The Process Transport of Drying Corn With Mixed-Adsorption Drying

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Abstract :

Mixed-adsorption drying with adsorptive material such as zeolite is an option to enhance the performance of drying corn. In this case, zeolite and seeds are mixed and fluidized by warm air as drying medium. The air will evaporate water from seed, and at the same time, zeolite will adsorb vapor from air. Thus, the humidity of air in dryer can be kept low in which improves the driving force for drying. So, the process can be more efficient in low or medium temperature and the corn quality can be retained.

This paper discusses the process transport of the drying formulated in two dimensional modelling. In this case, the drying rate and water diffusivity in corn was estimated with experimental data. While, the adsorption rate and diffusivity of water in zeolite as well as other important process constants was assumed based on literature. Results showed that the drying can run well and the model can describe the profiles of moisture and temperature in corn and zeolite. It can be also noted that saturation time of zeolites particles is faster than drying time of corn. It means that more zeolite is required in the mixture to keep driving force being still high.

Keywords: Mixed adsorption drying, process transport, modelling, diffusivity, zeolite

1. Introduction

Corn (*Zea mays L.*) is one of main food resources in the world. It contains carbohydrate, protein, and edible oil [1]. Postharvest treatment such as drying is an important steps to produce high quality of corn since it determines the water content and ingredients and long life storage.

Currently, there are several drying process applied for corn, for example: direct sun drying, hot air drying, microwave, fluidization, and vacuum freeze drying. Direct sun drying is the simplest one but weather dependency for dry product quality as well as process continuity [2]. Hot-air drying is usually applied to dry corn at rotary or fluidized bed dryer. An important consideration with this process is the air temperature that increases drying rate, shortens drying time. But the higher temperature decreases corn quality. Haros et.al (2003) found that increasing temperature higher than 110°C reduces starch yield drastically [3]. In addition, the solubility indexes of albumin, globulin, and zein also decreases at higher temperature [4].

Momenzadeh, et al (2011) tried to improve the performance of fluidized bed dryer completed with microwave heating [5]. Various temperature was also observed from 30-60°C which indicated the increasing 10°C, the drying time can be reduced up to 5%. By introducing microwave heating, the drying time can be reduced up to 50% [5]. Based on the Nair, et al (2011), the microwave applied in drying corn can reduce germination [6]. However, the amount of energy usage will be another problem to be solved.

The researcher also attempted to increase the performance of fluidized corn and rice by implementing two stage dryer [7]. The process can reduce the operational temperature as well as improving the quality of corn during storage. However, the operating temperature is still higher than 60°C then the ingredients degradation has to be more considered.

Mixed-adsorption drying with water adsorbent such as zeolite or other solid adsorbents is an option to improve product quality as well as energy efficiency for fluidized. The method is firstly published by Falabella et al (1991) with bentonite clay. However, they cannot find the significant improvement [8]. Perhaps, this was due to the performance of adsorbent that was low affinity to water under drying condition. Positive results were published by Alikhan, et al (1992) and Revila et al (2006) who dried grain (corn, and seed) with zeolite [9,10]. Based on Revila et al (2006), the effect of zeolite to water removal from a product is the most superior compared to silica, alumina, sand and pillared clay [10].

In mixed adsorption dryer, zeolite and the seed product such as corn are mixed in a column and fluidized by air as drying medium. The air will evaporate water from the product, and at the same time, zeolite will adsorb vapour from air. As results, air humidity can be kept low. Moreover, operational temperature can be maintained at the certain condition due to the latent heat of adsorption. Thus, the driving force of drying can be kept high.

