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Analysis of dual fluidized bed gasification integrated system with liquid fuel and electricity products

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ABSTRACT

Dual fluidized bed (DFB) reactor is one of promising ways for biomass gasification. In this work, an integrated system is designed to produce multi products, i.e., liquid fuel and electricity using biomass as feedstock. The system consists of four main sections, i.e. Gasification, CO_2 capture, F-T synthesis, Power Generation. HRSG unit is applied to recover the sensible heat and produce steam, and the heat and electricity demanded by this system are produced by itself. The simulation is conducted in Aspen Plus and the results are verified with the literature and industrial data. Carbon chain analysis, energy analysis and green degree method are applied to evaluate the mass conversion, energy utilization and environmental influence of the system, which presents a clear description of the whole system. Furthermore, CO conversion of DFB reactor has a significant influence on oil production. The results show that 39.7% (HHV) of biomass energy is stored in products, 24.0% (HHV) in liquid fuel and 15.7% (HHV) in electricity. The energy efficiency comparison between several integrated systems is also given.

Introduction

Though fossil fuel can be consumed for hundred years, developing an alternative energy resource become necessary strategic reserves all over the world. Biomass such as wood, crops and other waste of agriculture, is the only one renewable carbon resource that can produce gas or liquid fuel to substitute for the fossil fuel [1]. Due to the carbon fixed from atmosphere by photosynthesis, biomass utilization is also a direct way to reduce greenhouse gas emissions. In China, 0.2–0.4 billion tce of biomass is available for energy purposes every year [2], most of which are in rural areas. Although biomass shows great potential as a substitution for fossil fuel, there are still some shortcomings, such as low energy/mass density, which will cause high cost for biomass's handling, storage and transportation. Technologies used for converting biomass to daily-use energy become the determining factor of biomass utilization.

Combustion, gasification, liquefaction, fermentation methods have been used for biomass conversion and utilization, and among this methods, biomass gasification is a

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major technology that is being extensively used due to its capability of handling various biomass feedstock and produce syngas consisting of H_2, CO and CH_4 which has possibility to convert into a wide range of application [3]. In recent years, dual fluidized bed (DFB) reactor shows better gasification performance [4] among various types of gasification reactors. DFB reactor produces a high hydrogen content and almost no nitrogen dilution syngas [5,6] and it also has a wide capacity for various feedstock conditions [7].

Experiments have been conducted to investigate the property of DFB reactor, different biomass, bed materials and operating parameters have been tested and the influence on tar content and gas composition have been measured [8–10]. However, there are only a few limited process simulation works on DFB gasification system, most of which are focused on CHP plant [11]. Klemens Marx [12] found that electric efficiency of small scale CHP plant using DFB reactors can be expected in the range of 32.5–35.8% based on simulation work. Jessica François [13] applied DFB gasifier to CHP plant where a rigorous model of DFB gasifier is employed to predicting tar and contaminants. A biomass-SOFC (solid oxide fuel cell) system using DFB technology is developed by Doherty [14] in order to predicting performance under diverse operating conditions. And the efficiency of this system is much higher than the traditional biomass system due to the high property syngas produced by DFB reactor. And there are also some simulation works [5,15,16] investigate the industrial performance of DFB technology, but most of which just combust this high property syngas to produce electricity. Considering that the syngas has a high hydrogen content and proper H_2/CO ratio, it is a promising way to convert biomass into liquid oil by Fischer–Tropsch technology [17,18].

In this work, the high property syngas produced by DFB reactor is used to generate liquid fuel, which present a more direct way to substitute for the oil resource. To take full advantage of biomass resource and decrease the environmental impact of this system, combustible gas produced by F-T technology and residual heat resource are used to produce electricity and heat product. What's more, Carbon chain analysis, energy analysis and green degree method are applied to evaluate the mass conversion, energy utilization and environmental influence of the system. Carbon chain analysis is used to describe the carbon flow of the whole system, which is helpful to understand the mass conversion efficiency of a complex system. The flows of energy contained in each stream are summarized by using energy flow method, which gives a better understanding of heat loss and energy efficiency. Moreover, green degree method [19] is brought into this work to evaluate the environment impact of the system, nine environmental impact categories are considered in this method, which can give a comprehensive evaluate result of each unit and whole system. This work not only aims at presenting a detailed description including materials/energy flow and environmental influence of this integrated system, but also provides some suggestions for the improvement of DFB reactor when it is used for producing both liquid fuel and electricity products. Besides that, a comparison to coal based gasification system and CHP plant based on DFB reactor is discussed to see the potential of this new integrated system.

Methodology and case study

Case description

In this work, the structure of a 10MW_{th} DFB gasification system integrated of liquid fuel and electricity products is shown in Fig. 1, four main sections including Gasification unit, Carbon capture storage unit (CCS unit), Liquid fuel unit (F-T unit) and Power Generation unit are established in the system, and HRSG unit is used to recover the sensible heat. Biomass converts into high quality syngas through DFB reactor, and then CCS part to remove CO_2. The decarbonized syngas enters a F-T unit to produce the liquid fuel. The fuel gas emitted from F-T unit and the steam by-produced by HRSG unit is used to generate electricity by gas/steam turbine. The whole system flow is calculated in Aspen plus, the key parameters of each units referring to the literature data are summarized in Table 1.

Gasification unit – DFB reactor

It is well known that gasifier is a key unit in a gasification process that determines the quality of syngas that effects the efficiency of the system directly. Compared with various types of gasifiers, DFB reactor shows a better gasification performance due to its special structure and operate condition. The structure of DFB reactor is shown in Fig. 2. The classical design of DFB systems integrates a combustion reactor (CR) and a gasification reactor (GR). A circulating stream of solids called bed material is applied to selectively transport energy and substance such as oxygen and carbon dioxide by the sorption enhanced reforming (SER) reaction and chemical loop combustion (CLC) [27,28] reaction, which have significant improvement of the syngas property.

In the process of gasification, the biomass is fed into GR and meet the steam where the gasification begins. Char generated from the gasification flows with circulating bed material to CR where it is combusted, and extra fuels such as natural gas and oil are put into CR to guarantee the heat supply to GR, then the circulating bed material carries heat from the CR to GR, CaO, MeO (Metal oxide particles) contained in bed material convert into $CaCO_3$ and Me (Metal) with SER and CLC reactions; With that special mechanism in DFB reactor, the syngas has much higher calorific value than normal air gasification [17].

$$\text{SER}: \quad CaO + CO_2 \rightarrow CaCO_3 \tag{1}$$

$$\text{CLC}: \quad MeO_\alpha + CO \rightarrow MeO_{\alpha-1} + CO_2 \tag{2}$$

In this work, parameters of the gasifier model are adjusted to match the characteristics of 100 KW DFB pilot plant at the Vienna University of Technology [8], the composition of bed materials is referred to Stefan's [29] work. Hofbauer's [8] work also showed the composition and ash melting behaviour of each feedstock, as well as the ranges of the product gas compositions. 40% straw/60% wood blended pellets are chosen as the feedstock in our system and defined as non-conventional components in