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Gasification of biomass with oxygen-enriched air in a pilot scale two-stage gasifier

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HIGHLIGHTS

- Gasification of biomass with oxygen-enriched air in a pilot scale two-stage gasifier.
- Oxygen concentration has marked effect on the content of $H_2 + CO$ in the syngas.
- Oxygen concentration has little effect on the H_2/CO ratio in the syngas.
- A syngas with about 70 v% of $H_2 + CO$ and $H_2/CO = 1$ is obtained when using 99.5 v% oxygen.

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ABSTRACT

Biomass gasification in a pilot scale two-stage gasification gasifier for BTL via one-step DME synthesis is developed. The effects of the concentrations of feeding oxygen and biomass species on the gasification temperature, gas composition, and carbon conversion efficiency are presented. The runs of the several tests show that a high and uniform temperature in the oxidation and reduction zones is generated in the gasifier with different oxygen levels. The oxygen levels in the gasifying agent have a marked impact on the content of $H_2 + CO$ in the syngas. However, the H_2/CO ratio is hardly impacted by the changes of oxygen levels, and the H_2/CO ratio is about 1 in all runs. The carbon conversion efficiency can reach 80% and a syngas containing more than 70 v% of $H_2 + CO$ and $H_2/CO = 1$ is obtained when 99.5 v% oxygen is employed. This syngas conform to the downstream application for one-step DME synthesis.

1. Introduction

Biomass is the only renewable option for the sustainable production of liquid transportation fuels. A promising option to do so is to convert biomass into a syngas by gasification and subsequently synthesize the required products including gasoline and diesel fuels, which is the so-called biomass-to-liquid (BTL) route [1]. BTL process includes syngas generation, FT (Fischer–Tropsch) synthesis or Mobil MTG (Methanol to gasoline) process involving the conversion steps of syngas-to-methanol and methanol-to-gasoline. The MTG process has a remarkable advantage in terms of product selectivity and lower plant investment cost compared to the FT process due to its products usually need further refining [2,3]. In the Mobile MTG process [4,5], the methanol is usually first subjected to a dehydrating step to form an equilibrium mixture of methanol, DME and water, and then this mixture is passed at elevated temperature and pressure over ZSM-5 zeolite catalyst for conversion to the hydrocarbon products which are mainly in the range of light gas to gasoline. Syngas can be directly converted into DME in one-step synthesis. Our research group has focused on the process of one-step synthesis of DME from syngas derived from biomass, and the previous research by our group indicated that the modified Cu–Zr–Al hybrid catalysts possessed superior catalytic performance with CO conversion of 73% and DME yield of 58% [6]. Compared with two-step DME synthesis process, one-step process provides advantages of higher syngas conversion due to relieving the unfavorable thermodynamic limitations for methanol synthesis and lower operating cost [7,8].

The reaction chemistry for typical one-step DME synthesis from syngas can be written as follows: $3CO + 3H_2 = CH_3OCH_3 + CO_2$. Therefore, another advantage of the one-step DME synthesis is that syngas with a H_2/CO ratio of 1 is required, which is close to the natural composition of biomass-derived syngas. This one-step conversion of syngas to DME can then be an ideal front end for further conversion to gasoline (DTG: Dimethyl ether to Gasoline). Furthermore, DTG process offers advantages over the MTG process in several areas including heat duty and heat of reaction, adiabatic

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temperature rise, hydrocarbon product yield and selectivity, syngas conversion, overall process efficiency, and production costs [9,10].

