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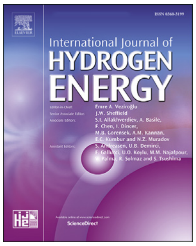

Influences of equivalence ratio, oxygen concentration and fluidization velocity on the characteristics of oxygen-enriched gasification products from biomass in a pilot-scale fluidized bed

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ABSTRACT

The influences of equivalence ratio (ER), oxygen concentration (OC) and fluidization velocity (FV) on the gasification performance in a pilot-scale fluidized bed with capacity of 1 ton biomass (the mixture of agricultural residue) per day were investigated using oxygen-enriched air as gasification agent and high-alumina bauxite as bed material. The characteristics of syngas (lower heating value (LHV), gas yield (Y), carbon conversion (CC) and cold gas efficiency (CGE)), bio-char (LHV and Proximate analysis) and tar (tar yield and LHV) were used to evaluate the gasification performance in this study. The results showed that 0.161 was the optimal ER due to the high quality of syngas produced and relatively lower tar generation with ER changing from 0.115 to 0.243 at OC ≈ 40% and FV ≈ 1.20.29.7% was the optimal OC due to the highest Y and CC and relatively low tar generation when OC varied from 21% to 44.7% at ER ≈ 1.40 and FV ≈ 1.15. Although higher FV could improve syngas quality, it also resulted in the higher tar yield and heavier wear, therefore, the optimal gasification performance was achieved at moderate FV (FV = 1.13). This study proved that oxygen-enriched gasification in a large-scale fluidized bed was an effective option to produce gaseous biofuels with high quality.

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Nomenclature

ER	Equivalence ratio
OC	Oxygen concentration
LHV	Lower heating value
RDF	Refuse-derived fuel
CFD	Computational Fluid Dynamic
FV	Fluidization velocity
BFB	Bubbling fluidized bed
PLC	Programmable logic controller
W_{iso}	The weight of bottles containing isopropanol
$W_{mixture}$	The weight of bottles containing the mixture of isopropanol and absorbed water and tar
W_{abs}	The weight of the absorbed water and tar
W_w	The weight of absorbed water in the mixture of isopropanol, water and tar
W_t	The weight of absorbed tar
GC	Gas chromatography
Y_g	Gas yield
CC	Carbon conversion efficiency
CGE	Cold gas efficiency

Introduction

Biomass, as the fourth greatest amount of available energy resource around the world following behind petroleum oil, coal and natural gas [1,2], has been regarded as an attractive renewable energy to deal with the problems such as fossil fuel depletion, environmental pollution, especially for global warming [3–6]. There are three main thermochemical methods including gasification, pyrolysis and combustion to convert biomass to valuable fuels for further utilization such as heat and electricity production [7–9]. Compared with other thermochemical methods, gasification has its own advantages: (1) It is flexible that the syngas produced by gasification can be used for heat or electricity production in engines or boilers, for Fischer-Tropsch synthesis to produce liquid biofuels or for other green chemical synthesis [10–14]. (2) Higher energy recovery and lower gas emissions than combustion [15]. (3) The greatest potential for producing H_2 at an industrialization scale in the near future [16]. Gasification can produce a mixture of the combustible gases such as CO, H_2 and CH_4, unavoidably, syngas produced by gasification contains the incombustible gas - CO_2 [2,4,10,12,13]. Air is commonly used as gasification agent in industry due to its simple operation, stable running and low capital cost, however, syngas produced by gasification has lower heating value (LHV) (about 4–6 MJ/Nm^3) due to the dilution of nitrogen [4,17]. Using oxygen as gasification agent can both increase LHV and H_2/CO rate, however, complex system design and high capital cost are required to produce pure oxygen. Therefore, using enriched-oxygen air as gasification agent is a promising way to utilize biomass [1,4,17–19].

The reactor configuration has a crucial influence on the oxygen-enriched gasification performance from biomass. Therefore, different reactor configurations such as entrained flow bed [1], cyclone furnace [5,20], fixed bed [21,22], and fluidized bed [[17–19] and [23–14]] were used to study the products from the oxygen-enriched gasification. Using a lab-scale entrained-flow gasifier, Yu et al. investigated the effects of temperature, equivalence ratio (ER) and oxygen concentration (OC) on the gasification performance from straw, and the optimum operating condition was found as follow: 1200 °C, ER = 0.25, OC = 40 vol% [1]. The influence of OC varying from 21% to 31.4% on oxygen-enriched gasification of micro biomass fuel produced from ramie residues was studied in a cyclone furnace and the maximum LHV of the syngas could reach 6.2 MJ/Nm^3 [5]. In the fixed bed, the OC variation in the gasification agent not only influenced on the temperature in the bed [21] and the syngas characteristics [21,22], but also on biomass consumption rate, oxygen/fuel ratio and flame front velocity [22]. Compared with above reactors, the fluidized bed is most commonly used technology as it is most easily scaled up and applied to industrial production [23,24]. Co-gasification of coal, plastics and wood using oxygen-enriched air was studied in a bubbling fluidized bed at the condition with the fixed fluidization velocity (FV), bed temperature and ER, however, only the effect of OC in the gasification agent on gasification performance was investigated in this experiment [18]. Oxygen-enriched gasification of refuse-derived fuel (RDF) produced from biomass residues using two different bed materials - calcined dolomite and high-alumina bauxite was investigated by Niu et al. in a lab-scale bubbling fluidized bed, the optimum condition for acquiring high quality syngas was achieved with ER = 0.22 and OC = 44.7% at 800 °C using calcined dolomite as bed material [19]. The effect of OC on the syngas quality was studied by Barisano et al. in a 1000 kW_{th} pilot-scale internally circulating bubbling fluidized bed [25]. Characteristics of syngas produced by gasification of pine wood, maple-oak wood and seed corn were investigated with OC varying by Huynh et al. in a pilot-scale pressurized bubbling fluidized bed with a capacity of 5 metric tons per day [17]. Besides the experimental studies above, there are also some mathematical models built to reflect the characteristics of oxygen-enriched gasification [26–28]. A statistical models, built based on the experimental results achieved in a lab-scale gasifier with respectively varying temperature, ER and OC, was used to predict the gasification performance in a pilot-scale gasifier, The results showed that the errors between the empirical values of the concentrations of H_2 and CH_4 in the syngas and the actual values were within 10%, while those of the CO and CO_2 concentrations were below 3% [26]. Silva and Rouboa developed a two-stage equilibrium model using carbon boundary point to simulate the effects of different operating parameters on the composition of the syngas [27]. An Eulerian-granular 2-D multiphase Computational Fluid Dynamic (CFD) model was used to predict the influence of the OC on the gasification temperature, steam to biomass ratio and the syngas quality [28].

The previous studies mainly paid attention to the characteristics of the gas phase influenced by the operating factors such as temperature in bed, ER and OC. However, there is lack of information about the characteristics of all three phase products consisting of the syngas, tar and bio-char affected by these factors. These characteristics are very important for finding an effective method to convert the energy contained in

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