Conference Paper

Paddy Drying in Batch Fluidized Bed and Scale-up Simulation in Continuous Operation Mode

Suherman, Mohammad Djaeni, Dyah Hesti Wardhani, and Andri Cahyo Kumoro

Department of Chemical Engineering, Faculty of Engineering, University of Diponegoro, Semarang, 50275, Indonesia

Corresponding Author: Suherman

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Abstract

The objective of this research is to develop the industrial-scale fluid bed dryer for paddy by scale-up of lab-scale experimental data. The developed dryer was conducted by simulation using a two phase model. Firstly, the experimental works by using lab-scale batch fluid bed dryer, was conducted to determine the drying curve of paddy (X_{in} 0.32 kg/kg dry base). In the experimental works,the inlet air temperature was varied (°C): 40; 50; 60. The drying rate curves as a function of moisture content showed only decreasing drying rate period. Then, a very good agreement between the measured and simualtion results of the profile of moisture content in solids was produced by simulator. Finally, asimulated continuous fluidized bed dryer for paddy with dimension 5 m of length and 1.5 of width was succesfully performed, in which the influence of mass solid flow rate 0.1; 0.2; 0.4 tons/h, height of bed 0.25; 0.50; 0.75 m, and air temperature 50; 70; 100 °C on drying process were studied.

Keywords: Paddy; fluid bed dryer; batch, contonious; modelling; simulation.

1. Introduction

Paddy as main food for Indonesian people is very popular. Normally, paddy is harvested with high moisture content 32% (db., dry base) has to be dried to 16%for storage. For tropical countries, it is an extremely serious problem due to high humid air condition can accelerate an excessive mould growth,and yellowing of grains [1]. Paddy drying consumes huge energy and is sensitive to product quality [2, 3]. Therefore an efficient energy paddy dryer and high quality product is of greatconcern for rice industry. For achieving this goal, many researcher works by combining a lab-scale experimental works with a computer simulation. It is a cheap and timesavingmethod to predict drying parameters for designing andoptimizing a dryer.

Mainly, drying paddy is performed by a fluidized bed dryer for due to (1) uniformproduct quality due to complete mixing, (2) high drying capacity dueto high ratio of air mass to mass of product [4]. The drying rate of paddy in fluidized bed dryer was affected by drying airtemperature and bed thickness [5]. The maximum drying temperature in fluidized bed was suggested as 115 °C to reduce moisture to 24-25% (db) for ensuring rice quality [4]. The drying temperature in pulsed fluidized bed should be less than 145 °C for initial paddy moisture content of 28% (db) to maintain rice quality [6].

Furthermore, paddydrying is a highly energy-intensive process and sensitive to thequality of rice [7]. They recommend that the maximum drying temperature to reduce paddy moisture become 22% (db) in a single pass is 150 °C to achieve acceptable quality of product. Fluidization techniques have been reported increase head rice yield compared to conventional drying methods [8]. No impact of air velocity on drying characteristics,and employing the tempering stages substantially reduces the energy consumption [9]. A bed thickness at 10 cm, specific air flow rate of 0.05 kg $kg^{-1}s^{-1}$, air temperature of 150 °C and residence time of 1 min were found to be suitable drying conditions for reducing paddy mc from 30 to 24.30% (db) in one season while the maximum throughput capacity of 15.7 tonne per hour might be achieved [10]. Energy and exergy analysis of industrial fluidized bed drying of paddy was also investigated by Sarker, et.al. [10]. The energy consumption of commercial fluidized bed dryer increased withincreasing paddy moisture content and drying temperature [11]. In addition, the study on modelling and simulation of paddy drying also was conducted by some researchers. Modelling of fluid bed dryer by two phase model was conducted by Burgschweiger et al. [12]. A new model of rough rice drying in fluidized bed based on thin layer model was succesfully developed by Midilli et al. [13]. From these data, showed that efforts to design and find the best method of operation drying paddy best is still underway. In addition, these data was used as basic information to choose the operating condition in this paper such as drying temperature, height of bed, and mass solid flow rate.

Therefore, the objective of this reserach was to develop the industrial-scale fluid bed dryer for paddy by using a two phase model which had been developed by Burgschweiger *et al*.,. [12] based on experimental data by a scale-up method. Firstly, the experiment works to get the drying kinetics data of paddy drying in lab-scale fluid bed dryer. Secondly, the derivation of single particle drying kinetics of paddy drying from experimental data by fluid bed model (FLUBED). Finally, scale up and simulation of industrial-scale fluid bed dryer for some operating condition parameters.

