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Performance characterization of a pilot-scale oxygen enriched-air and steam blown biomass gasification and combustion system

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Research Program: Renewable fuels

Introduction

Recently there has been a renewed interest in using biomass as energy sources due to increasing global energy demand coupled with fast diminishing of fossil fuel supplies. Additionally, pressures from stringent regulations on air pollutions and greenhouse gas emissions helped make biomass become even more attractive since the use of biomass is a carbon neutral process [1].

Conversion of biomass into biofuels (gaseous and liquid fuels) can be achieved primarily by biochemical and thermochemical processes [2]. Although biochemical technologies are well developed and widely used for biofuels production [3], however, the types of biomass can be used are limited. Thermochemical gasification appears to be a promising technology that can exploit the embedded energy within various types of biomass and convert into valuable intermediates with flexibility for many industrial market applications such as biofuels and heat and power [4].

Gasification turns solid biomass into low to medium heating values combustible gas mixtures (known as syngas) through simultaneous occurrence of exothermic oxidation and endothermic pyrolysis under limited oxygen supply [2].

The use of air as gasifying agent yields low heating value gas and is only suitable for heat and power applications [5]. Steam and oxygen on the other hand can increase gas heating value (HV) as well as main gas constituents which suitable for production of liquid fuels through synthesis process such as Fischer-Tropsch. Nevertheless, high capital costs and complex system design have precluded steam and/or oxygen gasification as viable for industrial scale. To avoid high costs and complex designs, researchers have looked into using combination of air, steam, and oxygen as gasifying agent. However, very limited works have been done and published. Furthermore, most works are only focused on increasing gas HV but neglected the effects on the formation of contaminants such as ammonia, NH_3.

It is well-known that during gasification process, nitrogen content in biomass will be converted into nitrogen-containing compounds such as NH_3 and hydrogen cyanide (HCN) with NH_3 as the dominant species [6]. These nitrogen-containing species will act as fuel-bound nitrogen (FBN) that lead to high NOx emissions during combustion which will compromise the neutral effect of biomass as clean energy sources. Hence it is crucial to characterize both gas heating value and the detailed syngas compositions.

The purpose of this study is to investigate and provide fundamental understanding of the effects of using mixtures of oxygen-enriched air and steam as gasifying agent on gas heating value, main gas compositions, and ammonia concentration. In addition, this study also aimed to characterize the relationship between different syngas compositions and NOx emissions during combustion.

Experimental Methods

Tests were conducted using a pressurized fluidized bed gasifier integrated with an industrial burner. All tests were performed at fixed bed temperature of 800 °C. Three types of biomass of different compositions and nitrogen contents were used. Each type of biomass was subjected to three different gasifying conditions—varying the oxygen percentage (OP) in gasifying agent mixtures from 21% to 30% and 40% O_2 (v/v) on wet basis. Biomass samples were sent to Huffman Lab Inc. for proximate and ultimate analyses based on ASME standards.

Syngas undergoes filtering process to drop out solid char particles before entering an air-staged, diffusion flame burner. NOx emissions were characterized from different burner operating conditions such as varying fuel flow rates and equivalence ratio (ER). Notice that ER is defined as the ratio of actual air-fuel ratio over stoichiometric air-fuel ratio.

Both syngas and flue gas (from burner) dry compositions were measured using micro Gas Chromatograph (micro G.C.) and chemiluminescence NOx analyzer. Ammonia concentration and water content of syngas were captured and quantified using modified IEA Tar Protocol. Syngas lower heating value and adiabatic flame temperature were calculated using EES.

Sample Results

For all biomass feedstocks, main gas compositions showed similar increasing trends when OP in gasifying agent increased from 21% to 40%. As shown in Fig. 1, H_2 and CO contents have increased greatly whereas N_2 showed reverse effects. The increased in H_2 is mainly due to hydrogen atoms from steam. The increased in H_2 and CO coupled with decreased in N_2 led to the increase in HV of syngas.

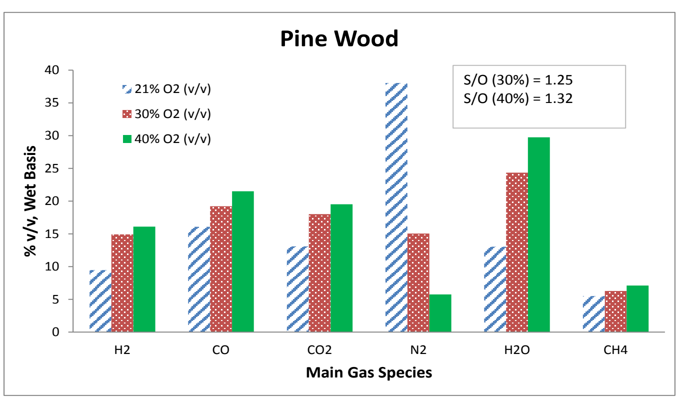

Fig. 1: Pine wood main gas compositions at different OP.

