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Study on the Fluidized-Bed Drying Characteristics of Sawdust as a Raw-Material for Wood-Pellet Fuel*1

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ABSTRACT

Wood fuel must be dried before combustion to minimize the energy loss. Sawdust of Japanese red pine was dried in a batch type fluidized-bed to investigate the drying characteristics of sawdust as a raw material for bio-fuel. The minimum fluidization air velocity was increased as particle size was increased. It took about 21 minutes and 8 minutes to dry 0.08 m-deep bed of particles with average particle size of 1.3 mm from 100% to 10% moisture content at air temperature of 20°C and 50°C, respectively.

Keywords : sawdust drying, fluidized-bed drying, minimum fluidization air velocity, wood pellet fuel

1. INTRODUCTION

Wood has been the most important fuel used by humans for thousands of years. With reference to the reduction of CO_2 emissions, renewable fuels are pointed out as important substitutes for fossil fuels. The renewed interest in wood fuels, one of the most promising renewable energy, is being driven largely by economic and environmental concerns. Wood fuel is now increasingly price competitive with fossil fuel alternatives and the environmental benefits of wood fuel are being recognized and valued. The production and use of wood fuel provides social benefits too, such as the creation of additional employment.

Wood fuels, such as wood chips, barks and sawdust, contain water. High moisture levels lead to energy losses. If the wood fuels are burned without being dried, a significant fraction of the heating value of the fuel is used to evaporate the moisture in wood fuels. This results in decreased efficiency and increased emissions in the combustion. There might also be higher risks of mould formation during storage of moist wood fuels. Therefore drying is a key step in the processing of wood fuels.

There have been many studies to determine the most efficient drying method for wood fuels. Hermansson *et al.* (1992), discovered that the inhomogeneity of the wood fuels caused an uneven mass flow distribution through the ma-

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Table 1. Characteristics of the solids used in the experiments

Species	Japanese red pine (*Pinus densiflora* Sieb. et Zucc)
Particle basic density	400 kg/m^3
Initial moisture content	35% (dry basis)
Particle size	<0.6, 0.6~2.0, 2.0~4.0 mm according to sieve aperture size

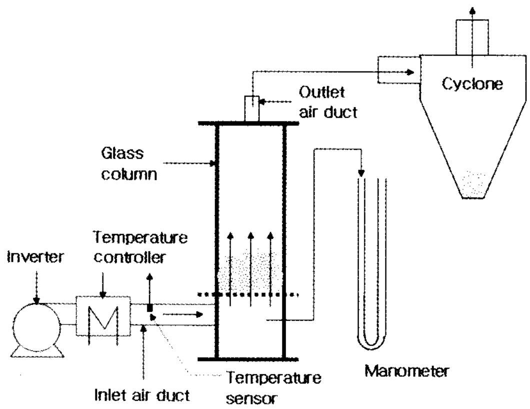

Fig. 1. Diagram of the experimental equipment used.

terial bed which led to a decreased thermal efficiency in their expceriments on fixed-bed drying of wood chips and barks with super-heated-steam. Johansson and Rasmusson (1997) investigated the effect of drying mediums for wood chips theoretically and showed that shorter periods of constant drying rate, higher maximal drying rates and shorter drying times were obtained with air as drying medium rather than superheated-steam. Fyhr and Rasmuson (1997) studied on the optimal length of pneumatic conveying chip dryer to obtain the desired final moisture content. Lee and Kang (1998) investigated the effect of air-temperature on the drying characteristics of wood chips in fixed bed.

Renstrom and Berghel (2002) performed tests on drying sawdust in a spouted bed steam dryer at atmospheric pressure. Their results show that it should be possible to control the outgoing moisture content using the temperature after the dryer as a control parameter.

Yrjola and Saastamoinen (2002) discussed on the practical operation of dryers within the boiler plants through the modelling of drying in fixed and moving bed of wood chips. Danielsson and Rasmuson (2002) studied experimentally the release of volatile organic components (VOC) during drying of wood chips. They found that the release rate is more intensive at higher drying temperatures, especially when using super-heated-steam as drying medium. Recently Gruber and Becker (2003) insisted that the significant reduction of emission levels could be guaranteed by the integrated vapour treatment in steam drying of wood fuels.

