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Application of the self-heat recuperation technology for energy saving in biomass drying system

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ABSTRACT

An advanced energy-saving drying process based on self-heat recuperation technology was proposed for biomass drying. Compared with previously developed design, the newly developed design further reduced energy consumption by 40%. Energy consumptions in the drying systems were qualified and compared through the process simulator PRO/II. Energy consumption of self-heat recuperative dryers in this study can be reduced to 1/4–1/7 of that of a conventional heat recovery dryer. Effects of the heat exchange type, ratio of air to product, minimum temperature difference between the hot and cold streams in the heat exchanger, and drying medium on the system energy consumption were evaluated when applying self-heat recuperation technology to a biomass drying system.

1. Introduction

Biomass is one of the desirable renewable primary energy sources, because of its low net carbon dioxide emissions and potential sustainability if the economic, environmental and social impacts are properly managed. However, applications of biomass as an alternative fuel are limited due to the high transportation cost, storage difficulties and reduced thermal efficiency during energy conversion. This results from the low energy density of biomass compared with traditional fossil fuels due to the high moisture content that commonly exceeds 50 wt.% (wet basis, wb). Biomass densification has been used to increase energy density and deliver bulk and widespread biomass to bioconversion plants, however, consumes a large amount of energy. In a typical pellet plant using fresh chopped wood feedstock, the drying operation is responsible for 80–82% of total energy consumption and 85% total greenhouse gas emissions [1]. This is because of the significant amount of energy consumption required when drying biomass to a water content of 8–20 wt.% (wb) for economic use [2], which comes from heating solids to the discharge temperature, water evaporation, bound water desorption, power consumptions of fans and pumps and so on [3]. So far, many energy-saving drying systems have been developed to improve energy efficiency. They include integration of the drying system with other exothermic processes, heat recovery of the exhausted heat from the dryer, multistage drying, heat pump drying, process control and optimization and solar drying [4–9]. For most existing drying systems employing conventional heat recovery devices, less than 30% of the thermal energy can be recovered because of the minimum temperature difference required for heat exchange between the hot and cold streams [10]. Significant high energy consumption is still required for the drying process which becomes the major barrier in making biomass competitive with high-grade fuel energy.

Recent developments in self-heat recuperation (SHR) technology have enabled the recovery of both the sensible and latent heats without any heat addition [11] and show a great energy-saving potential in distillation and gas separation processes [12,13]. To improve the energy efficiency of the drying process, Fushimi et al. [14] developed an energy-saving drying concept; however, the heat in the process cannot be fully recirculated. Aziz et al. [15] developed a self-heat recuperative fluidized bed dryer for biomass drying, which showed that up to 75% energy-saving potential could be achieved compared with a conventional heat recovery dryer. However, energy consumption was still much higher compared to the theoretical minimum input energy for the drying process [16]. In addition, SHR technology has so far only been applied to fluidized bed dryers. It is known that there are many other drying systems for biomass drying, such as the rotary dryer [17], conveyor dryer [18,19] and fixed and moving bed dryers [20]. No investigation into the application of SHR technology to these drying systems has been conducted.

This work aims to evaluate the energy-saving potential by applying SHR technology to biomass drying systems including both concurrent and countercurrent dryers. Energy consumption of each drying system was calculated and compared with that of a conventional heat recovery drying process. Reasons for energy saving in biomass drying system

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were discussed and factors such as the heat exchange type, ratio of air to product, minimum temperature difference in the heat exchanger, and drying medium were evaluated when applying SHR technology to a biomass drying system.

2. Energy-saving drying process based on self-heat recuperation technology

Fig. 1 shows the schematic layout of a self-heat recuperative drying process for biomass drying. Compared to the previous drying process developed by Aziz et al. [15], the advanced drying process focuses on performing heat pairing for sensible heat and latent heat. Good heat pairing which means that the sensible and latent heats are paired with the corresponding sensible and latent heats, is feasible to form the heat circulation for the energy saving. Heat capacities of hot and cold streams are slightly affected by the pressure rather than the temperature. Thus, a good heat pairing makes lines of hot and cold streams at different pressures in the temperature–heat diagram in almost parallel which are separated by the minimum temperature difference. Initially, wet biomass is fed into heat exchangers (HX1–HX4) for preheating to a certain temperature. HX1, HX2 and HX3 are heat exchangers to recuperate the sensible heat of condensed water, dried biomass and hot air, respectively. The sensible heat of the air–steam mixture is used for preheating the wet biomass (HX4). Thus, the latent heat of steam condensation could be paired with the latent heat of water evaporation in HX5 where the liquid water in the biomass is converted into vapor. HX5 is a concurrent heat exchanger in the case of fluidized bed dryer, and a countercurrent heat exchanger in the case of the rotary and screw conveyor dryers. The air–steam mixture from the evaporator is compressed by a compressor, and recirculated for subsequent biomass drying. Air humidity decreases due to temperature drop of the air–steam mixture following the heat exchange and expansion in the expander to recuperate a part of compression work. During this process, water vapor can be separated from air. Then, the dry air is recycled for the subsequent drying process. As a result, all the heat involved in drying can be recuperated and reused. This includes recuperation of the sensible heat from the gas serving as the drying medium, the dried products, and both the sensible and latent heats of the evaporated water.

