Fluidized bed drying of Loy Yang coal using air as a bubbling gas under various humidity conditions

Hyun-Seok Kim, Noriko Mitsuhara, Yohsuke Matsushita, Jin Miyawaki, Seong-Ho Yoon, Isao Mochida (Kyushu Univ.), Motohira Oomori (Kyuden Sangyo), Tatsuro Harada (KEPCO)

Synopsis
Drying of Victorian low-rank coal that was sized from 600 to 850 μm was examined under various temperature and relative humidity conditions in the fluidized bed using air as a bubbling gas. The self-manufactured dryer of its height and diameter were 200 mm and 22 mm, respectively, was used as the fluidized bed apparatus for successful obtaining the fundamentals of drying behaviors and the drying rate. The model of drying rate was achieved through the definition of drying rate based on simple equation with respect to drying gas temperature, humidity and equilibrium moisture contents.

1. Introduction
Although the increase of oil production and the promotion of renewable energy come up with as practical alternatives, there still remain the restrictions due to limited deposit and undeveloped technology. To handle such problems, the overall energy balances must be reminded with considering every usable energy sources. Therefore, the fossil fuel-fired power, which usually is represented by coal combustion, is still attractive. More exactly, low-rank coal is one of most important resources by virtue of its abundant deposit.

However, it is pointed out that low-rank coals such as brown coal are generally featured by high moisture contents due to the abundant oxygen-containing functional groups in their structure, as much as 65 wt% on wet basis. Thus, the removal of this water is an essential process for the effective utilization of brown coal.

In this study, the present authors have attempted to reutilize the gases including air which were evolved from processes for energy saving. The drying behavior of Loy Yang coal as low-rank coal was examined under the various conditions of low temperatures and humidities using self-manufactured fluidized bed dryer. A simple equation was modeled to predict the drying rate with variation of drying gas temperature and humidity.

2. Experimental
2-1. Coal sample and preparation
Loy Yang brown coal which is classified as soft brown coal as lignite B [1] by the US ASTM classification was used as a sample for this study. As-received Loy Yang coal was milled to approximately 2 mm, than sieved to the sizes from 600 to 850μm, and finally was stored in an air-tight container for the subsequent use.

2-2. Fluidized bed dryer
A fluidized bed dryer of 200 mm in height and 22 mm in diameter was self-manufactured and used for this study. Fig.1 shows the schematic diagram for the apparatus. The bubbled gas was injected from the side of a fluidized bed. Alumina ball, 1 mm in diameter, was used as a distributor.

To prevent small particles from escaping during drying, a lid equipped with glass fiber filter was also installed on the outlet of a bed.

Fig. 1 Schematic diagram of fluidized bed drying system.

After the temperature and the humidity reached to the intended conditions, 2.5 g of Loy Yang coal was put into the bed and the weight loss was measured. Temperature and relative humidity were carefully controlled by the water bubbling system using a PID-adjusted constant temperature bath and an electric furnace ranging from 40°C – 80°C, 0% – 40% RH, respectively.

3. Formulation of drying rate
In the previous studies, drying rate was determined only for the function of temperature. In this time, we tried to develop the formulation for the associated factors of the humidity and the temperature [2-3].

\[
\frac{dw}{dt} = k(T)(1-X)^n
\]

Using the conversion of moisture contents in Loy Yang coal, \( w \), the drying rate could be defined by the decreasing rate, \( dw/dt \), given by

\[
\frac{dw}{dt} = k(1-X)^n = k\left(\frac{w-w_e}{w}x\right)^n
\]

where, \( 1-X \) denotes the change of the water contents considering equilibrium moisture contents on the progress of drying.
4. Results and Discussion
In the previous research, the drying rate as an approximate discrete solution could be predicted as a function of only temperature by iterating with the reaction order of 0.25. It must be mentioned that 1-x, drying fraction, is useful only if there's no moisture source during the drying progress. However, this equation should be converted into an enhanced formulation using \( w_r \), or remains of water to express the portion of water, the equilibrium moisture contents, which cannot be removed and is still existent in coal under the bubbled gas. 

As shown in Fig. 2, the linear equations could be obtained at each temperature from plotting of \( 1-x \) versus \( dw/dt(1-x)^{0.75} \) for the several different humidity conditions under constant temperature. By plotting slopes of these linear equations versus relative humidity, drying rate constant, \( k \), as proportional constant could be found as shown in Fig. 3. The Remaining water, \( w_r \), could be also easily evaluated by plotting relative humidity versus equilibrium moisture contents.

Finding out the interrelationship between \( k, w_r \) with variation of humidity and different temperature, the variables could be derived as follows;

\[
\begin{align*}
k & = -1.700 \times 10^3 (3.530 \times 10^2 T - 4.118 \times 10^3) h + 1.240 \times 10^4 (3.290 \times 10^2 T - 3.192 \times 10^3) \\
w_r & = 2.000 \times 10^3 (1.300 \times 10^2 T + 9.417 \times 10^3) h + 3.520 \times 10^2 (-1.680 \times 10^2 T + 1.686) 
\end{align*}
\]

\( n = 0.25, \ 40 \leq T \leq 80, \ 0 \leq h \leq 40 \)

Finally, the unique equation which can illustrate the drying rate with variation of overall experimental temperature and humidity was successfully developed.

![Graph](image)

Fig. 4 Comparison between the experimental weight loss curves and the curves calculated by above equation

The curves of experimental drying rates were well matched with curves predicted from the newly developed equation as shown in Fig. 4.

5. Conclusions
The water contents typically decrease after the first short period during raw brown coal is heated to the vaporization temperature with the progress of drying and the graphic curves of the drying rate show almost linear fallings, then they move toward the horizontal, and finally level off to the equilibrium moisture contents.

Fluidized bed drying was very effective and the developed formulation is successfully available to predict the drying rate ranging from 40–80°C, 0–40% R.H., respectively.

Symbols
\( h \) Relative humidity [%]
\( k \) Drying rate constant [g/min]
\( n \) Reaction order in drying rate equation
\( T \) Temperature [°C]
\( t \) Time [min]
\( w \) Mass of water [g]
\( w_i \) Initial mass of water [g]
\( w_r \) Remains of water [g]
\( X' \) Drying fraction [-]
\( X_e \) Equilibrium moisture contents [g]
\( X_f \) Free water [g]
\( X_T \) Total moisture contents [g]

6. References