In this study, an experimental analysis of sawdust drying in a batch fluidized-bed was carried out to investigate the drying characteristics of sawdust as a raw material for bio-fuel.

2. MATERIALS and METHODS

Fig. 1 shows the experimental equipment used in this study, which is composed by a fluidization column made of transparent 6 mm-thick glass with inner diameter of 205 mm to observe the hydrodynamic behaviour of the particle bed. The centrifugal blower has a motor with a frequency convertor to regulate air velocity from 0 to 3 m/sec in inlet air duct. Cyclone was connected to the outlet air duct to collect the dust from the drying column. Pressure drop in the solid bed were measured by connecting to water manometer. Electric heater supplied heat energy to maintain inlet air temperature at two conditions of 20°C and 50°C. Air velocity at

Fig. 2. Fluidization of sawdust.

Table 2. Inlet air velocity, pressure drop, and outlet air flow rate at fluidization with inlet air temperature of 20°C

Particle characteristics (mm)	Inlet air velocity (m/s)	Pressure drop (mmAq)	Outlet air flow rate (m^3/min.)
0.6-dry	1	25	0.084
2.0-dry	3	256	0.396
2.0-wet	3	276	0.480
4.0-dry	3	249	0.427

outlet air duct was measured by Biram anemometer.

The experiments were performed with a bed height of 80 mm. The sawdust used in this study was produced with a 3 mm-thick bandsaw of lumber manufacturing plant. Its properties are summarized in Table 1.

The sawdust particles were separated by a shaker with sieves of aperture size of 0.6, 2.0, 4.0, and 6.0 mm. Average proportions of particle sizes were 17, 60, 23, and 0% for the particle

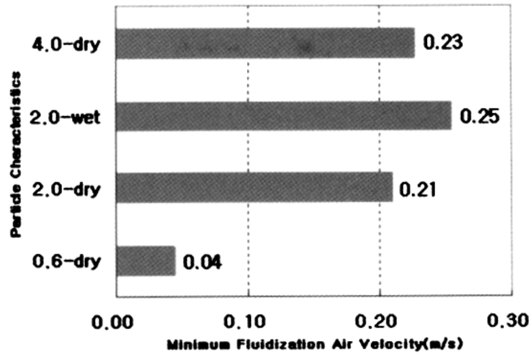

Fig. 3. The minimum fluidization air velocities according to the particle characteristics.

size smaller than 0.6, between 0.6 and 2.0, between 2.0 and 4.0, and between 4.0 and 6.0 mm, respectively. Then a part of particles of size between 0.6 and 2.0 mm was mixed with water to prepare the sample of higher moisture content (about 140%) which could give drying curves over broad moisture content range.

3. RESULTS and DISCUSSION

3.1. Bed Fluid Dynamics

One of the most important hydrodynamic parameters to set the operating conditions of the fluidized-bed dryer is the minimum fluidization air velocity U_{mf}. Velocity of inlet air to the solid bed was increased gradually to recognize the fluidization of particles with naked eyes as in Fig. 2. The inlet air velocities, pressure drop across the bed, and outlet air flow rate for different particle characteristics at fluidization of particles are summarized in Table 2. The minimum fluidization air velocity could be calculated using equation (1) and the results were shown in Fig. 3.

$$U_{mf}=\frac{Q_o}{60D_c} \tag{1}$$

where U_{mf} : minimum fluidization air velocity (m/s)
Q_o : outlet air flow rate (m^3/min.)
D_c : cross sectional area of column (m^2)

The minimum air velocity to fluidize the bed was increased with the increase of particle size. However the bed of wet particles with particle size between 0.6 and 2.0 mm required higher air velocity to be fluidized than that of dry particles between 2.0 and 4.0 mm because of the particle weight increase. Thus the moisture content of particle should be considered to apply proper air velocity for the fluidization of bed and efficient drying process.