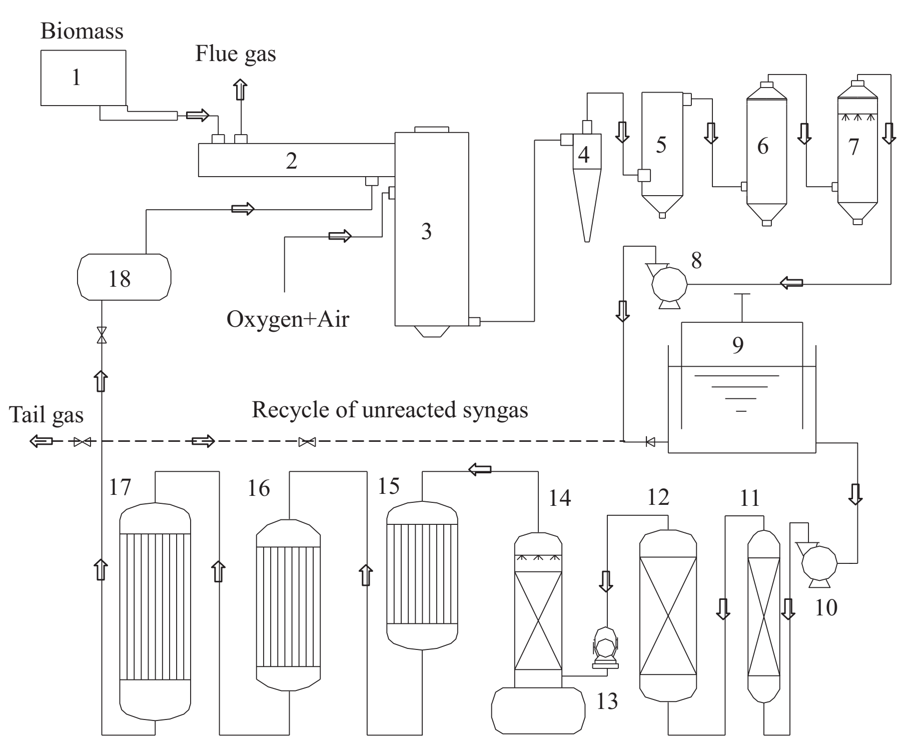
Our research group has developed the concept of DTG: syngas produced from biomass gasification is first converted into DME by one-step synthesis method and then DME is transformed into gasoline. The basic steps in the process are depicted in Fig. 1. A syngas is obtained by oxygen-enriched gasification of biomass, and the syngas composition is controlled to fit the specifications for one-step DME synthesis. The stream mixture from the first synthesis reactor is directly introduced into the second reactor for gasoline synthesis at the same pressure level. The off-gas from the second synthesis reactor is recycled or combusted to produce heat. This concept is demonstrated in a pilot scale system with an annual output capacity of 100 tons for gasoline.

Biomass gasification, which converts biomass to syngas that meet the specification of one-step synthesis of DME, is the premise and basis for synthetic biofuels. Apart from fuel gas or product gas of biomass gasification toward power generation, the definition of syngas emphasizes two chemical components, CO and H_2. Furthermore, depending on the different synthesis specifications for biofuels, the H_2/CO ratio is of major concern for synthesis process, which requires gas reforming or controlling the gasification parameters. Therefore, gas reforming and conditioning is a major technical and economic challenge for biomass gasification. Different gasifiers are employed in the gasification process, mainly including fixed bed, fluidized bed and entrained flow. The fixed bed gasifier is of simple construction and generally operated with high carbon conversion, and low gas velocity and ash carry over. There are three types of fixed bed gasifier with varying schemes for both reactor design and reaction medium. The fixed bed gasifier can be classified according to the ways in which the gasifying agent enters the gasifier as updraft, downdraft, and two-stage gasifier.

Among the fixed bed gasification technologies, the downdraft gasification is suitable to produce fuel gas toward power generation at affordable price even in small scale applications, about 75% of the designs are fixed-bed downdraft type in the commercial gasification plants in Europe, the United States, and Canada [11], and the same situation for small scale biomass gasification demonstration systems occurs in China [12]. Generally, the downdraft gasifier produces relatively low tar during gasification than updraft gasifier [13,14], and in recent years there has been growing interest in the use of fixed bed downdraft facility for biomass and waste gasification and the performance analysis of downdraft biomass gasifier has been done using different models [15–17].

In contrast to the updraft, downdraft gasifier where pyrolysis and gasification zones occur in the same reactor, pyrolysis and gasification zones are separated in the two-stage gasifier with a high temperature tar cracking zone which improved control of the process temperatures resulting in markedly lower tar production and a high energy efficiency. Studies have showed that the two-stage gasifier is very effective in producing clean gas [18–20], a fuel gas emanating from the two-stage gasifier with a tar content of less than 15 mg/Nm^3 has been reported [21].

Based on the above description, a two-stage gasifier (a separated pyrolyzer and throated downdraft gasifier) is adopted to produce clean syngas from biomass for DTG, thereby enabling the generation of CO, H_2, tar and char to be controlled. This paper addresses the oxygen-enriched gasification of biomass in a pilot-scale gasifier, and the typical results such as the effects of the concentrations of feeding oxygen and biomass species on the gasification temperature, gas composition, and carbon conversion



1. Hopper; 2. Pyrolyzer; 3. Downdraft gasifier; 4. Cyclone; 5. Bag filter; 6. Heat exchanger; 7. Scrubber; 8, 10. Roots blower; 9. Wet gas tank; 11. Sulfur removal; 12. Oxygen removal; 13. Compressor; 14. CO_2/Water-removal; 15. DME reactor; 16. Preheater; 17. Gasoline reactor; 18. Burner

Fig. 1. Schematic of the process of BTL via one-step DME synthesis.