Zeolite is an alumino-silicate compound with tetrahedral bound linked by oxygen. Atom Al is negative that can be neralized by cation. The exchangable cation affects the adsorption ability of zeolite. Beside that, the ability is also influenced by Si/Al ratio, surface area, and size of zeolite pore [11- 13]. In Indonesia, the natural zeolite is available in market. Even, the potential of zeolite production is high [14]. However, adsorbing capacity of natural zeolite is too low rounding 0.07-0.09 gr water/gr dry zeolite. By activation using KOH or NaOH, the adsorbing capacity can be enhanced up to 0.15-0.20 gr water/gr zeolite.

This paper discusses the effect of the activated natural zeolite to dry corn. As comparison, the commercial Zeolite 3A obtained from Zeochem was also used. Each zeolite was mixed with corn at various weight percentage and temperature. Their performance in term of drying rate was observed and compared.

2. Material and Methods

2.1. Principle of Mixed-Adsorption Dryer

Figure 1 presents the phenomena of mixed-adsorption dryer with zeolite. In the process, the dry air will contact with corn. The sensible heat of air is transferred to heat up the surface of corn, and water will be evaporated (endothermic process). Parallel with the process, the zeolite having affinity to water, will adsorb water from air quickly by releasing adsorption heat (exothermic process). The heat is transferred to the air than can compensate sensible heat transferred to corn. Hence, two advantageous will be obtained from the process: temperature of air can be kept warm/medium by adsorption heat of water, and humidity of air during drying can be kept low. So, the driving force of drying can be kept high. The process occurs simultaneously and repeated several times until zeolite saturated by water.
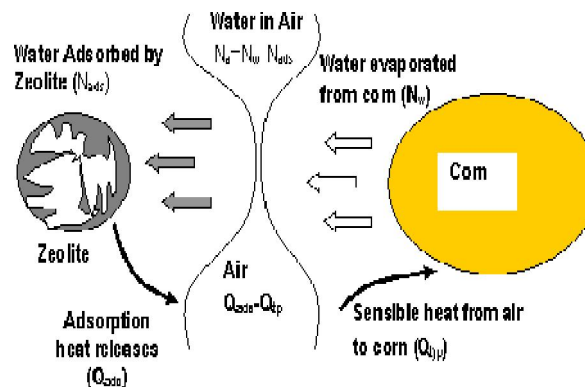

Figure 1. Mixed-Adsorption Dryer With Zeolite

The most important point here is the operational temperature that affects the driving force of adsorption and drying as well as product quality. In the higher temperature, equilibrium moisture (water loaded capacity) both for product and zeolite is lower. In this case, the driving force for drying will be higher, but it will be lower for adsorption. Considering to the protein and starch content in corn, the operational temperature is not more than 60^oC. In this operational temperature, the adsorption capacity of zeolite is still higher. By assuming that the adsorption rate of vapor in zeolite is faster than that of desorption of water from corn, the water transport for mixed adsorption drying views the desorption rate as follows:

Water in corn

Water diffusivity corn D_w ($m^2.s^{-1}$) can be derived from the following equation:

$$\ln(\frac{q_{e,p}-q_{w,p}}{q_{e,p}-q_{e,0}}) = \ln(\frac{8}{\pi^2}) - \frac{\pi^2 D_w t}{l^2} \tag{1}$$

The water will desorb from inside to the surface of corn when the value of $q_{e,p}$ is lower than that of $q_{w,p}$. From the product properties the equilibrium moisture refers to Oswin's equation [15]:

$$q_{e,p} = (\frac{13.77 - 0.077T_a}{100})(\frac{a_w}{(1-a_w)})^{0.33} \tag{2}$$

Where, $q_{e,d}$ is the equilibrium moisture refers to Oswin's equation, kg water per kg dry corn [15], t is sampling/operational time (s), $q_{w,p}$ is the moisture in corn at operational time, kg water per kg dry corn, k_{dry} is drying rate of corn, s^{-1}, a_w is the water activity equals to relative humidity (RH) and T_a is air temperature (^{o}C).