Hovmand (1995) represented a approximation for U_{mf}, assuming $S=6/d$ and taking $\varepsilon_0=0.4$.

$$U_{mf}=\frac{d^2(\rho_s-\rho_f)g}{1695\mu} \qquad (2)$$

where d : particle diameter (m)
ρ_s : density of particle (kg/m^3)
ρ_f : density of air (kg/m^3)
g : acceleration due to gravity (= 9.8 m/s^2)
μ : viscosity of air (kg/m · s)
S : specific surface of particle (m^2)
ε_0 : bed voidage at incipient fluidization (fractional)

Assuming the normal distribution of particle sizes between 0.6 and 2.0 mm, average particle diameter would be 0.0013 m. Density of dry particle at 35% moisture content with basic density of 400 kg/m^3 is calculated as 530 kg/m^3. Density and viscosity of air at 20°C is about 1.210 kg/m^3 and 1.914 × 10^{-5} kg/m · s, respectively. Then the minimum fluidization velocity for the bed of particles with average diameter of 0.0013 m was calculated as about 0.216 m/s at inlet air temperature of 20°C. This estimation matches very well with experimental result.

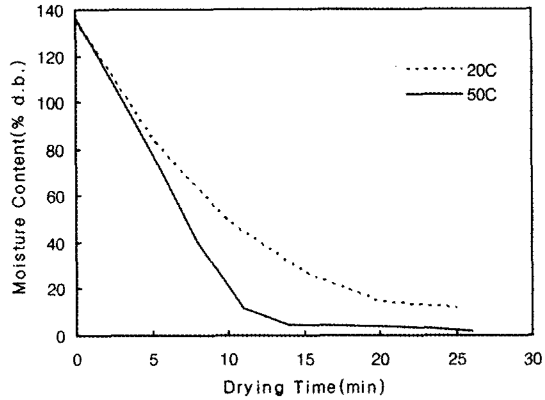

Fig. 4. Fluidized-bed drying curves of sawdust.

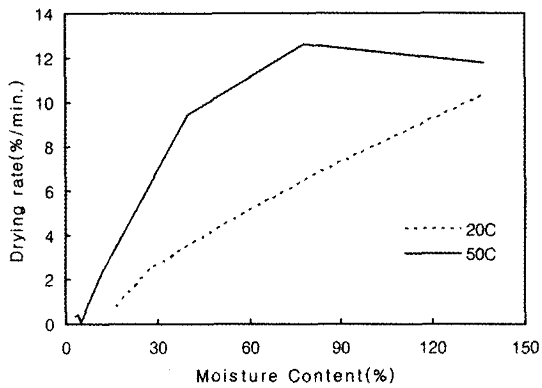

Fig. 5. Fluidized-bed drying rate curves of sawdust.

3.2. Drying Curves

The influence of inlet air temperature on drying rate is shown in Fig. 4 and 5, which were obtained for the bed of particle size between 0.6 and 2.0 mm at about 140% moisture content. It took about 21 minutes and 8 minutes for drying from 100% to 10% moisture content at 20°C and 50°C, respectively. The target moisture content was determined as 10% because raw material for wood fuel such as wood pellets is generally required to be dried below 10% moisture content before pelletization.

Higher temperature will guarantee the faster

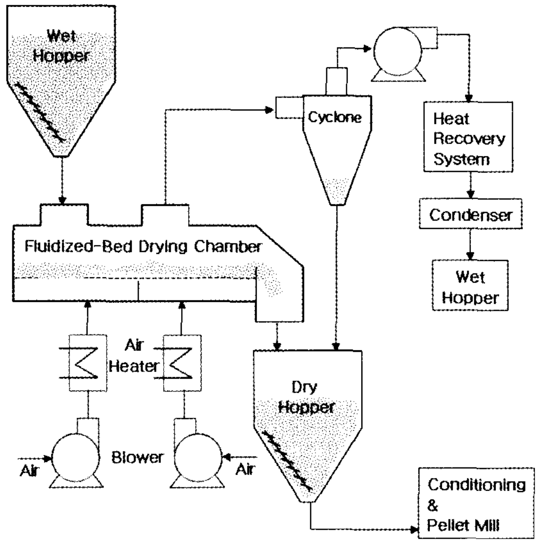

Fig. 6. Diagram of fluidized-bed drying system for wood-pellet fuel.

drying rate. However, since this drying process for sawdust is to be the part of wood fuel manufacturing process, the energy efficiency of drying process should also be considered. It might be a good strategy for energy saving to pre-dry stored sawdust with ambient air before fed into drying process.

