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Research Paper

Modelling of superheated steam drying for combined heat and power at a corn ethanol plant using Aspen Plus software

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A superheated steam drying (SSD) model was developed in Aspen Plus software to determine energy and water recovery for drying the co-products in a corn ethanol plant. The SSD was integrated into a biomass integrated gasification combined cycle (BIGCC) heat and power production model developed for a 190 million litre per year corn ethanol plant. The BIGCC system was fuelled with either corn stover or a mixture of syrup and corn stover at a rate of 110 MW. Results were compared to estimates for steam tube drying (STD). Energy consumed for the SSD was 759–804 kJ kg^{-1} of water removed compared to 2660–2690 kJ kg^{-1} for the STD. Approximately 1.3 l of water were recovered per litre of ethanol produced with the SSD, with none for the STD. Less power was generated in the BIGCC system with SSD due to its smaller heat sink than for the BIGCC system with STD.

1. Introduction

Drying of agricultural and industrial products requires significant amounts of energy. It is often one of the most energy intensive unit operations in a complex process. For example, at dry-grind fuel ethanol plants 30%–40% of total process energy is required for co-product drying (De Kam, 2008; Liska et al., 2009; Plevin, 2009). The energy requirement for drying is large because water removed from the product is evaporated and carried away as a vapour, usually in air, in most drying systems. One way to reduce the energy requirement is to condense the water after it leaves the dryer and capture the heat that is released during condensation. Although theoretically attractive, this is difficult to accomplish in many practical situations.

One approach to this problem is to use superheated steam drying (SSD). Superheated steam drying is a process that uses steam heated beyond its boiling point, in lieu of air, in a direct contact dryer to remove moisture from the wet material. Because air is not used, it is sometimes referred to as "airless" drying. Several manufacturers produce superheated steam or airless drying systems (e.g., GEA Barr-Rosin, 2010; Keith

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Nomenclature

BIGCC	biomass integrated gasification combined cycle
DDG	distillers dried grains
DDGS	distillers dried grains with solubles
DWG	distillers wet grains
$E_{compress}$	energy required to compress the separated water vapour, W
E_{fan}	fan energy required to re-circulate the superheated steam, W
$E_{process\ steam}$	energy in the process steam used to reheat the re-circulating steam, W
Heat Exc.	heat exchanger
HRSG	heat recovery steam generator
m_{water}	mass of water removed, kg s^{-1}
NA	not applicable
RSS	recirculating superheated steam
SS	superheated steam
SSD	superheated steam drying
STD	steam tube drying
VOC	volatile organic compounds

Engineering, 2010). A schematic of a typical SSD system is shown in Fig. 1a. Wet product is introduced into the superheated steam. After passing through the dryer, the mixture of dried product and superheated steam is separated in a cyclone. After the superheated steam leaves the cyclone, excess steam, equal to the amount of water dried from the product, is removed and the remainder reheated and re-circulated through the dryer.

Several experimental investigations on SSD of a variety of food and non-food products have been conducted (van Deventer & Heijmans, 2001; Karimi, 2010; Mujumdar, 2007; Pronyk, Cenkowski, & Muir, 2004; Satyanarayan & Raghavan, 2012). It has been demonstrated that grain (e.g., rice) and grain-based products (e.g., brewers' barley spent grain and distillers' wheat spent grain) can be successfully dried using superheated steam at 110–180 °C and 101 kPa (Pronyk et al., 2004; Taechapairoj, Prachayawarakorn, & Soponronnarit, 2004; Tang, Cenkowski, & Izydorczyk, 2005). Attempts have been made to develop theoretical mathematical models for simulating SSD (Iyota, Nishimura, Yoshida, & Nomura, 2001; Martinello, Mattea, & Crapiste, 2003; Tang, Cenkowski, & Muir, 2005). A few studies have modelled SSD using Aspen Plus process simulation software (AspenTech, http://www.aspentech.com) when integrating the superheated steam dryer (for drying wood-based fuels) with the gaseous/liquid biofuel production systems (Gribik, Mizia, Gatley, & Phillips, 2007; Heyne & Harvey, 2009; Sassner & Zacchi, 2008).

The objectives of this study were to:

1. Develop an SSD model for drying co-products of corn ethanol plant or biomass fuels such as corn stover,
2. Integrate the SSD model into a biomass integrated gasification combined cycle (BIGCC) heat and power model for a fuel ethanol plant, and
3. Compare overall system performance for SSD to steam tube drying.

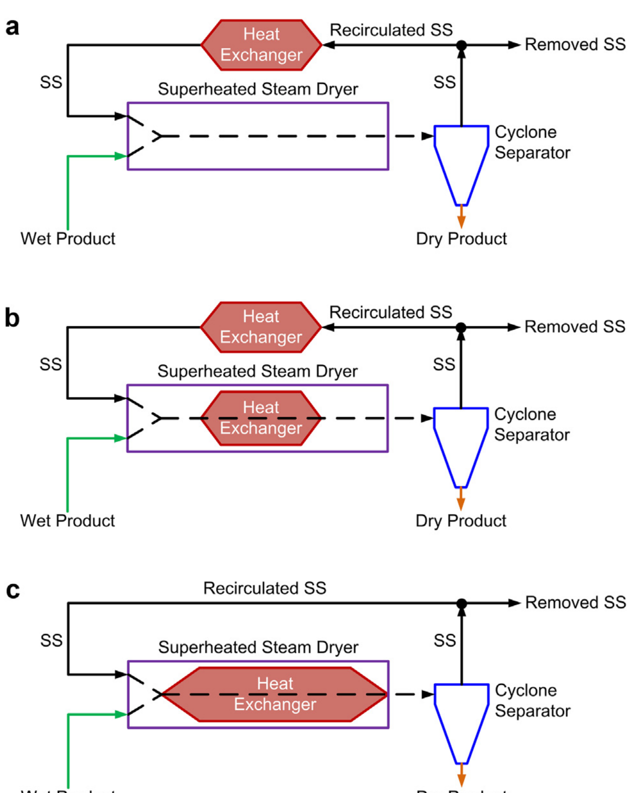

Fig. 1 – Schematic diagram of SSD systems. (a) One heating location outside of dryer; (b) Two heating locations (one outside of dryer, and one inside of dryer); and (c) Continuous heating inside of dryer (SS = superheated steam; SSD = superheated steam drying).

2. Process simulation modelling

2.1. *Superheated steam drying (SSD)*

Three conceptual models were evaluated for SSD: SSD with one heating location (Fig. 1a), SSD with two heating locations (Fig. 1b), and SSD with continuous heating (Fig. 1c). The application shown here is drying of co-product, distillers dried grains with solubles (DDGS), at a dry-grind corn ethanol plant (Figs. 2–4). SSD models were developed in Aspen Plus 2006 software (AspenTech, http://www.aspentech.com).

2.1.1. *SSD with one heating location*

A schematic diagram of the SSD model with one heating location is shown in Fig. 2. The implementation of this model in the Aspen Plus software involves use of the relevant Aspen Plus elements for each device or process described in Fig. 2 and specifying operating parameters for each element as listed in Table 1. When running the Aspen Plus model, the mass