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Drying kinetics of coarse lignite particles in a fixed bed

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ABSTRACT

In this study, experimental works for a Turkish lignite in a fixed bed dryer were carried out. Drying experiments were carried out at 70, 100 and 130 °C drying air temperatures, 0.4, 1.7 and 1.1 m/s drying air velocities, 80, 130 and 150 mm sample heights and 20, 35 and 50 mm sample sizes. Suitability of twelve thin-layer drying models in describing the drying kinetics of lignite was evaluated by using statistical analyses. The results show that Wang&Singh model is the best model describing the drying behavior of coarse lignite particles in a fixed bed dryer, which is different from the literature. Additionally, the effects of drying parameters on model coefficients were studied by multiple regression analysis. Finally, apparent diffusion coefficient range was presented.

1. Introduction

Today, lignite is one of the cheapest energy sources [1,2]. Lignite constitutes about 45% of the total coal reserves and are distributed throughout the world [3]. Low Rank Coals (LRCs) including brown and subbituminous coals, which are known as having high moisture content (up to 65%, wet basis), are very important for LRC fired power plants, gasification and liquefaction [4]. However, high moisture content of LRC limits its availability in spite of its low cost [5].

Moisture in the coal causes problems in handling, storage, transportation, milling and burning [4,6]. In coal burning, an important part of energy is consumed to evaporate moisture inside the coal [5–8]. The burning of coal with high moisture content creates some problems such as insufficient combustion and additional exhaust discharge [8]. LRC should be dried to required moisture level to decrease energy losses and transportation costs, and to increase the quality of the products [9, 10].

Both heat and mass transfer mechanisms are valid in a drying process. In evaporative drying of the coal, heat is provided to remove water from the coal particle. In references [5,11] and [12], it is stated that effective parameters on drying of lignite are temperature, drying media flow rate, sample thickness, and particle size. Many studies have been done about lignite drying. In the literature, there are some attempts to review studies about coal drying such as references [13–19].

The design of a suitable dryer mostly depends on drying kinetics which is generally determined by the experimental studies. However, all the different drying conditions can't be investigated experimentally due to high cost and long time. Therefore, drying models have been developed for numerous organic and inorganic materials and many different drying methods. Thin-layer drying models have been used in various drying operations. They are easy to use, and their results are sufficiently well [20].

Thin-layer drying models have been adopted to coal drying in a few studies [21–24]. Pickles et al. investigated microwave drying of a low-rank sub-bituminous coal [21]. They examined the effects of microwave power, sample mass and initial moisture content on a 2.45 GHz microwave system. They used ten different thin-layer drying models to describe drying kinetics of Highvale coal, and Midilli model fitted well to their experimental results. Tahmasebi et al. studied on drying kinetics of Chinese lignite in nitrogen fluidized bed, superheated steam fluidized bed and microwave dryers [22]. They examined the effects of drying temperature, gas flow rate, particle size and microwave power level. They used ten different thin-layer drying models to describe drying kinetics. In nitrogen and superheated steam fluidized bed drying, Midilli model fitted well, while in microwave drying, Page model fitted well to the experimental results. Zhao et al. investigated the effects of operating conditions (air temperature and velocity, frequency, amplitude, particle size and bed height) on drying of Chinese lignite in a vibration fluidized bed [23]. They used three different thin-layer drying models to describe drying kinetics, and Midilli model fitted well to their experimental results. Stokie et al. compared drying characteristics of Victorian Brown Coals in superheated steam and air fluidized-bed dryers [24]. They investigated the effects of gas temperature and velocity and particle size. They used ten thin-layer drying models to describe drying characteristics of Victorian Brown Coals, and Midilli model fitted well to their experimental results.

Many different drying methods have been used for coal drying processes. Some of them are fluidized bed, fixed bed, moving fixed bed, rotary dryer, flash dryer, microwave dryer, etc. Fixed bed dryers

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Table 1
Proximate analysis and heating values of Konya-Ilgın lignite, as received basis.

Total moisture	%	52.42
Ash	%	8.79
Volatile matter	%	21.20
Fixed carbon	%	17.59
Lower heating value	kcal/kg	2144
Higher heating value	kcal/kg	2561

Table 2
Experimental procedure.

1	Turn on the system with no lignite in the bed and allow it to reach steady-state at desired experimental conditions.
2	Once air temperature and velocity at steady-state, turn off the system and load the lignite samples in to the bed.
3	Turn on the system again and start the experiment. In every 10 min, take a lignite sample from the upper side of the bed and load them into crucibles.
4	At the end of the experiment, turn off the system, and place all the crucibles into oven and measure the moisture of the removed lignite samples.
5	Analyze the results.

are widely used for different organic and inorganic products [25,26]. Results of a fixed bed dryer can be used to design a dryer such as band and chamber dryers. Cost of a fixed bed dryers is low, and they have an easy construction [27]. However, they have some disadvantages such as inhomogeneous output and long drying time [28].