By knowing $q_{e,p}$ and measuring $q_{w,p}$, the value of D_w at every operational temperature can be estimated.

$$D_w = D_0 \exp^{(\frac{B}{273.15+T_a})} \tag{3}$$

D_0 is a constant of diffusion (m^2.s^{-1}), B is the activation energy (J.kmole^{-1}) divided by R (the constant of ideal gas (8.314 J.mole^{-1}. K^{-1})).

2.2. Experimental set up

The research aimed to study the presence of Zeolite 3A (provided by Zeochem, Switzerland), air velocity, and operating temperature on the diffusivity of water in corn. The process was conducted in fluidized bed dryer (see Figure 2). As a sample, the sweet corn harvested from local farmer in Semarang was used with initial water content 35-40%, average bulk density 840 kg/m^3, and dimensión of length, width, and thickness 8.5x6.5x2.8 mm.

In the first step, Zeolite 3A and corn were mixed with certain zeolite percentage (supposed 50%) with a total weigh of 50 gram. The mixture was then fluidized using warm air in dryer colum (ID 5 cm H 50 cm) at 40°C and linear air velocity 3 m/sec. The response, water content in corn was measured every 10 minutes during 2 hours with gravimetry. The water diffusivity was then calculated refers to the Equation 1. The procedure was repeated for a percentage of Zeolite 3A 25%, without zeolite (0%), and operating temperature 30°C and 50°C.
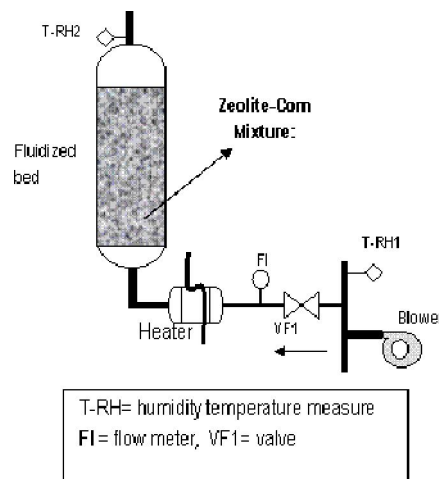

Figure 2. Fluidized bed mixed-adsorption dryer

3. Result and Discussion

3.1. Effect of Zeolite

Zeolite 3A give positive effects on drying corn as indicated in water content during operation. The presence of zeolites can speed up water removal as indicated in Figure 3. For example, at the same operational time the water content of corn dried with zeolite is lower than that of without zeolite (zeolite 0%). It means that the zeolite can improve driving force for drying or keep it high by adsorbing water from the air as drying medium.
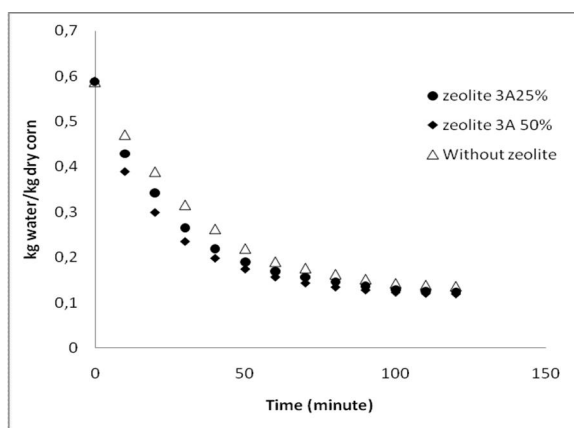
Figure 3. Comparison of water removal in corn at operational drying 40°C

3.2. Effect of Operating temperature

The temperature takes important role for both desorption and adsorption of water. At higher temperature, equilibrium moisture in materials (zeolite and corn) is lower [2, 16]. It means that water loaded in both material decreases. In this case, driving force for drying increases. In addition, the capacity of the air for evaporating water increases significantly. Hence, higher temperature, higher water can be evaporated from material (see Figure 4). Using equation 1, the higher temperature, the diffusivity of water in corn increases (see Table 1). The constant process regarding to the equation 3, can be estimated.

