

Research Article

Drying of Soybean Seeds in Fluidized Bed: Experimental and Scale-up Simulation in Continuous Operation Mode

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Abstract: The drying curve of the soybean seed (X_{in} 0.4 kg/kg dry base) was obtained experimentally by fluid bed dryer. The experimental works was performed by varying inlet air temperature ($^{\circ}\text{C}$): 35; 40; 45, bed mass of particles (kg): 0.2; 0.3; 0.4 and superficial air velocity (m/sec): 7.6; 8.4; 9.1. The drying rate curves as a function of moisture content showed only the decreasing rate period. Among the variables examined, only temperature had a significant influence on the soybean seed drying in fluidized bed. The normalized drying curve of the single particles as well as the critical moisture content (X_{cr} 0.5) was derived. A simulated continuous fluidized bed dryer for soybean with capacity 500 kg/h seed had been successfully designed by scale-up method.

Keywords: Drying, fluid bed, seed, simulation, soybean

INTRODUCTION

Soybean (*Glycine max* (L.) Merr.) is the most important of vegetable proteins due to its high quality as a source of protein for human and animal diets (Rafiee *et al.*, 2009). The importance of soybean in grain production has been increasing due to its high yield capacity and its lower harvest cost in comparison to other grains (Duarte *et al.*, 2004). Soybean contains 40% protein and 20% oil along with calcium, iron, carotene, thiamine and ascorbic acid (Barrozo *et al.*, 2006). For cropping and production levels, it needs high quality soybean seeds.

The quality of stored seeds is a serious constraint to agricultural development in many countries. Usually after harvesting, seeds must be dried to lengthen their storage life. The appropriate moisture levels for stored seeds depend on the species, storage conditions and length of storage (Copeland and McDonald, 2001). Although there are many drying methods to dry soybean seeds, different drying methods can result in dissimilar seed germination. Different types of dryer for drying of soybean seed were applied such as sliding bed dryer (Pfeifer *et al.*, 2010), moving bed dryer (Barrozo *et al.*, 2006) and sorption drying in fluid bed dryer (Zhanyong *et al.*, 2002). In general, these researches only discuss the relationship between the effects of drying operating conditions to soybean seed quality. In addition, these studies had not discussed the scale-up to industrial scale, a comparison between batch and continuous conditions, as well as single particle drying kinetics.

Meanwhile, to be able to design an optimal drier, the drying kinetics curves of the single particles of the

solid product is must be known. The single particle drying curve can be in the form of normalized drying curve. The derivation of single particle drying kinetics from integral drying only can be conducted by scaling down using model. The fluidized bed dryer models that have been developed based on two-phase models (bubble and suspension phase) and the concept of normalized drying curve (Suherman *et al.*, 2008), here in after referred to as FLUBED (Suherman, 2007). The FLUBED was successfully applied in derivation of single particle drying curve of cassava starch (Suherman *et al.*, 2013). Therefore, in the present work, the FLUBED was used also in derivation of single particle drying curve of soybean from experimental measurements. Finally, the simulation works in continuous mode.

EXPERIMENTS AND MODELING METHOD

Experiments method: Figure 1 shows the apparatus set-up. The soybean seed was taken from agricultural land, then rewetted again by soaking in water for more 24 h until the moisture content 0.4 kg/kg (dry base). The physical properties and experimental conditions is shown in Table 1. The process starts with an experiment that will turn on the blower air flow dryer. Furthermore, air heaters be positioned as desired, e.g., 40°C . After drying air temperature reaches the temperature desired, soybean seed material is inserted into the bed. Finally, the drying process is conducted for 60 min. The temperature controller TIC (below distributor) maintain inlet air temperature at the desired level. During the experiment, inlet air temperature, outlet air temperature and outlet air humidity is

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Fig. 1: Apparatus set-up

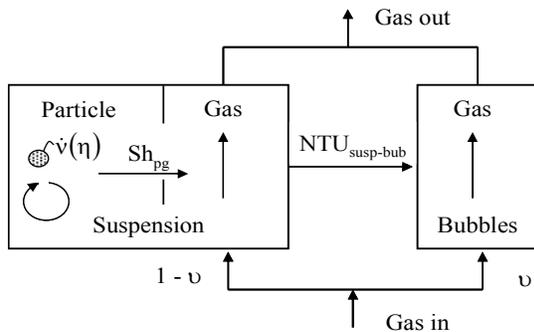


Fig. 2: Schematic of two phase fluid bed drying model

Table 1: Physical properties and experimental conditions

Parameter	Value
Density of solid, ρ_s (kg/m ³)	1170
Density of gas (air), ρ_g (kg/m ³)	1.103
Particle diameter, d_p (mm)	6
Initial solids temperature (°C)	25
Initial solid moisture content (db) (kg/kg)	0.4
Bed height (m)	0.5
Bed width (cm)	10
Minimum fluidization velocity (u_{mf}) (m/sec)	1.7
Air temperature, T_{air} (°C)	35, 40, 45
Bed mass of particles (kg)	0.2, 0.3, 0.4
Superficial air velocity, u_{air} (m/sec)	7.6, 8.4, 9.1

measured each 10 min. At the end of the experiment, samples were taken for the starch solids are then measured the water vapor content using the gravimetric method by oven.