According to Fig.2, NH_3 concentration in syngas increases as OP in gasifying agent increased. This is due to crack down of nitrogen-containing species in char in the presence of steam and oxygen.

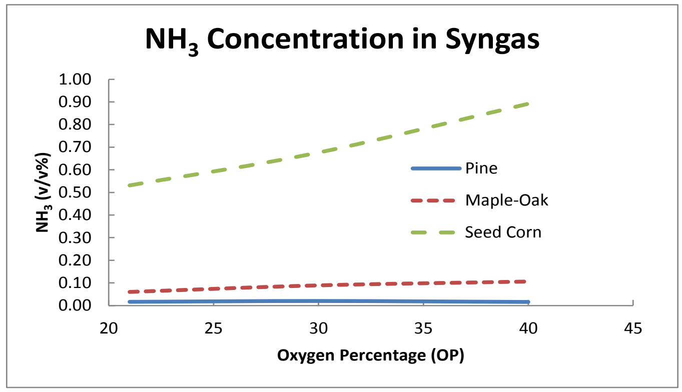

Fig. 2: NH_3 concentration at different OP.

Fig. 3 showed NOx emissions for seed corn at different ER and fuel flow rates using 21% O_2 syngas composition. The NOx trends for seed corn tend to reach a peak value and then decrease as conditions change from ER=1.1 to ER=2.2 (relatively lean). This trend is exhibited in all fueling rates and all oxygen-enriched air conditions. Another trend showed in Fig. 3 is that as the fueling rate increased, the peaked NOx values tend to shift toward leaner mixtures. This is because as the fueling rate increased, NH_3 concentration also increased thus the excessive oxygen at the leaner conditions is very favorable for further oxidation of NH_3 to NOx.

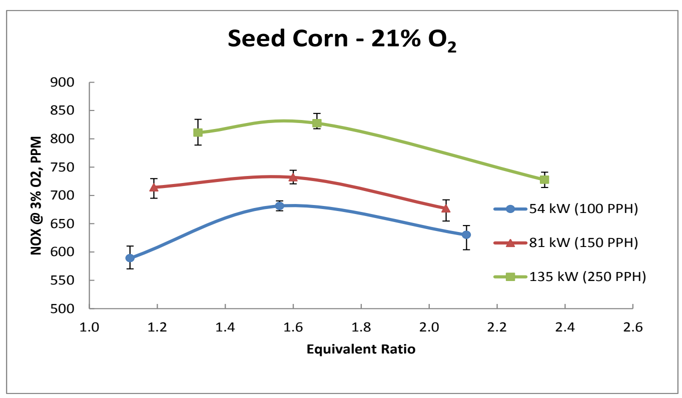

Fig. 3: Seed Corn NOx emissions from 21% O_2 syngas.

The effects of syngas composition at different gasifying conditions on NOx emissions are shown in Fig. 4. For the same fueling rate, Fig. 4 showed that NOx emissions increased with syngas at higher OP. This is because syngas from higher OP gasification has higher NH_3 concentration as well as higher HV. Higher NH_3 and higher HV mean higher NOx formation from fuel-NOx and thermal-NOx pathways.

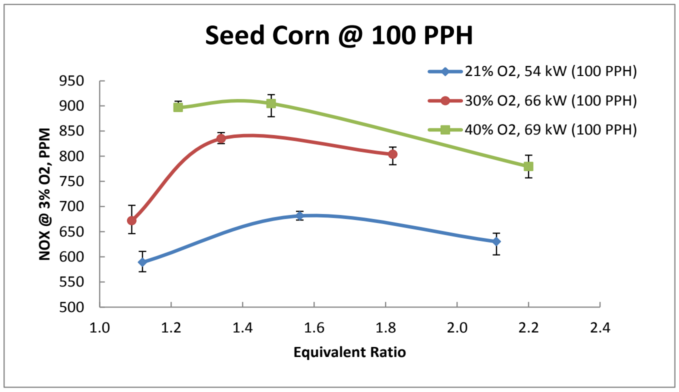

Fig. 4: Seed Corn NOx emissions comparison between 21% and 40% O_2 syngas.

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