In general, the increase of temperature will inhibit the adsorption process because of reducing water loaded capacity. But using zeolite and current operational temperature, the effect does not change significantly.
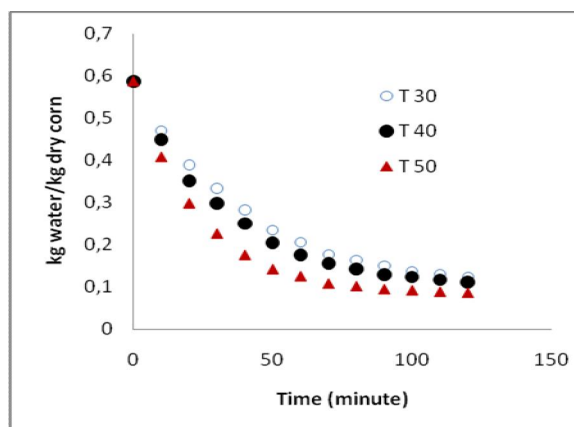

Figure 4. Water in corn versus time at different operating temperature for natural zeolite (25%)

Table 1. Moisture diffusivity, whiteness and gel strength of carrageenan at different temperature

Temperature, ^{o}C	D_w x10^{-10}, $m^2.s^{-1}$	
30 (303.15 K)	6.90	$D_0 = 3.00x10^{-13}$
40 (313.15 K)	8.11	$B=0.024K$
50 (325.15 K)	11.36	

3.3. Water and Temperature Profile

Based on Figure 1, the water and heat transfer can be formulated in partial differential equation. Assuming that, both corn and zeolite are spheres, the accumulation of water is a function of water transport due to the diffusion, and water uptake/release [2]:

$$\frac{dq_{w,s}}{dt} = D_w \nabla^2 q_{w,s} \pm \text{rate of water transfer} \tag{4}$$

The accumulation of water in air is similar [2]:

$$\frac{dq_{v,a}}{dt} = D_v \nabla^2 q_{v,a} - F_a \nabla q_{v,a} \mp \text{rate of water transfer} \tag{5}$$

Where, q_{ws} is water in solid material (zeolite or corn) in kg water per kg dry solid, $q_{v,a}$ is water in air (kg water/kg dry air), F_a is the flow of air ($m^2.s^{-1}$), D_w and D_v are the diffusion of water in solid ($8x10^{-7} m^2.s^{-1}$ for zeolite [16]) and vapor in air (around $3.0x10^{-6}$ $m^2.s^{-1}$[17]), respectively. Because the air flow is turbulance, the water in air closes to steady.

The accumulation of energy in the zeolite or corn is a function of conductive and convective heat transport, the amount of energy involved in adsorption/desorption and the energy exchange with the air:

$$\rho_s cp_s \frac{dT_s}{dt} = k_s \nabla^2 T_s \pm \begin{bmatrix} \text{adsorption} \\ \text{desorption} \end{bmatrix} \text{heat} \pm \text{heat transfered} \tag{6}$$

Where, ρ_s is the density of solid (zeolite and corn), cp_s is the specific heat of corn and zeolite ($kJ.kg^{-1}.^oC^{-1}$), and k_s is the conductivity of material ($kJ.m^{-1}.s^{-1}$)[2,15,16,18]. For instant, it is assumed the conductivity of corn and zeolite is comparable.

The accumulation of energy in air is a function of conductive and convective heat transport and the energy exchange with the zeolite [2]:

$$\rho_a cp_a \frac{dT_a}{dt} = k_a \nabla^2 T_a - F_a \rho_a cp_a \nabla T_a \mp \text{heat transfered} \tag{7}$$

Where, ρ_a is the density of solid (zeolite and corn), cp_a is the specific heat of air ($kJ.kg^{-1}.^oC^{-1}$), and k_a is the conductivity of material ($kJ.m^{-1}.s^{-1}$)[2,15,16,18]. Because the air flow is turbulance, the accumulation of heat in air closes to zero.