For each time, the solid moisture content is calculated by:

$$X(t) = X_0 - \frac{\dot{M}_g}{M_{s,dry}} \int_{t=0}^t (Y_{out}(t) - Y_{in}(t)) dt \quad (1)$$

where,

- X_0 = Initial moisture content
- \dot{M}_g = Air mass flow-rate
- $M_{s,dry}$ = Dry mass of particle
- Y = Air humidity

And drying rate is calculate by:

$$\dot{m} = \frac{\dot{M}_g}{M_{s,dry}} \frac{\rho_p d_p}{6} (Y_{out}(t) - Y_{in}) \quad (2)$$

where,

- ρ_p = Particle density
- d_p = Particle diameter

Modeling: In present study, the simulator fluid bed drying, which is called as FLUBED, was used for derivation of single particle drying kinetics and simulation in continuous mode. FLUBED was developed by using a two-phase model which it is introduced by Tsotsas (Groenewold and Tsotsas, 2007) which can be described schematically as in Fig. 2. In this simulator contains several equations, namely total mass balance for the particles, mass balance between the suspension and the bubble phase, kinetics of particle-suspension and suspension-bubble and so on, which it had been written clearly and complete in Suherman *et al.* (2013).

RESULTS AND DISCUSSION

Experimental results: Figure 3 shows the drying curves of soybean seed for different inlet drying air temperatures, keeping the same experimental conditions of air humidity 14.3 g/kg, bed mass of particle 0.2 kg and air velocity 7.6 m/sec. It can be observed, that air temperature had significant influence on the drying process. Increases of air temperature will increase drying rates, then the drying process were achieved in a shorter time.

Figure 4 shows the drying rate curves of soybean seed for different inlet drying air temperatures, keeping the same experimental conditions of air humidity 14.3 g/kg, bed mass of particle 0.2 kg and air velocity 7.6 m/sec. It shows that the drying rate curves presented only the period of decreasing rate, indicating that water diffusion inside the particles was the rate-controlling step. This pattern is similar that was observed by Soponronnarit *et al.* (2001), Barrozo *et al.* (2006) and Da Silva *et al.* (2012) in the study of convective drying of soybean. However, the drying rate curve at moisture content close to zero shows scatter data, due to the accuracy of apparatus for measurement air humidity.

Figure 5 presents soybean seed drying curves for different bed mass of particles, keeping the same experimental conditions of air temperature 40°C, inlet air relative humidity 60% and air velocity 7.6 m/sec. The bed mass of 200, 300 and 400 g can be converted as bed height namely 0.097, 0.142 and 0.190 m, respectively. These bed height very low comparing with total bed height of apparatus is namely 0.5 m. It can be observed that bed mass did not exert significant influence on the drying process. It can suggested that the mixture in the bed was very intense and might be assumed as ideal. Only for higher bed mass, the drying times were found to be slightly longer.

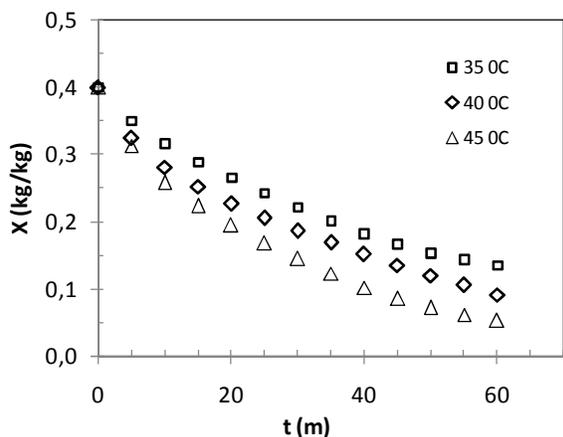


Fig. 3: Drying curves of soybean seed for different drying air temperature at inlet air relative humidity 60%, bed mass of particle 0.2 kg and air velocity 7.6 m/sec