2. Nomenclature

X solid moisture content (dry basis) (kg_l/kg_s)
M_g gass mass flow rate (kg/s)
M mass (kg)

Y absolute humidity of air (kg_v/kg_g)
t time (s)
m drying rate (kg/m^2s)
d_p particle diameter (m)

3. Methods

Figure 1 shows the apparatus set-up of lab scale batch fluid bed dryer. The paddy (the moisture content is 32% dry bases) was taken from farmer in Demak, Central Java, Indonesia. The experiment was started by measuring the minimum fluidization velocity. Then, the intake air velocity was set 2 times above the minimum fluidization velocity. Inlet air temperature (T_{gi}) was varied namely 50, 60, and 70°C. The process started with an experiment that should turn on the blower air flow dryer. Furthermore, air heaters had been positioned as desired, *e.g.* at 50 °C. After drying air temperature reached the temperature desired, paddy material was inserted into the bed. Finally, the drying process was stopped until the solid moisture content below 16% due to product quality. The temperature controller TIC (below distributor) maintained inlet air temperature at the desired level. During the experiment, inlet air temperature, inlet air humidity, outlet air temperature, and outlet air humidity were measured each 5 minutes. At the end of the experiment, samples were taken for measuring the water vapor content using an electrical air oven at a temperature of 103 °C for 72 h.

From the measured humidity of air both inlet and outlet, then the solid moisture content were calculated by;

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

And for drying rate was calculated by;

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

Modeling of fluidized bed drying using a two-phase theory had been introduced by Tsotsas [1] which can be described schematically as in Fig. 2. The model was dicussed thoroughly and solved by a numerical method in Suherman [14] and Suherman, *et al.* [15]. Furthermore, the above model equation can be solved analytically and then be made programming language in MS Excel, and called as FLUBED.

4. Results and Discussion

Figure 1: Apparatus Set Up.

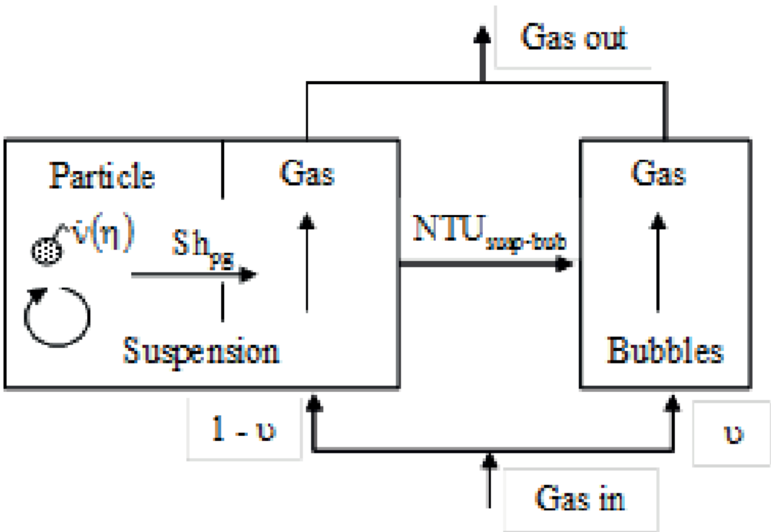


Figure 2: Schematic of Two Phase Fluid Bed Drying Model.

4.1. Typical Drying Curve of Paddy

A typical experimental result for drying paddy in batch fluid bed dryer is represented in the Figure 3. Figure 3(a) shows the measured of outlet air humidity over time. From

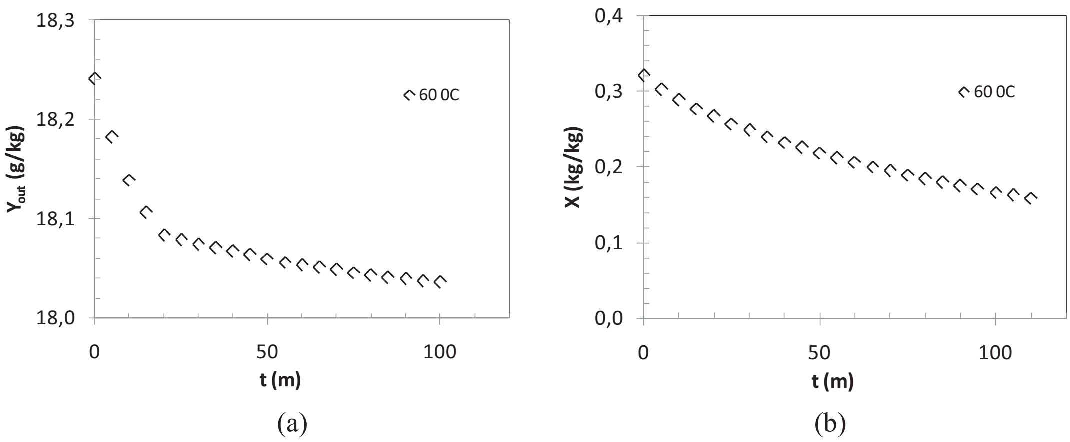


Figure 3: Typical measurement result of drying of paddy in fluidized bed; (a) humidity of outlet gas; (b) solid moisture content.