3.3. Design of Commercial Drying System

Fig. 6 shows the diagram of fluidized-bed dryer for wood-pellet fuel manufacturing process which is scaled-up to produce 1000 kg of dry wood-pellet fuel (average moisture content 10%) per hour. Weight of green sawdust that should be fed into dryer per hour is estimated as follow, assuming the average initial moisture content and particle size of sawdust as 100% and 2 mm, respectively.

$$W_f = \frac{W_d(1+M_f/100)}{1+M_d/100} \quad (3)$$

where W_f : feed rate of green sawdust required to produce W_d (kg/hr)

W_d : production rate of dry sawdust (=1000 kg/hr)

M_f : moisture content of green sawdust (=100%)

M_d : moisture content of dry sawdust (=10%)

Therefore, W_f is estimated as about 1818.18 kg/hr. If the bed height is assumed to be 0.08 m, the bulk density of green sawdust 200 kg/m^3, and the drying time required to dry from 100% to 10% moisture content 8 minutes at the inlet air temperature of 50°C, the minimum bed area needed is calculated as follow.

$$A_b = \frac{W_f T_d}{60\rho_b D_b} \quad (4)$$

where A_b : the minimum bed area to satisfy production rate (m^2)

T_d : average drying time from M_f to M_d (minute)

ρ_b : bulk density of green sawdust (kg/m^3)

D_b : bed height (m)

Therefore the bed area should be larger than 15.15 m^2. Then the amount of air needed to fluidize and dry sawdust can be estimated as about 227.27 m^3/min (= 15.15 m^2 × 0.25 m/sec × 60 sec/min) with pressure drop of 279 mmAq.

The energy required to heat and dry sawdust from 100% to 10% moisture content can be calculated as follow.

$$\dot{Q} = \frac{W_d}{1+M_d/100}\left[\left(\frac{M_f - M_d}{100} Q_v + \frac{M_f}{100} c_w(t_0 - t_a)\right) + c_d(t_0 - t_a)\right] \quad (5)$$

where $\dot{Q}$: energy required to dry sawdust from initial to final moisture content (kcal/hr)

Q_v : latent heat of vaporization (= 539 kcal/kg-water)

c_w : specific heat of water (=1 kcal/kg°C))

c_d : specific heat of oven-dried sawdust $(=0.268+0.00055(t_0+t_a))$ (kcal/kg°C) (from Skaar (1972))

t_0 : initial temperature of sawdust (°C)

t_a : inlet air temperature (°C)

Assuming the initial temperature of green sawdust as 20°C, the energy to heat oven-dried sawdust itself, heat water in sawdust, and evaporate water in wood is estimated as about 8359 kcal, 27273 kcal, and 441000 kcal, respectively. Then the total net energy to dry sawdust turns out to be 476632 kcal or 554 kWh (1 kWh=860 kcal). If the energy loss of drying system is presumed to be 20% of total net energy, more than 665 kWh should be supplied to this drying system.

Average calorific value of wood is about 4500 kcal/kg (Abe (1986)). Thus 1 ton of wood fuel can produce 4500000 kcal, and over 13% of that energy will be consumed only for drying wood fuel, including the electric energy for air blowing. Therefore it is highly recommended to find the energy-saving methods. Pre-drying of sawdust to somewhat lower moisture content with ambient air can be one of that methods. About 55% of energy can be saved when pre-dried to 50% moisture content with ambient air. It will takes about 6 minutes for pre-drying with ambient air at 20°C. Then the total drying time will be increased to about 11 minutes, including 5 minutes spent in finish-drying from 50% to 10% moisture content by hot air at 50°C. Productivity is lowered by 37.5%, but lots of energy can be saved.

4. CONCLUSIONS

An experimental analysis of sawdust drying in a batch fluidized-bed was carried out to investigate the drying characteristics of sawdust as a raw material for wood-pellet fuel. The minimum fluidization air velocity was increased as particle size was increased. It took about 21 minutes and 8 minutes to dry 0.08 m-deep bed of particles with average particle size of 1.3 mm from 100% to 10% moisture content at air temperature of 20°C and 50°C, respectively. However, pre-drying with ambient air is highly recommended to save energy. Development of new technologies which can produce high quality wood fuel even with moist sawdust may also be one of the best ways to save energy and enhance the productivity at the same time.

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