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Research paper

Simulation study of improved biomass drying efficiency for biomass gasification plants by integration of the water gas shift section in the drying process

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ABSTRACT

This paper examines thermochemical biomass conversion plants that produce synthesis gas that can be converted into synthetic fuels. Biomass requires forced drying before torrefaction or gasification to increase the heating value of the feed, an energy consuming step that weighs heavy in the energy balance of the plant. This paper shows that decreasing the humidity of the admitted drying air greatly improves the efficiency of the biomass drying. It is possible to reduce the humidity of the air by passing the air on a water adsorbent solid such as activated alumina. The alumina loaded with water can then be regenerated with waste heat, but more efficiently by using synthesis gas and convert the adsorbed water to hydrogen in the water gas shift section. The energy saved in the improved drying step amounts to 2–8% of the total fuel consumption of the plant, depending on the ambient conditions.

1. Introduction

Biomass gasification and more precisely Biomass to Liquids (BtL) plants have been described in a large number of publications together with estimations for investment and fuel production costs [1,2]. The various BtL plants that are currently being designed are mostly demonstration projects to test and validate the technology chain. Commercial BtL plants are not yet in operation, all studies presenting production economics should be considered prospective. The predicted cost of biofuels is higher than fossil fuels [2] and economies of scale are difficult to realise. The competitiveness of BtL plants should, at least partly, come from technology improvements.

The BtL process is built up from a large number of steps as described by Refs. [2], these include drying, grinding, gasification and fuel synthesis. After gasification, the synthesis gas is made up to specification in the water gas shift section and in the purification section. The fuel synthesis section produces the desired final product (diesel, gasoline, methanol or others). In this paper we concentrate on the biomass dryer and the water gas shift section.

Forced biomass drying is deemed unavoidable in most BtL plants designs. Drying of woodchips is slow and generally consumes a lot of energy, typically 3.2–4.5 MJ kg^{-1} of evaporated water (30–50% more than the latent heat). There is little free water and the mass transfer rates are low. The air leaving the dryer is not saturated to maintain correct drying rates all through the dryer. This means that the energy efficiency (energy consumed compared to the latent heat of the evaporated water) is generally low (order of 50–70%) and a large amount of hot air is required.

Due to the high energy costs of the drying operation in biomass plants, this part of the process has received a lot of attention. Various solutions have been found. Process integration applying thermo-economic optimisation is common practice [3,4]. In this approach the complete heat balance of a process plant is examined and the plant is fully integrated using pinch analysis and heat integration tools. In practice, for industrial plants, the process integration is far from complete and usually does not take into account the requirements for start-up procedures. This approach makes better use of the available energy, rather than reducing the heat requirement for one particular process unit.

Most technology solutions to improve the energy balance of the drying process are based on complex heat integration with heat pumps [5,6] or more often with steam recompression [7–10]. These solutions invariably lead to an additional electrical load, suffer from fouling and are expensive. Improvements to the biomass drying are ideally simple and robust. An interesting alternative are forced solar dryers [11] interesting in localities with sufficient sunshine

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available, but mostly applied to products with a higher added value such as timber and vegetables.

The solution proposed in this paper does not involve rotating equipment and is based on a reduction of the amount of drying air required. The amount of air can be reduced by drying the air before it is put in contact with the biomass. Air drying can be performed efficiently with activated alumina to a very low dew point; this is a well-known technique. All techniques and technologies that are used in the biomass drying and gasification processes are detailed in section 2. Regeneration can be performed with another well-known technique using the water gas shift reaction that is required anyway in most gasification processes.

2. Review of technologies used in the BtL process

Gasification was originally developed for coal, biomass however has a much lower heating value and a lower energy density. Coal gasification is relatively insensitive to humidity in the coal, to the point that some gasifiers are feed with a coal water slurry. For coal with a Lower Heating Value of 40 MJ kg^{-1} and a water mass fraction of 50%, heating and evaporation of water at 1000 °C at atmospheric pressure represents 10% of the heating value of the coal. Humidity in the fuel has more impact on the gasification yield in the case of biomass. For woody biomass with a Lower Heating Value of 18 MJ kg^{-1} and a water mass fraction of 50%, heating and evaporation of water at 1000 °C at atmospheric pressure represents 23% of the heating value of the biomass. The net heat release during combustion or gasification of wet biomass is too low. This deteriorates the operability and yield of the process. Drying of the feed is therefore an important issue in a BtL plant. The drying section consumes a large amount of (low grade) energy.