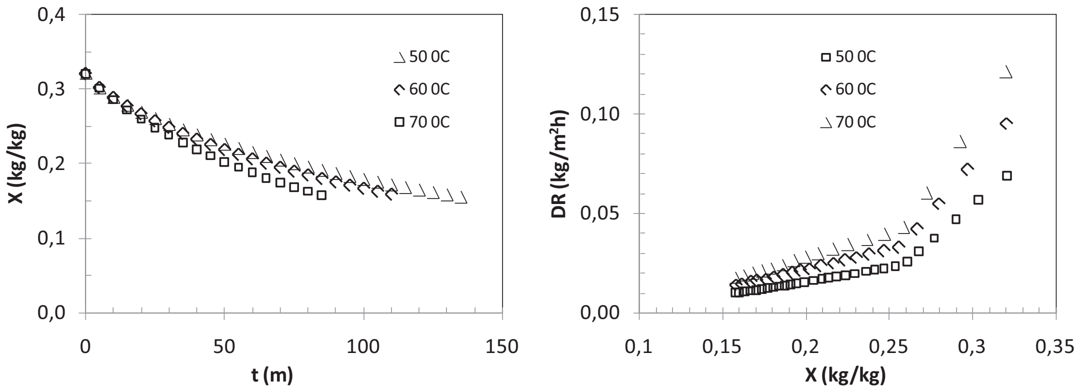
the beginning of drying process, the humidity of outlet gas dropped strongly and led to a flatter process of the solid moisture content in the Figure 3(b). It was caused by the decrease of drying rate. The drying process was considered as terminated when the solid moisture content below 16%. The solid moisture content was calculated by indirect method *i.e.,* the evaporation mass flow of water in gas phase (see Eq. 1). To ensure these results, the solid moisture content of samples both at the beginning and the end of the drying process were measured again by oven drying.

4.2. The influence of temperature

Figure 4 shows the influence of temperature on drying process. Increased drying temperatures would faster the decrease of the solid moisture content (see Fig 4(a)). It was caused by increasing air temperature, where the diffusion moisture from inside particle to drying air would be increased. Therefore, the drying rate increased by increasing temperature (see Fig 4(b). Fig 4(b) shows that the paddy drying mainly was influenced by the diffusion moisture inside the particle. There were no first drying constant periods. At the end of drying, the drying rate turned down to zero, then the decreases of solid moisture content became steeper and also the residual solid moisture content became lower which was caused by the decreases of the solid moisture content where the diffusion of moisturedecreased.

4.3. Validation of simulator

The validation process of simulator was conducted by fitting the experimental data with simulation data at three different temperature conditions (50, 60, and 70 °C). This process was also referred to the scaling-down process, namely the derivation of



(a) (b)

Figure 4: The influence of air temperature; (a) profile solid moisture content again time, (b) profile drying rate again solid moisture content.

Table 1: The value of normalized drying curve of paddy where X_{cr} is 0.43.

η	0,20	0,40	0,60	0,80	0,9	1	0,20
$\dot{v}$	0,001	0,003	0,006	0,021	0,071	1	0,001

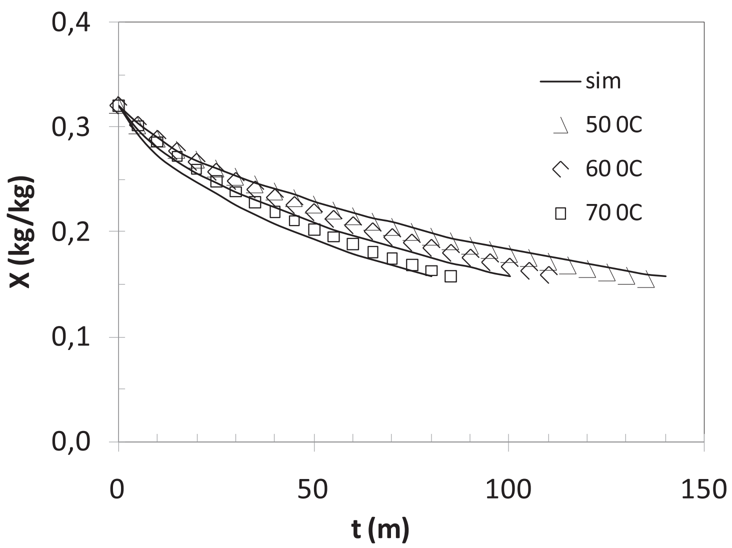


Figure 5: Profile of solid moisture content: comparison between measurement and simulation results.

