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Drying Kinetics of Saw Dust in Tray Dryer

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Abstract

Drying kinetics of palm wood saw in tray drying covering wide range in operating conditions have been investigated in the present study. The drying rate increased with an increase in the temperature and flow rate of the heating medium increased, and decreased with an increase in the bed height. A model has been developed based on Fick's law of diffusion to explain the drying kinetics.

Keywords: Drying kinetics, Palm wood sawdust, Tray dryer, Kinetic model

1. Introduction

Malaysia contributes more than 50% of the world palm oil production. Palm tree based plywood's are increasingly used due to its environmental friendliness. Nearly 100,000 hectares of replanting is carried out every year. Several saw mills ranging from small scale to large scale engaged in plywood production resulting generation of large amount of saw dust. The saw dust generated during plywood processing finds extensive applications in compressed powder boards, fuel pellets, mosquito coils, incense sticks, activated carbon etc. The mosquito coils prepared based on sawdust are reported to have less toxic compared to the coils prepared using coconut shells, resulting larger potential for utilization of saw dust for mosquito coil production (Akpinar et al., 2003; Crank, 1975) . Further the large scale saw mills can utilize the saw dust for cogeneration facility utilizing Integrated Gasification Combined Cycle (IGCC) technology. The high moisture content of saw dust deteriorates the quality of sawdust resulting restricted application. This forces the researchers to design a suitable drying unit to handle the saw dust for longer storage and cost reduction in transportation.

Drying is fundamentally a simultaneous heat and mass transfer operation and used for various thermal energy applications. Several drying methods have been proposed in the literature for high quality products. Among the drying techniques, tray drying is one of the most frequently used methods in chemical process industries. A proper drier design requires knowledge on the characteristics of the material to be dried and the drying kinetics. Extensive work has been reported in literature on tray drying, with respect to kinetics, mechanism and modeling (Larson at al., 2001; Marcello and Osvaldir, 2007; Srinivasakannan et al., 1995). The present study attempts to study the drying kinetics of drying of palm sawdust covering wide range in operating conditions.

2. Experimental

The sawdust collected from near by palm tree industry was 2 mm in size with 93% moisture. The samples moisture content were estimated by standard weight difference method and reported on dry basis (kg of moisture/kg of dry sawdust). The initial moisture content of the samples was estimated for each experimental run. Figure 1 shows the schematic representation of drying set-up. It consists of a fan, heating system, a drying chamber with tray and a weighing balance. The weighing balance had an accuracy of ± 0.01g. The drying chamber has the dimensions of 3m X 0.3mX 0.3m with a facility to load and unloading. The material depth in the tray can be varied with material loading. Experiments were conducted by varying material loading, temperature of heating medium and moisture content.

3. Results and Discussion

The drying medium was allowed at a desired flow rate and temperature. The temperature of the drying medium was recorded at both inlet and outlet of the drying chamber. Once the flow rate and temperature of the drying medium reached steady state, a known quantity of known moisture content of saw dust was taken in the holder and fed into the chamber. Experiments were carried out covering wide range in operating conditions: flow rate and temperature of the drying medium and material holdup and the experimental results are discussed below:

The Figure 2 shows the variation of moisture content with drying time. It can be ascertained from the figure that the rate of drying increases with increase in the temperature of the drying medium. This phenomenon is well known and it is generally attributed to the increase in diffusivity of moisture at higher temperatures. The flux between heating medium and the solid material increased with increase in the temperature of the heating medium, due to increased thermal and mass driving force resulting in increased drying rate.

The influence of the flow rate of drying medium on drying rate is shown in Figure 3. It can be seen from the figure that the drying rate increases with an increase in the flow rate of the drying medium. This can be explained that an increase in the flow rate of the drying medium reduces the external resistance for mass transfer and hence an increased drying rate. The external mass transfer resistance is significant during the early stages of drying and becomes less significant at the later stages of drying where the internal resistance for moisture transfer plays an important role. This is evident from the Figure 3 that the high slope of the drying curve during early stages of drying where the moisture content is high. This observation qualitatively matches with reported observation (Srivastava et al., 2002)