2.1. Biomass drying

Woody biomass has a high to very high water content when harvested. The water content depends on the type of wood, the harvesting season and how the biomass is stored [12]. Water associated with the biomass reduces the efficiency of the gasification as it needs to be evaporated in the gasifier (unlike additional steam that can be raised from other sources). Drying the biomass feed is interesting both for combustion [13] and for gasification, rather than using raw biomass. In any case the drying operation has a large impact on the energy balance of the plant [14].

The water content decreases by natural drying. The level and the speed of natural drying that can be obtained depend on the storage, duration, air temperature and water content [15]. Natural drying down to a water content of 30% is generally not a problem; below this value forced drying in industrial dryers is usually applied to accelerate the process. Höldrich and Hartmann [16] found that natural drying from a water content of 50–60% to 30% takes less than six months, descending down to 15% takes another year when the drying takes place in a well ventilated protected location. During this period around 5% of the organic matter was lost. Microbial and fungal activity consumes some of the biomass making it unattractive to leave the biomass for a long time to dry. Scholz et al. [17] found that unventilated humid biomass can lose 10–30% of its organic matter per year.

One is always tempted to dry wood as best as is possible for best gasification performance. Simpson [18] gives the formula (1) for the equilibrium moisture content (*EMC* in %) in wood as a function of the air temperature (in the range of 0–65 °C) and relative humidity or the air.

$$EMC = \frac{1800}{W}\left(\frac{K\cdot h}{1-K\cdot h} + \frac{K_1\cdot K\cdot h + 2\cdot K_1\cdot K_2\cdot K^2\cdot h^2}{1+K_1\cdot K\cdot h + K_1\cdot K_2\cdot K^2\cdot h^2}\right) \tag{1}$$

With

$$W = 349 + 1.29\cdot T + 0.0135\cdot T^2$$

$$K = 0.805 + 0.000736\cdot T + 0.00000273\cdot T^2$$

$$K_1 = 6.27 - 0.00938\cdot T - 0.000303\cdot T^2$$

$$K_2 = 1.91 + 0.0407\cdot T + 0.000293\cdot T^2$$

T is the temperature (in °C) and *h* is the relative humidity of the air, 100% being defined as saturated at a particular temperature. The parameters *K*, *K₁*, *K₂* and *W* are defined respectively. The actual water content can be calculated from equation (2). Plotting the water content as a function of the relative air humidity gives the graph presented in Fig. 1.

$$x_{H_2O} = \frac{EMC}{100 + EMC} \tag{2}$$

This formula gives no information on the kinetics of the drying process; however it gives an indication to how dry wood can be dried naturally. It also shows that wood dried to a water content of 15% and stored does only regain humidity in very cold and damp conditions. Drying to a water content of 10% or below is often uninteresting in moderate conditions (temperatures 10–30 °C and relative humidity above 60%).

Forced biomass drying can be done with a wide variety of technologies depending on the type of biomass and the heat sources available. The heat source of dryers can be hot flue gas or steam. The drying medium can operate in a closed loop with a purge to evacuate the humidity or can be a once through air stream. Each biomass plant is different (type of heat available and its value) and the selected technology will largely depend on this.

For most belt dryers, ambient air is heated to lower its relative humidity and to activate the drying kinetics. To maintain acceptable drying kinetics, the process air cannot be completely saturated with water vapour. This study is based on a number of commercial and technical offers for woodchips dryers to be used in a process including a biomass gasifier. The thermal efficiency in the technical

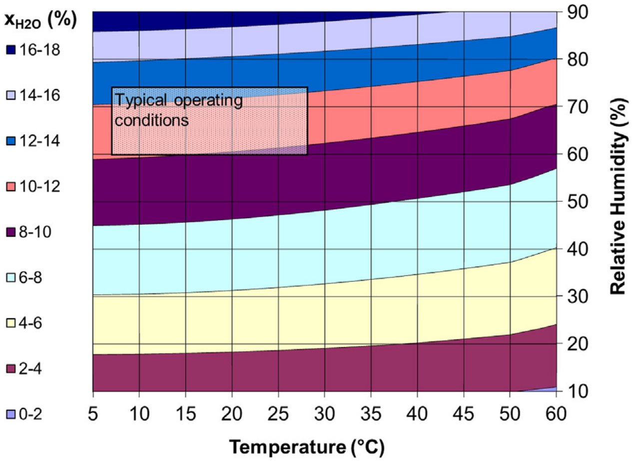

Fig. 1. Moisture content at equilibrium (x_{H_2O}) as a function of the temperature and relative humidity of the air.