single particle drying kinetics from intergral drying data. Fluidized bed dryer simulator (FLUBED) program had made use Visual Basic Programming Language in MS Excel. The program valid, if the experimental data with simulated data show a very good agreement. Fig 5 shows a very good agreement between the measured and simulation results of the profile of moisture contents in solids. Table 1 shows the value of a normalized drying curve of paddy where X_{cr} was assumed 0.43.

Table 2: Design parameters of fluidized bed continuous dryer for paddy.

Parameter		Value
Dryer	Length (m)	5
	Width (m)	1.5
Solid	Flow rate (tons/h)	0.1; 0.2; 0.4
	Inlet moisture content (kg/kg)	0.32
	Height of bed (m)	0.25; 0.50; 0.75
Air	Flow rate (m^3/h)	50000
	Temperature (°C)	50; 70; 100
	Humidity (g/kg)	18

4.4. Simulation Design of Continuous Dryer

Furthermore is the design of a continuous dryer for plant scale (SMEs). Table 2 shows the design parameter of continuous fluid bed dryer. The influence of three operating conditions to drying process had been investigated, namely, the solid mass flow rate, the height of bed, and the temperature of drying air.

Fig. 6(a) shows that the influence of drying air temperature on drying process was very significant. Increasing the drying air temperature would faster the decreases of solid moisture contents, due to the increase of the moisture diffusion rate. It is shown that only at the temperature of 100 °C, the residual solid moisture content has achieved product quality, *i.e.* below 16%. Fig. 6(b) shows the influence of bed height on drying process. The increases of bed height would decrease the drying rate, where the residual moisture content increased. Finally, Fig. 6(c) shows the influence of solid mass flow rate on drying process. The increaseof the solid mass flow rate would decrease the drying rate due to the increase of drying load to evaporate moisture.

5. Conclusion

The lab scale batch fluid bed dryer was successfully measured drying curve of paddy. The simulator fluid bed drying performed a very good agreement between the measured and simulation results of the profile of moisture content in solids. The simulation of continuous fluidized bed dryer with dimension 5 m of length and 1.5 m of width and a capacity of 0.1 to 0.4 tons/h could work well.

References

[1] Sarker M.S.H., M.N. Ibrahim, N.A. Aziz, M.S. Punan, 2013, Drying Kinetics, Energy Consumption, and Quality of Paddy (MAR-219) during Drying by the Industrial

