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Superheated steam drying of sawdust in continuous feed spouted beds – A design perspective

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ABSTRACT

Spouted bed drying technology shows promising results for the drying of unscreened sawdust in superheated steam. In this paper, the experiences from designing, running and evaluating two spouted bed continuous feed dryers are presented. Stable running conditions and drying results have been achieved. This has been particularly important for sawdust that will be compressed into pellets or briquettes. The spouted bed superheated steam dryer also shows high potential for energy efficient integration into sawmills. Our recommendation is thus, to use the outlet steam temperature as the control parameter for the outlet moisture content. A drying rate above and one below the fibre saturation level, can be identified. Visual observations through the viewing glass in the drying zone in both the dryers clearly showed that not all of the material participated in the spout at all times; there were, however, no indications of dead zones. A heat transfer analysis indicated that only about 70% of the surface area of the material was in thermal contact with the steam. This paper sums up the experiences regarding drying properties, control and system properties obtained when sawdust is dried using superheated steam as the drying medium. Further work on standardised dryers in series or in parallel is necessary to increase the capacity in the spouted bed dryer.

1. Introduction

Biofuel is perceived as an important substitute for fossil fuels. Sweden's forests hold large amounts of material that could potentially become biofuel [1]. The Swedish government favours the use of biofuel by imposing taxes on fossil fuels. This has resulted in an increased interest in biofuel systems. The need for drying the biofuel is partly due to technical factors in the manufacturing process, and partly due to storage and transport factors [2]. In order to avoid significant microbiological degradation during storage, the material should be dried to a moisture content of $w_{H_2O} = 20\ \%–25\ \%$ [3]. A dried material moisture content interval of $w_{H_2O} = 4.7\ \%–13.0\ \%$ is of special interest for the production of pellets and briquettes [4]. All moisture content in this paper has been reported on wet basis.

The drying process is very energy intensive. For example, the energy requirement for drying sawdust with a moisture content of $w_{H_2O} = 55\%$ down to 15% is roughly 10% of the calorific energy value of the wet biomass [5]. In recent years, considerable amounts of research have been carried out on

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various drying methods, and great development efforts have been made. The published results have predominantly concerned laboratory scale dryers [6–9]. Paper [10] presents a review of biomass in spouted beds that focuses on fundamentals; sawdust, however, is not mentioned.

In superheated steam dryers, the energy efficiency is defined as the proportion of condenser energy in relation to the energy supplied to the dryer. The energy efficiency can be used to show the variation of the recoverable heat and to point out the heat recovery potential. In general, the energy efficiency improves with decreasing moisture content in the dried sawdust and with an increasing inlet steam temperature. Leakage, however, is a big issue in superheated steam dryers. Even very small leakages can prove to be devastating to the energy efficiency. The material feed, into and out from the dryer, has also proven especially difficult to seal [5]. Superheated steam fluidised bed drying offers advantages such as higher drying rates, product quality and energy efficiency, and there is an absence of fire or explosion hazards, or oxidative damage [11].

Mujumdar [12] notes that even minor changes in the composition or physical properties of a given product can influence the drying characteristics or handling properties. He also notes the energy savings made from the use of superheated steam, but these savings depend on the integration of a successful process.

Not all materials are fluidisable [13]. By applying the criteria of fluidisation to the drying of standard sawmill assortment, we can conclude that sawdust is the only wood fuel assortment that can be expected to fluidise without preprocessing. When sawdust is dried, the bed will probably be spouted. Pallai et al. [14] point out a significant potential for future applications using spouted bed drying. Many papers also demonstrate that fluidised and spouted bed dryers can handle a wide range of materials [15–18].

The production of fuel pellets is another complex process. The optimal moisture content varies from plant to plant [19]. In order to produce high quality pellets, the moisture content distribution in the dried material must be low. An accurate control of the dried sawdust moisture content is of major importance in the production of high quality fuel pellets [20].

Integration of the pellet plants with the raw material flow and the heat demand is a key issue in order to minimise raw material transportation and to achieve energy efficient drying processes. Sawmills have the raw material and a considerable heat demand capacity in the drying sheds that can be utilised when drying in superheated steam. Therefore, sawmills have the potential to play a leading role in the market for dried wood fuel [21]; and this is a good example of how to use the limited wood fuel resources efficiently [22]. In a case study of a conventional biomass-based combined heat and power (CHP) plant, integrated pellet production was studied. The integration enabled an increase in annual operational hours and an increased use of biofuels, as the pellets could be economically and technically transported from regions with a surplus to regions with a demand [23].

A fluidised bed has high heat and mass transfer coefficients. This, in combination with relatively high fluid speeds, makes it possible to create a design using small temperature differences, which in turn makes it easier to integrate the dryer into already existing boilers and heat demands [19]. When drying sawdust in a continuous feed spouted bed, the heat and mass transfer coefficients are difficult to state due to the fact that not all of the material is in the spout, and the flue gas speed, volume flow and mass flow differ in different sections of the dryer.

When drying in a spouted bed, the heat power flux is given by the temperature difference and the mass flow rate of the drying gas. The maximum temperature of the drying gas in a superheated steam dryer is given by the availability of sufficiently high temperatures. The mass flow rate of the drying gas cannot exceed the mass flow rate of pneumatic transport. The spouted bed dryer, thus, has a narrow capacity window in which to work, especially if it is a superheated steam dryer.

In Sweden, a number of plants for the drying of biofuels are in operation. Most of them use flue gas. In 2013 in Sweden there was about 320,000 tons of dry matter biomass that was dried in super-heated steam dryers at five different locations: Borås energi producing 120,000 tons in a fluidised bed; Härjedalens miljöbränsle AB 170,000 tons in a flash dryer; Södra cell 20,000 tons in a fluidised bed; Skellefteå Kraft Hedensbyn 130,000 tons in a flash dryer; and there is one plant up for sale in Storuman, with 105,000 tons in a flash dryer.

In this paper, the experiences from designing, running and evaluating two spouted bed continuous feed dryers are presented. The two dryers were introduced separately in earlier works [5,24], but the differences in drying properties due to design have not previously been compared, discussed and analysed. In the literature, the dryers are presented as the Nordic Roasted Tree dryer (NRT dryer) and the Karlstad University dryer (KaU dryer). In order to avoid misunderstandings, the same terminology is used here. The classic conventional spouted bed dryer suffers from limited capacity [14]. We have for this reason included a discussion on how the differences in design and running conditions influence the capacity.

2. Material and methods

The NRT and KaU dryer systems are two different spouted bed dryers using superheated steam as the drying gas (see Figs. 1 and 2), and both drying systems are described in detail in Refs. [5,19,24,25]. In both dryers, there is a viewing glass in the conical section that allows for observation of the amount and movement of the material. The size, dimensions and performance of the two dryers are shown in Tables 1 and 2.

In addition to the difference in scaling, there are three major differences between the NRT and the KaU dryers: (1) the different designs of the material outlet, (2) the higher inlet gas velocity in the KaU dryer, and (3) the control systems. The NRT dryer is equipped with a screw located on the conical part of the chamber a few centimetres above the bottom of the cone. The higher gas velocity compensates for the lack of an active discharge of dried material in the KaU dryer. Accordingly, all dried material is pneumatically transported out of the dryer.

In the NRT dryer, the sawdust feed rate is controlled by the pressure drop in the drying chamber. A decrease in pressure drop compared with the set value resulted in an increase in