The Figure 4 shows the influence bed loading on the drying rate. The Figure 4 is plotted for two different bed heights of $3x10^{-3}$ and $5x10^{-3}$m respectively. It can be ascertained from the Figure 4 that an increase in solid loading decreases the drying rate. This can be explained that an increase in the solid loading increases the bed height which eventually increases the distance for the moisture movement to reach the surface of the bed resulting in reduction in the drying rate. Since the moisture diffusion in tray dryer is unidirectional, the moisture should diffuse through the bed void to reach the top of the bed for drying which results in a significant reduction in the drying rate with the bed height. Further it can be ascertained from the Figures 2 to 4 that the saw dust material used in the present investigation exhibits complete falling rate period with insignificant constant rate period. Since the material exhibits only falling rate period, the moisture movement can be modeled using Fick's Diffusion to estimate the effective diffusion coefficient. The drying chamber is considered as rectangular slab of thickness 2L having unidirectional flow of moisture with uniform initial moisture content as,

$$\frac{\delta X}{\delta t} = D \frac{\delta^2 X}{\delta r^2} \qquad (1)$$

the following boundary conditions can be used to solve the equation (1),

at $t = 0$ $0 < r < L$ $X = X_o$

at $t > 0$ $r = 0$ $\delta X/\delta r = 0$

at $t > 0$ $r = L$ $X = X_e$

The analytical solution of the above equation can be obtained from (Weili et al., 2003) as

$$\frac{X - X_e}{X_0 - X_e} = \frac{8}{\pi^2} \sum_{n=1}^{\infty} \frac{1}{(2n+1)^2} \exp\left[\frac{-(2n+1)^2 \pi^2 Dt}{4L^2}\right] \qquad (2)$$

The diffusion coefficient is estimated by minimizing the standard deviation between the experimental data and the prediction using equation (2) as given below,

$$SSE = \sqrt{\frac{\sum_{i=1}^{n} \left(X_{i,pre} - X_{i,\exp}\right)^2}{N}} \qquad (3)$$

The Table 1 shows the variation of diffusion coefficient with operating parameters. The dependence of diffusion coefficient with temperature of the heating medium is well known from the mass transfer concept. It can be noticed that than an increase in the flow rate of heating medium increases the diffusion coefficient. It can be explained that though the present model accounts only the internal resistance for mass transfer, an increase in the drying rate due to reduction in the external mass transfer during early stage of drying is reflected on the diffusion coefficient (Yutthana et al., 2004). Further it can be noticed that diffusion coefficient is not influenced significantly by the bed depth (L).

4. Conclusion

Experiments were carried out in a tray drier to study the drying kinetics of wood sawdust covering wide range in the operating conditions. A model has been proposed based on Fick's law diffusion and the diffusion coefficients were estimated under various operating conditions. The present experimental study has given better insight to the drying kinetics in tray drier. The following conclusions can be made from the present investigation:

1. The drying rate increases with an increase in the flow rate and temperature of the heating medium
2. The rate of drying decreased with an increase in the solid loading
3. The diffusivity coefficient increased with an increase in the flow rate and temperature of the heating medium
4. There is no significant effect of bed loading on diffusion coefficient

5. Nomenclature

D	:	Effective diffusion coefficient, $m^2 min^{-1}$
L	:	Thickness of the slab, m
N	:	Number of summation term in equation (3)
r	:	Diffusion path, m
t	:	Time, min
SSE		Sum of squares of error
T_g	:	Temperature of heating medium, $^{\circ}C$
U_g	:	Flow rate of the heating medium, ms^{-1}
X	:	Moisture content of solids at any time `t` , kg of moisture/kg of dry solids
X_o	:	Initial moisture content of solids, kg of moisture/kg of dry solids
X_e	:	Equilibrium moisture content of solids, kg of moisture/kg of dry solids

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Table 1. Evaluated Effective Diffusivity Coefficient

Temp °C	**U (ms^{-1})**	**L (m)**	**D X 10^{10} m^2s^{-1}**	**SSE**
40	0.3	0.03	5.0	0.116
50	0.3	0.03	6.0	0.125
60	0.3	0.03	10	0.110
50	0.5	0.03	9.1	0.125
50	0.3	0.05	6.8	0.082

