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An experimental research on woodchip drying using a screw conveyor dryer

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ABSTRACT

Drying of woodchip in particleboard manufacturing, combustion, gasification and pyrolysis is important. It is crucial to dry wood before these processes in order to perform a smooth operation, derive high quality products and increase process efficiency. In this study, drying characteristics of woodchips with 0–2 mm and 2–5 mm particle sizes used in particle board manufacturing were determined under various drying air flow rates (10 m^3/h and 20 m^3/h), flow conditions (co-current and counter-current) and screw rotation speed (10 rpm and 20 rpm). It was managed to reduce the moisture content of the woodchips to 12,6% (wt%, wet basis) using co-current flow conditions, 10 rpm screw rotation speed, 20 m^3/h air flow rate with both of the particle sizes.

1. Introduction

Wood is widely used in industrial processes such as power generation; solid, liquid and gas fuel production and particleboard manufacturing. Power generation and fuel production from biomass requires an adequate thermal or bioconversion technology. Bioconversion technologies such as fermentation and anaerobic digestion can be operated with feedstock's that have higher moisture contents. On the other hand thermal conversion technologies such as combustion, gasification and pyrolysis require lower moisture contents (below 50%) as the moisture in the biomass decreases its calorific value and it causes the overall energy balance to be impacted adversely [1,2].

Higher moisture content of wood cause operational problems and decrease combustion efficiency in combustion, results with higher tar concentration in gasification and decreases the quality of the liquid product in pyrolysis processes [3]. Particleboard board manufacturing process consists of raw material procurement or generation, size classification, drying, blending with resin, forming the resinated material into a mat, hot pressing and finishing [4]. Woodchips were dried in order to bond liquid resins with woodchips [5].

Drying of woodchip is also important in pellet production. Pellets with higher amount of moisture causes low combustion temperatures, low energy efficiency and high hydrocarbon and particle emissions. Drying biomass in pellet production provides controlled moisture content, higher energy density and easier transport. Pellets produced from dried biomass also take up less room and they would be unlikely attacked by insects during storage [6]. Wahlund et al. [7] investigated the integration of a CHP plant with a pellet production line in which they also called it as "a bioenergy combine". The waste heat of the CHP plant was used in the upgrading of pellets and the produced pellets are transported to regions with demand for biofuel. This integration increased the annual operation hours of the CHP plant and increased the usage of the biomass. Their study also stated that system has a great potential for reducing CO_2 generation, which is a greenhouse gas.

As it can be understood above, it is crucial to dry wood before these processes in order to perform a smooth operation, derive high quality products and increase process efficiency.

Woodchips can be dried with perforated floor bin dryers, conveyor dryers, direct and indirect fired rotary dryers, cascade dryers, flash or pneumatic dryers, superheated steam dryers, microwave dryers [8], fluidized bed dryers [9] and screw conveyor dryers [3].

Screw conveyor dryers are gaining attention in the recent years. Sabarez and Noomhorm [10] used an experimental screw conveyor dryer using rice huskfired furnace as heat source was developed for safe roasting of cashew nuts. Their result was Roasting cashew nuts from the experimental dryer at 300 °C temperature for 2.0 min exposure time in 12 kg/min feed rate gave maximal whole kernel yield with an acceptable whiteness. Al-Kassir et al. [11] developed a one dimensional model for the calculation and design of a direct contact thermal screw dryer for biomass residues. It was found out in their study that Frössling correlation can be used to calculate Nusselt number in the model. Kim et al. [12] used a gas-agitated double screw type of dryer to apply thermal treatment to dehydrated, highly viscous sewage sludge. They've managed to reduce the moisture content of the sewage sludge approximately 75%wt. Kiyakoglu [13] used a water jacket heated 3 screw conveyor dryer for drying of tea. Screw conveyor dryer provided higher amounts of tea extract then classical tea drying machines. Waje et al. [14] investigated residence time distribution (RTD) and mean

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residence time (MRT) in screw dryer conveyor and found out that with the increasing screw speed, degree of mixing is increased but MRT (mean residence time) is decreased. The flow in a screw conveyor dryer approaches plug flow as the feed rate increased, whereas an increase in the screw speed results in a mixed flow. Waje et al. [15] stated that the MRT can better be controlled with screw speed rather than the solids flow rate. The discharge uniformity found to be a strong function of the solids flow rate and the screw speed. Waje et al. [16] used a water jacket covered screw conveyor dryer in their studies. Nitrogen gas was used to sweep the moisture inside the dryer. They investigated the maximum specific consumption of mechanical energy for conveying and it was found to be 1 kJ/kg. The flow behavior of the material at the dryer discharge found to depend strongly on the screw speed and the material feed rate. Waje et al. [17] dried fine crystalline solid and found out the thermal efficiency of the dryer between 25 and 62%. Martel [18] used an induction heated double-screw conveyor dryer to dry sand. Gonzalez et al. [19] dried common reed in a screw conveyor dryer. Exhaust gases and hot air generated from the exchange body of a 6.7 kW boiler for domestic heating were used as drying agent in their study. Three different biomass pellet types (pine, pear tree and coniferous) were burned in the boiler. Coniferous residue was found to give the best performance as yield of combustion and drying yield was 80.2% and 47.5% respectively. Jangam et al. [20] described that a screw conveyor dryer with a heated water jacket can be used in drying of low rank coals. Kaplan and Çelik [3] dried Turkish Pine woodchips in a screw conveyor dryer under various drying conditions which are 150 °C, 175 °C and 200 °C drying temperature, 20 m^3/h and 30 m^3/h drying air flow rate and co-current and counter-current flow conditions. Hot air was used as drying agent. They found out that increasing drying air temperature and flow rate increases rate of drying with co-current flow conditions. Wang et al. published a review work on process intensification applied to solids handling which includes further details about drying [21].