Using equation 4-7, the profile of water and temperature in corn and zeolite can be simulated by Femlab (COMSOL) as illustrated in figure 5 and 6. Figures 5 presents the profiles for moisture content in zeolite and corn at operation time 3600 s (60 minutes) and drying temperature 60°C. Firstly, the air contacts with the surface of corn. Then, the moisture in the surface is evaporated, and the water concentration decreases. Due to the different concentration, the water diffuses from the inside to the surface. After 60 minute, the water in corn can reach 12% as expected. The vapour in the air is adsorbed by zeolite. With higher adsorption rate, porosity and diffusivity, the zeolite saturation can run quickly [17].
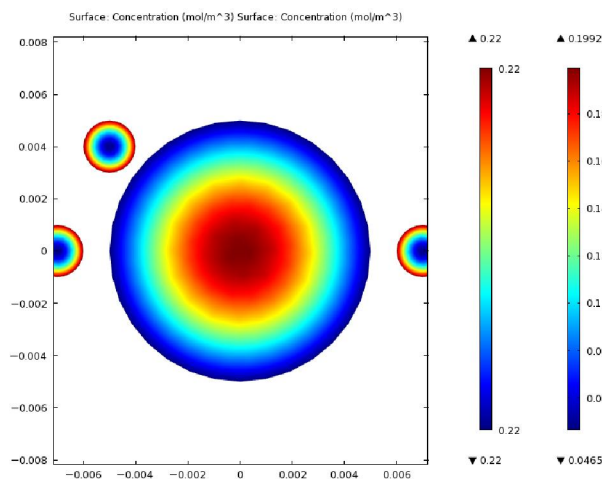
Figure 5. Profile of moisture in zeolite,and corn at time 60 minutes and temperature 60°C (333.15 K)

Figures 6 presents the profiles of temperature of corn, and zeolite at operating temperature 60°C. The air introduces heat in the surface of corn. The surface temperature increases and the heat moves from the surface to the inside layer. However, for operational time 60 minutes, the temperature difference is not significant.
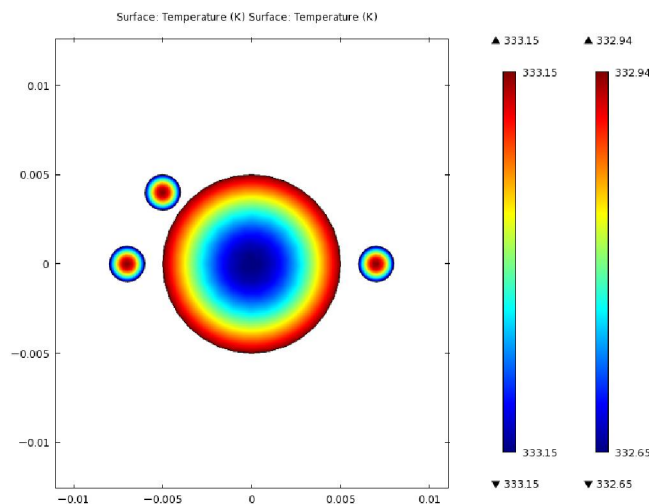
Figure 6. Profile of temperature in zeolite and corn at time 60 minutes and temperature 60°C (333.15 K)

Conclusion

Mixed-adsorption drying with adsorptive material such as zeolite can enhance the performance of drying corn. The result showed that the drying time can be faster with zeolite. In addition, transfer of water from corn to air can be positively improved. Using the estimated diffusivity, the transport of water and temperature in zeolite, corn, and air can be predicted by the partial differential model. The model can describe the profiles of moisture and temperature in corn, and zeolite. It can be also noted that saturation time of zeolites particles is faster than drying time of corn. So, more zeolite is required in the mixture to keep driving force being still high.

Acknowledgement

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