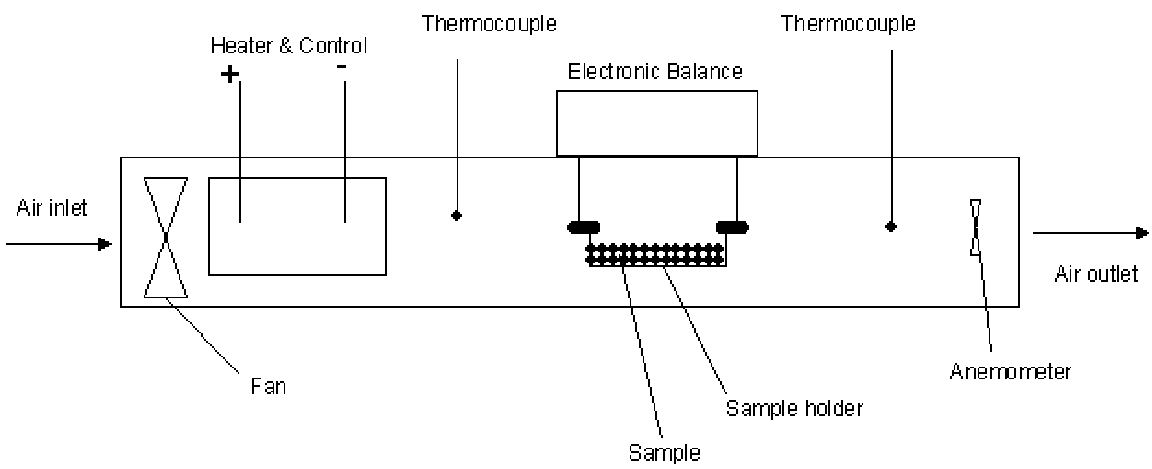

Figure 1. Schematic representation of the experimental set-up.

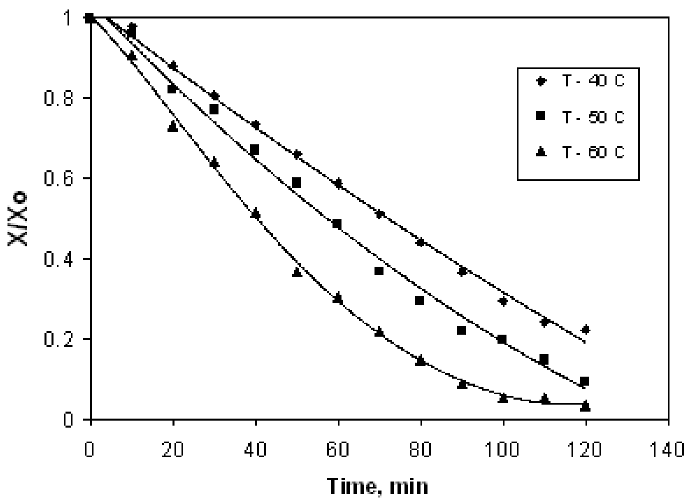

Figure 2. The variation of moisture content with drying time. U_g: 0.3 ms^{-1}; X_o: 0.93; L: 0.003m

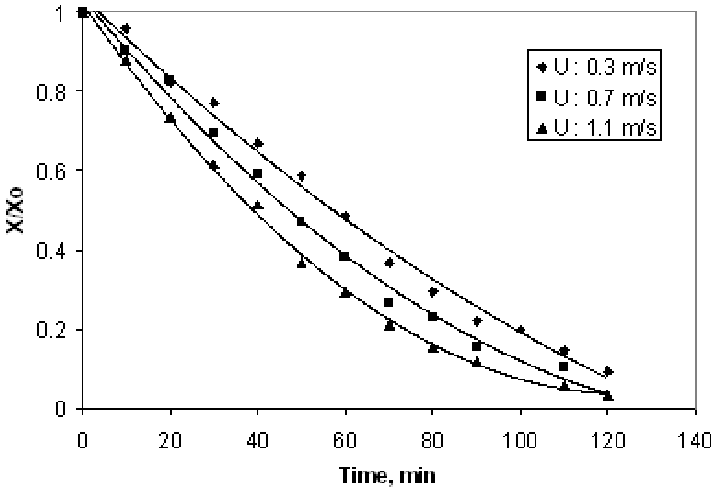

Figure 3. The effect of flow rate of the drying medium on drying rate. T_g: 50°C; X_o: 0.93; L: 0.003m

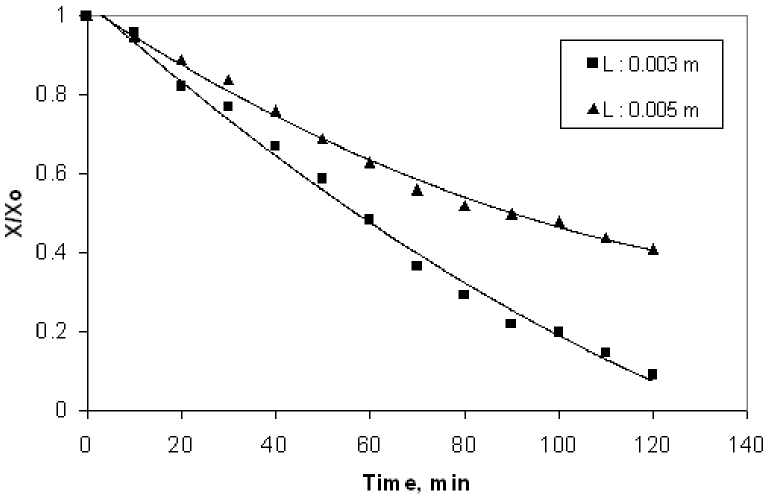

Figure 4. The effect of solid loading on drying rate. T_g: 50°C;, U_g:: 0.3 m/s, X_o:0.93