The energy and material flow diagrams shown in Fig. 2, present the method for improvements in the system energy efficiency by distinguishing the heating and cooling loads of the process. The boxes represent the units, and the lines represent the flow of materials or energy. The material flow in the diagrams comprises the flow of air, (dry) biomass and water. Wet biomass is considered to be the combined (dry) biomass and water. We assumed that a heat exchanger (HX) can be divided into a self-heat transmitter (HT) and a self-heat receiver (HR). A better heat pairing has been performed in the advance drying process as shown in Fig. 2a, compared with the previously designed self-heat recuperative drying process as shown in Fig. 2b. Hot dried biomass and hot air are exchanged with cold biomass and cold air, correspondently. The compressed air–steam mixture provides heat for the water evaporation. The total heating energy is provided by self-heat exchange because of the increase in the effluent temperature due to adiabatic compression. Thus, energy input in the advanced drying process can be calculated as:

$$W_{\text{tot,SHR}} = W_{\text{cp}} + W_{\text{mc}} - W_{\text{ex}}, \quad (1)$$

where W_{mc} is the mechanical energy consumptions of blower and motor, and W_{cp} is the compression work, which can be partly recovered by the expander as the expander work W_{ex}. As a basic case, a conventional heat recovery dryer based on pinch technology is investigated as shown in Fig. 2c. The exhaust heat from the dryer including the heat of drying medium, evaporated water and dried biomass is recovered for preheating of drying medium and wet biomass. In general, efficient heat matching between sensible heat with sensible heat, and latent heat with latent heat, is impossible because of the existence of the pinch point, resulting in a large amount of energy input. Thus, additional energy in the form of heat is required to evaporate the water.

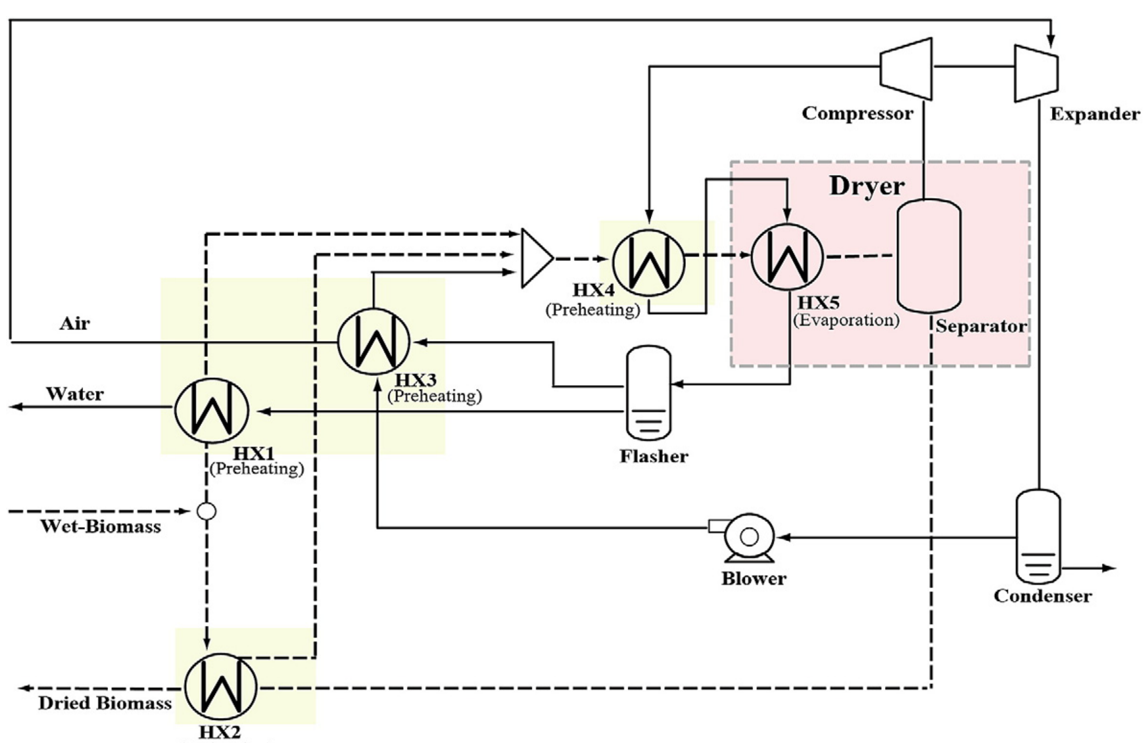

Fig. 1. Schematic layout of the advanced drying process.