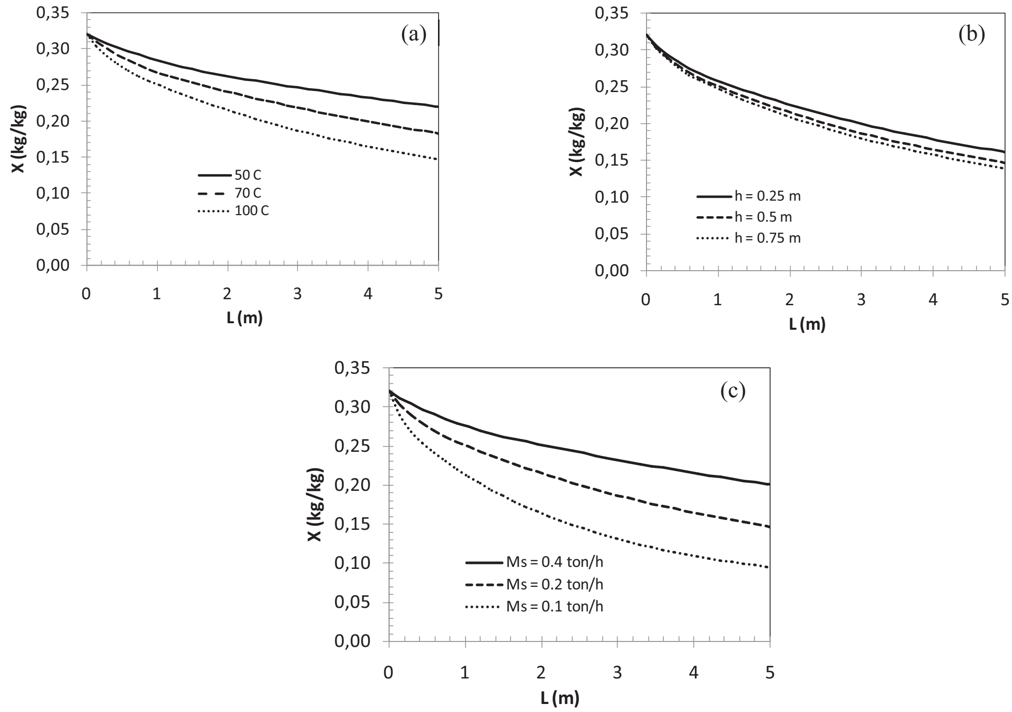


Figure 6: Simulation fluid bed continuous dryer for paddy; (a) the influence of temperature, (b) the influence of bed height, (c) the influence of solid mass flow.

Inclined Bed Dryer with or without the Fluidized Bed Dryer, Drying Technology, 31: 286–294.

[2] Sarker M. S. H., M. N. Ibrahim, N.A. Aziz., M.S. Punan, 2015a, Energy and Exergy Analysis of Industrial Fluidized Bed Drying of Paddy, Energy 84, 131-138.

[3] Morteza G., A. Moein, R.H. Mehdi, S.J. Hashemia, 2015, Energy Efficiency Investigation of Intermittent Paddy Rice Dryer: Modeling and Experimental Study. Food and bioproducts processing 94, 275–283.

[4] Soponronnarit, S., S. Prachayawarakorn, 1994. Optimum strategy for fluidized bed paddy drying. Drying Technology, 12, 1667-1686.

[5] Tumambing, J.A., R.H, Driscoll, 1991. Modeling the performance of continuous fluidized bed paddy dryer for rapid pre-drying of paddy. In: Proceedings of the14th ASEAN Seminar on Grain Post-harvest Technology, pp. 193-213 (Manila,Philippines).

[6] Prachayawarakorn, S., W. Tia, K. Poopaiboon, S. Soponronnarit, 2005. Comparison of performances of pulsed and conventional fluidized-bed dryers. J. Stored Prod. Res. 41, 479-497.

[7] Jittanit, W., N. Saeteaw, A. Charoenchaisri, 2010. Industrial paddy drying and energy saving options. J. Stored Prod. Res. 46, 209-213.

[8] Tirawanichakul, S., S. Prachayawarakorn, W.Varanyanond, P. Tungtrakul, S. Soponronnarit, 2004. Effect of fluidized bed drying temperature on various quality attributes of paddy. Drying. Technology. 22, 1731-1754.

[9] Morteza G., A. Moein, R.H. Mehdi, S.J. Hashemia, 2015, Energy Efficiency Investigation of Intermittent Paddy Rice Dryer: Modeling and Experimental Study. Food and bioproducts processing 94, 275–283.

[10] Sarker M.S.H., M.N. Ibrahim, N.A. Aziz, M.S. Punan, 2015b, Application of Simulation in Determining Suitable Operating Parameters for Industrial Scale Fluidized Bed Dryer During Drying of High Impurity Moist Paddy, Journal of Stored Products Research 61, 76-84.

[11] Soponronnarit, S., S. Prachayawarakorn, M. Wangji, 1996. Commercial fluidized bed paddy dryer. In: Strumillo, C., Pakowski, Z. (Eds.), Proceedings of the 10th International Drying Symposium, Vol. (A), Krakow, Poland, 30 July - 2 August, pp. 638-644.

[12] Burgschweiger, J., H. Groenewold, C. Hirschmann, E. Tsotsas, 1999. From hygroscopic single particle to batch fluidized bed drying kinetics. Can. J. Chem. Eng. 77 (2), 333-341.

[13] Midilli, A., H. Kucuk, Z. Yapar, 2002, A new model for single layer drying, Drying Technology 20(7), 1503-1513.

[14] Suherman, 2007. Drying Kinetics of Granular and Powdery Polymers. Docupoint Verlag, Magdeburg, Germany, ISBN: 978-3-939665-63-2.

[15] Suherman, T.K., B. Fajar, A.M. Praba, 2013, Derivation of Single Particle Drying Kinetics of Tapioca Flour, Advance Journal of Food Science and Technology,5(5): 565-570.