Screw conveyors are used in conveying of materials such as woodchip and they could also function as a dryer while they transport the material inside it. From that point, it is important to investigate how woodchips dry along the screw conveyor dryer and what is the effect of different sized material inside it.

In this study, drying characteristics of two different sized woodchips (0–2 mm and 2–5 mm) were determined by using a screw conveyor dryer under various drying conditions which were 10 m^3/h and 20 m^3/h drying air flow rate, 10 rpm and 20 rpm screw rotation speed and co-current and counter-current flow conditions.

2. Material and method

Woodchips were obtained from Kastamonu Entegre Factory. They were produced from various kind of logs which were imported and used in particle board manufacturing. Woodchips have an initial moisture content of 41,83%wt. They were sieved with a 2 mm Retsch test sieve and sieved part is named as 0–2 mm woodchip. Leftovers of the 2 mm sieve were sieved in a 5 mm Retsch test sieve and sieved part was named as 2–5 mm woodchip. As it can be seen in Fig. 1 geometry of the woodchips was not standard. Sizes of the woodchips were different and there are no geometrical similarities between them. 0–2 mm woodchips seem like spherical particles but 2–5 mm woodchips contains spherical like, cylindrical like and shapeless particles. Despite 0–2 mm woodchip is a dust like material, 2–5 mm woodchip don't have an exact shape. Sieving processes were done at Fuel Processing Laboratories of TUBITAK Marmara Research Center. Proximate analysis was applied to the woodchips. 4,93% Ash content (ASTM E 1755-01, Reapp.2007), 75,90% volatile solid matter (ASTM D 7582-15), %19,17 fixed carbon (ASTM D 3172-13) and 0,12% total sulphur (ASTM D 4239-14) was obtained with both of the woodchips in dry basis.

The screw conveyor dryer in Fig. 2 was used in the drying experiments. Hot air was selected as drying agent. A blower and electric furnaces were used to heat the air. The transportation of the material inside the dryer was accomplished with a screw which is powered by an electric motor and gearbox. Any further details of this dryer can be found in our previous work [3]. Operating type, drying air flow rate and screw revolution speed was changed in the experiments in order to investigate the drying characteristics of two different sized woodchips. Drying air temperature was kept constant at 205 °C (± 5 °C). Flow rate measurement was made within an error range of ± 0,8% of measured value. Two different flow conditions (or operating type) in namely co-current and counter-current were available in this dryer. Materials were always fed from material inlet section. Flow conditions depend on the delivery of the hot air. When the hot air was introduced to dryer from Pipe 1 its co-current flow and when it was Pipe 2 its counter-current flow. Since Kaplan and Çelik [3] recommended flow rates below 30 m^3/h for this type of dryer, flow rates are determined as 10 m^3/h and 20 m^3/h.

Screw rotation speed is an important parameter in screw conveyor dryers. Determination of the screw speed was accomplished with a tachometer with ± 0,05% accuracy. It was also aimed to investigate the effect of screw rotation speed on woodchip drying in this type of dryer. At the end of the experiments, it was understood that residence time is a function of material type as it was stated by Waje et al. [16]. Details of experimental conditions and experiment codes can be found in Table 1. Material inlet section is fully filled with woodchip in all experiments.

Woodchip was fed from material inlet and then collected from material outlet section. A sample for moisture content measurement was taken and then this process repeated again. By this way, three moisture data was obtained for every case.

Moisture content of the woodchip was determined by Sartorius MA 100 thermogravimetric moisture content analyzer with 1 g: ± 0.1% repeatability and 1 mg, 0.01% readability.

3. Results and discussion

The third moisture data in every experiment was gathered and Figs. 3, 4 and 6 were drawn. In Fig. 3, data was organized to analyze the effect of operating type on the drying process. When the other conditions kept constant, lower moisture contents were reached with co-current flow conditions. Kaplan and Çelik [3] stated that in counter-current drying, drying agent losses from material outlet section is greater than the drying agent losses from the material inlet section in co-current. This could explain why lower moisture contents can be reached with co-current flow conditions.

The effect of air flow rate to drying process can be found in Fig. 4. It is clear that increasing air flow rate increases the rate of drying and consequently lower moisture contents can be reached with higher air flow rates. Since higher air flow rates increases the heat transferred to the woodchips, it's normal to get these results. Hot air was used as drying agent in the experiments. Besides hot air, flue gas [19] and super-heated steam can also be used as drying agent. If a screw conveyor dryer is thought to be coupled with an incineration plant, exhaust gas of the plant can be used as drying agent. By this way, the cost of drying process could be reduced. But when using flue gas as drying agent, the drying agent losses from material inlet and outlet sides should be taken into consideration. Without minimizing drying agent losses, flue gas emissions could be released to atmosphere or to workplace. There is no study in the open literature which super-heated steam is used as drying agent in a screw conveyor dryer.

When the material losses all its moisture, temperature of the material will increase over time and it could ignite when it reaches its combustion temperature [22]. This could start a fire in the dryer. Air and flue gas dryers have fire risks and air emission problems but these are not an issue in super-heated steam dryers [8]. In order to eliminate fire risks, super-heated steam could be used in the screw conveyor dryers which is also a research subject in the field.

Three moisture data were obtained for every experiment. These data