the driving force for mass transfer improved. As seen in Fig. 8, with zeolite the water in onion became lower for same operational temperature.

3.2.2 The Pilot Test for Onion Drying

The pilot test for paddy was conducted in capacity 120 kg per batch with air temperature 50 - 55°C and air velocity 0.7 m.s^{-1}. As heat source, the rice husk furnace was used. The result was presented in Fig. 9.
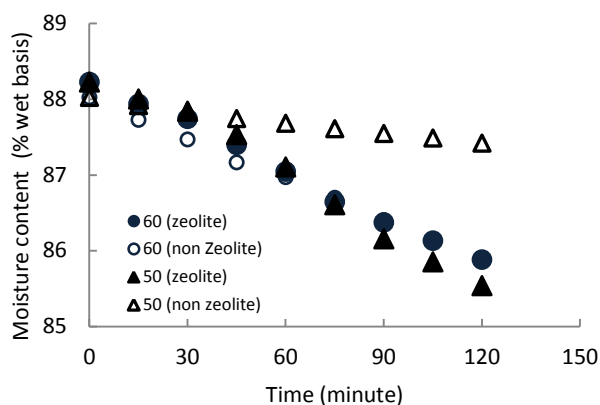
Fig. 8. Onion drying with and without zeolite at different dryer temperature for air velocity 5 m.s⁻¹

The moisture content in onion was slowly reduced. This is due to the air velocity is too slow. While, the water load must be evaporated was very high. In this test, not only water from the outer layer of onion, but also the water in onion leaf. The water in onion leaf must be kept below 20%. The leaf was about 30% from total weight of onion. So, the average moisture in onion and leaf after drying was about 75%). With dry leaf, the onion degradation during storage can be minimized.

Based on Fig 9, with preferring average moisture in onion 75%, the drying time of 8 hours was required. With 120 kg capacity at initial moisture 90%, the total water evaporated was 72 kg with total heat for evaporation 180 MJ. During the process, about 16 kg of rice husk with total heat value 240 MJ was required. Hence, the heat efficiency was about 75%. Meanwhile, the drying without zeolite needed 1 hour longer. It required 18 kg rice husk with total heat 270 MJ. Then, the heat efficiency was about 66%.
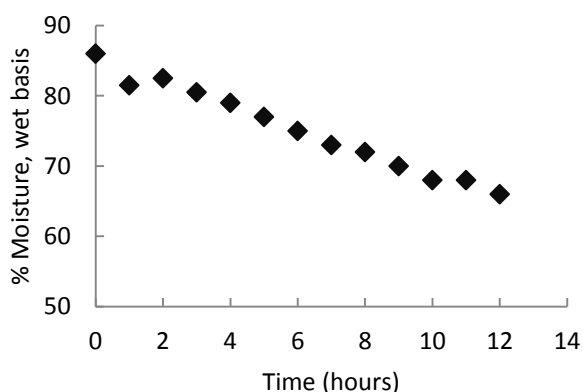

Fig. 9. Onion drying with zeolite at 50 - 55°C

7. Conclusion

Two kinds of agriculture products were dried under air dehumidification with zeolite. The results showed that the dryer performance respecting to the heat efficiency can be positively improved. The processes were then scaled up and rice husk as renewable fuel source was used. Results showed that the heat efficiency can be kept high. For air temperature 60°C, the heat efficiency was about 75%. It implied that one kilogram of rice husk (heat value 15 MJ/kg) was able to evaporate 4.5 -5.0 kg of moisture from paddy or onion. The results can be a potential option for energy efficient dryer development.

8. Acknowledgments

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