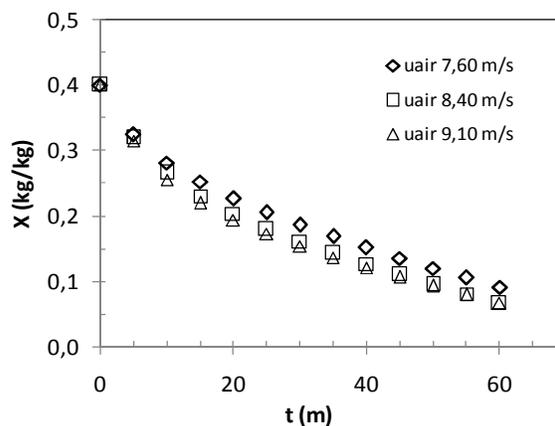


Fig. 6: Drying curves of soybean seed for different air velocity at air temperature 40°C, inlet air relative humidity 60% and bed mass of particle 0.2 kg

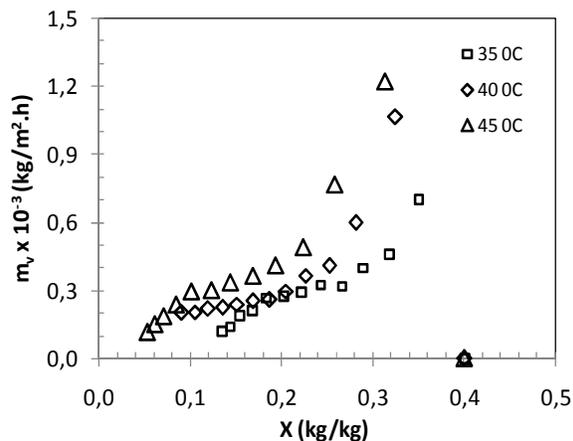


Fig. 4: Drying rate curves of soybean seed for different drying air temperature at inlet air relative humidity 60%, bed mass of particle 0.2 kg and air velocity 7.6 m/sec

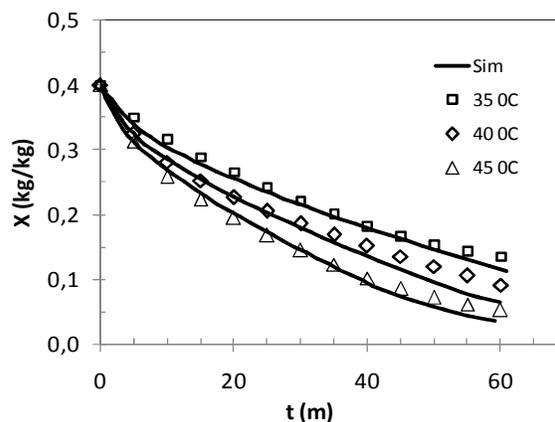


Fig. 7: Comparison drying curves between measurement and simulation results

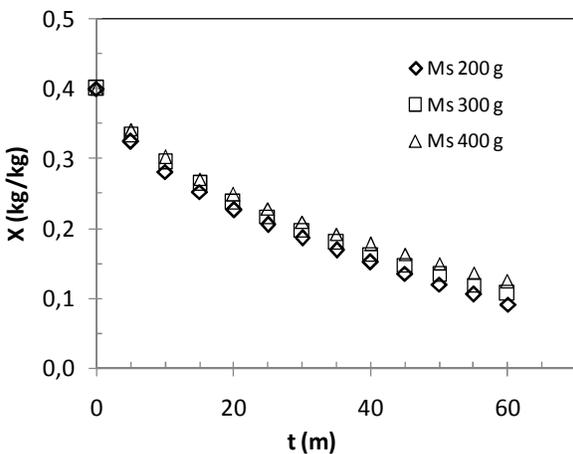


Fig. 5: Drying curves of soybean seed for different bed mass of particles at air temperature 40°C, inlet air relative humidity 60% and air velocity 7.6 m/sec

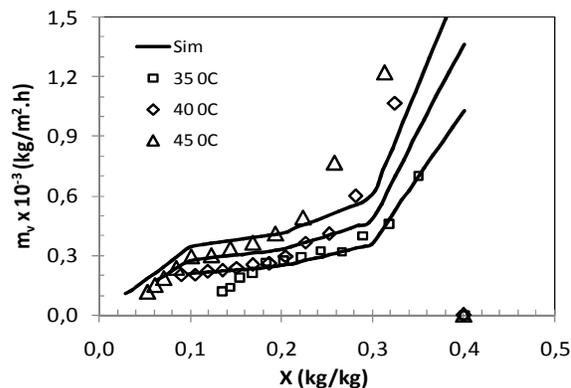


Fig. 8: Comparison drying rate curves between measurement and simulation results

Figure 6 shows drying curves of soybean seed for different air velocity, keeping the same experimental conditions of air temperature 40°C, inlet air relative humidity 60% and bed mass of particle 0.2 kg. It can be observed that air velocity had no significant influence