In the literature, there isn't much study on drying of Turkish coals. Most of the coal reserves of Turkey are LRC. Therefore, there is a high need for studies on drying. Modeling the drying of coarse lignite particles is a necessity to design a suitable dryer. Fluidizing of coarse particles isn't applicable. Hence, fixed bed dryer is an important solution for coarse particle drying. In the experimental studies, a fixed bed dryer was used to analyze and evaluate the results for a possible dryer (band, chamber, etc.) design.

In this study, experiments were carried out at 70, 100 and 130 °C drying air temperatures, 0.4, 1.7 and 1.1 m/s drying air velocities, 80, 130 and 150 mm sample heights and 20, 35 and 50 mm sample sizes. The aim of this study is to adopt twelve thin-layer drying models to the experimental results of Konya-Ilgın lignite dried in a fixed bed dryer. Therefore, a model would be developed for the range of the experimental conditions taken into consideration in this study.

2. Materials and methods

A Turkish lignite, Konya-Ilgın lignite, was used in the experimental works. The proximate analysis and heating values of the lignite are shown in Table 1. As can be seen, Konya-Ilgın lignite is a LRC with a very low heating value.

2.1. Experimental set-up and procedure

Fig. 1 shows a schematic diagram of the fixed bed dryer used in the experimental studies. The airflow rate is adjusted by the fan speed control and airflow rate is measured by an orifice type flowmeter with an accuracy of 1%. The air is heated using six 1.5 kW electrical heaters placed inside the heater box with equal distances. The fixed bed drying chamber temperature is adjusted by the heater power control. The air flow is regulated by a flow straightener just below the drying chamber, and the lignite samples are placed on the perforated plate. Locations of the temperature (Ts), humidity (Hs) and pressure (Ps) measurements are shown in the figure. A digital balance (Sartorius — CPA1003S-0CE) is used in weight measurements. Its measurement range is 0–1000 g and accuracy is 1 mg.

The aim of the experiments is to understand the effects of different parameters on fixed bed drying and to model the drying process. In this study, the effects of air temperature (T) and velocity (V), sample size (S) and height (H) on drying were investigated. Drying experiments were carried out at 70, 100 and 130 °C drying air temperatures, 0.4, 1.7 and 1.1 m/s drying air velocities, 80, 130 and 150 mm sample heights and 20, 35 and 50 mm sample sizes.

Experimental procedure used in the experiments is presented in Table 2. The drying experiments were performed with inlet air temperature ranging from 70 to 130 °C. One sample of the lignite was removed and collected from the fixed bed periodically during the experiments and the lignite moisture content was measured.

2.2. Kinetics modeling

In all experiments moisture content values were calculated using Eq. (1).

$$M = \frac{W_0 - W_t}{W_0} \qquad (1)$$

where M is the moisture content (g moisture/g wet coal), W_0 is the initial sample weight, and W_t is the dry coal weight at time intervals.

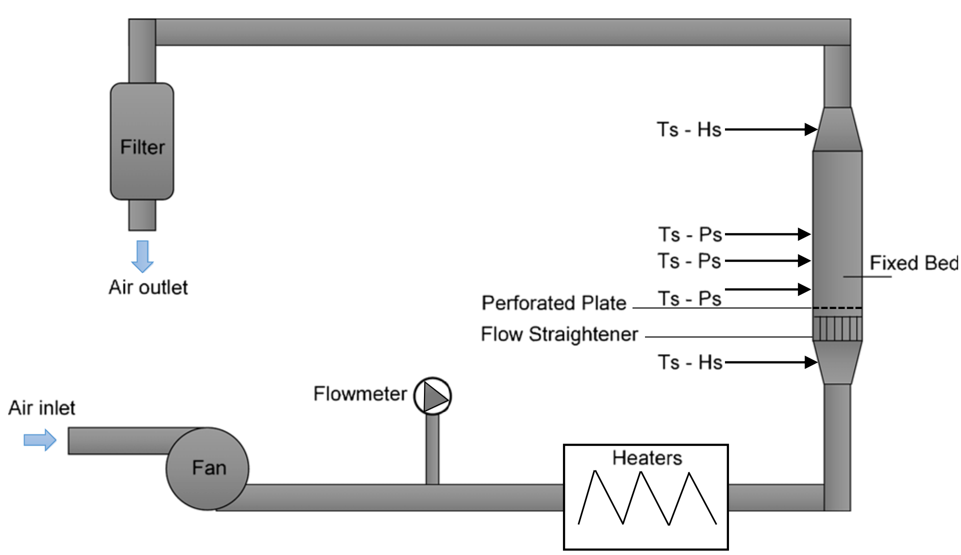

Fig. 1. A schematic view of the experimental setup.