Table 2: Normalized drying curve of soybean seed where X_{cr} is 0.5

η	0.20	0.40	0.60	0.80	0.9	1
\bar{V}	0.06	0.07	0.10	0.30	0.4	1

Table 3: Design parameters for continuous dryer 500 kg/h

Parameter	Value	
Dryer	Length (m)	5
	Width (m)	1.50
	Bed height (m)	0.50
Solid	Flow rate (kg/h)	500
	Inlet moisture content (kg/kg) (db)	0.40
Air	Temperature (°C)	35
	Humidity (kg/kg)	14.27
	Flow rate (kg/h)	100,000

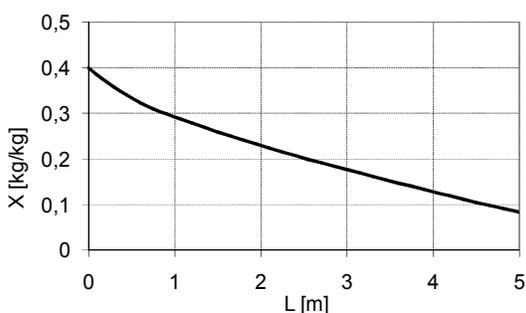


Fig. 9: Solid moisture content curve along the simulated continuous dryer

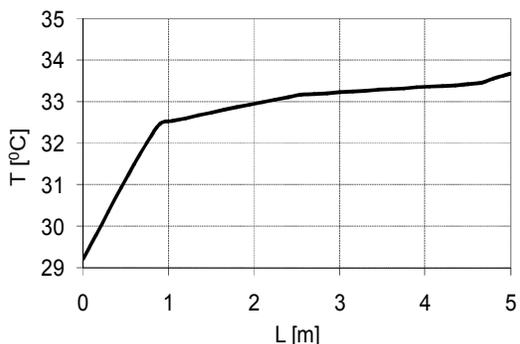


Fig. 10: Temperature profiles along the simulated continuous dryer

on the drying process in fluidized bed under the conditions studied, confirming that the limiting mass transfer step occurs inside the particles.

Comparison between measurement with simulation results: Figure 7 and 8 shows a good agreement between the measured and the simulated both residual solid moisture content and drying rate curves. In this diagram, the inlet gas temperatures as parameter in order to illustrate their influence on the drying process.

This also applies in particular to the influence of the temperature. Due to the normalized drying curve is independent to the outside conditions, the excellent performance of results intend that the normalization method works well. The change of the drying rate which causes a variation of the temperature toward end

of the drying process is proportional to the change of the drying rate which takes place at same variation of the gas temperature in the first drying period.

Derivation of single particle drying curve: The normalized drying curves of the single particles as well as the critical moisture content are derived from measurement results by iterative adjustment in the software FLUBED. For all measurements will give only one normalized drying curve as well as a critical moisture content X_{cr} 0.5. This result is summarized in Table 2. In the application, between the fixed corner points of the normalized drying curve is to be interpolated by linear interpolation.

Simulation design of continuous fluid bed dryer: Furthermore is the simulation design of a continuous dryer for plant scale of 500 kg/h. This means that in just one hour, the product could be as much as 500 kg of dried to moisture content below 10%. Table 3 is design parameter of continuous dryer capacity of 500 kg/h. Dryer will be operated with constant bed height of 0.5 m.

Furthermore, based on the design of the above, it can be predicted moisture content profiles in solids along the dryer (Fig. 9). Here the content of water vapor out of the dryer at 8%, it meets the standards which the moisture content below 10%. If desired, the water vapor content of the output can be reduced further to below 10% by increasing the rate of air or temperature.

While the temperature profile along the dryer is shown in Fig. 10. Seen in the curve, the maximum temperature in a position output air at 33.7°C. In this temperatures the soybean seed will safe.

CONCLUSION

The drying curve of the soybean seed obtained experimentally was similar to that of other materials presented in literature. The drying rate curves as a function of moisture content showed only the decreasing rate period, concluding that the limiting factor of the process is moisture migration from the interior to the surface of the solid. Among the variables examined (air temperature and air velocity and bed height) and at the operating conditions used, only temperature had a significant influence on the soybean seed drying in fluidized bed. A good agreement between measured and simulated results concluded that the fluidized bed model can works well. The normalized drying curve of the single particles as well as the critical moisture content was derived from measurement results by iterative adjustment in the software FLUBED. A simulated continuous fluidized bed dryer for soybean seed has been successfully designed by scale-up method.

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