

Catalytic Gasification of Biomass Over Fe-MgO Catalyst

QINGYUN REN, SONGTAO WANG*

Department of Chemistry, Jining Normal University, Wulanchabu, 012000, China

Given the significant abundance of non-food biomass resources, rural areas are endowed with a great potential for development of biomass energy systems which can make a significant contribution to economic development without public health issues. In this work, an experimental work done on air-steam gasification of biomass in presence of Fe/MgO for hydrogen rich gas production and CO₂ reduction. As reactor temperature increased from 800 to 1000 °C, the tar and char yields decreased from 6.4 to 1.6 % and 18.4 to 5.6 %, respectively, while the syngas yield increased from 75.2 to 92.8 %. With the increase of C/B from 0.1 to 1.0, H₂ concentration increased by 39 % while the CO₂ concentration decreased from 35.4 vol% to 20.4 vol%.

Keywords: Gasification, Tar; Hydrogen; Char; Fe/MgO

Nowadays, environmental problems are increasing in developing countries due to their industrial activities and economic growth. China is one of the world's biggest producers of coal, but due to the cost of supply and transmission of electricity to rural areas, a vast majority of the population of villages do not have access to electricity and home gas [1, 2]. This problem may be solved by introducing modern energy systems such as biomass energy. Given the significant abundance of non-food biomass resources, rural areas are endowed with a great potential for development of biomass energy systems which can make a significant contribution to economic development without public health issues. Although the idea of application of biomass for the production of synthesis gas or chemicals is not new, the biomass-to-energy is still at the stage of demonstration [3].

Amongst other methods, gasification is considered as a promising renewable energy technology which can convert the solid/liquid fuels to clean syngas. This process is recognized to be more suitable for electricity production from biomass than combustion due to little environmental concerns. However, CO₂ emissions from the gasification of biomass and the presence of organic impurities (tars) explain significant technical and environmental challenges. Tar is a complex mixture of heavy hydrocarbons associated with several technical and operational problems such as blockage of pipelines and filters, it, however, contains significant amounts of energy that can improve the caloric value of produced syngas. Generally, tar can be eliminated by non-catalytic and catalytic processes. However, gasification in presence of an alkaline catalyst is more interesting because it has the potential to decrease greenhouse gas emissions while simultaneously eliminating the volatile matters and char residues.

A few papers specifically report on air-steam gasification in presence of alkali/alkaline catalysts for reducing CO₂ emission and eliminating the condensable fractions. Mahishi and Goswami [4] determined experimentally the influence of adding sorbent to the hydrogen concentration and CO₂ emission during gasification of Southern pine bark, and concluded that when the reactor temperature is less than the equilibrium temperature corresponding to the CaO-CaCO₃ reaction, CO₂ is absorbed and the CaO is converted to CaCO₃, and above the reference temperature CaCO₃ is desorbed to generate the original sorbent. Hanaoka et al. [5] studied the influence of some critical parameters such as reaction pressure and CaO/biomass ratio on hydrogen yield from woody biomass by steam

gasification using CaO as a CO₂ sorbent, and indicated that the hydrogen yield strongly depends on the reaction pressure, and reaches to a maximum value at 0.6 MPa. Acharya et al. [6] carried out an experimental study to find out the potential of hydrogen production from biomass gasification in presence of sorbent CaO, and found that the CaO/biomass ratio has a significant influence on the hydrogen yield and the amount of CO₂ absorbed, but as the reaction temperature increases from a standard level (800 °C), the hydrogen yield becomes almost constant. Zhang et al. [7] made a sorbent by mixing dolomite and limestone and found that the best results (higher H₂ and lower CO₂) obtained as the mass ratio of calcined dolomite and limestone is 1.0.

As mentioned above, not much research has been conducted on the catalytic gasification of biomass in presence of Fe/MgO for tar destruction and hydrogen production. Therefore, this research aims to carry out an experimental work on air-steam gasification of biomass in presence of Fe/MgO for hydrogen rich gas production.

Experimental part

Figure 1 shows the schematic diagram of fixed bed reactor. The ultimate and elemental analyses have been done in a TGA (5500 series) and CHNS/O elemental analyzer (2400 series II), respectively. Table 1 shows the properties of biomass. The reactor is an insulated tube made of stainless steel with a thickness of 150 cm. Two K type thermocouples were installed in the outer edge of reactor (middle and bottom). Fuel was fed into the gasifier by a feeding system on the top of the gasification system, which were continuously performed at a constant flow rate of 8.0 g/min. The produced gas was collected by gasbags and then analyzed by a gas chromatography (HP 5890 Agilent). To remove the condensable products (tars) from the condenser walls, methylene chloride (CH₂Cl₂) was used. The collected tar was then calculated by a gas chromatography (HP-4890).

Results and discussions

Biomass gasification is a complex reaction and occurs via two main steps including: (i) the pyrolysis process occurring in an inert atmosphere which can be considered as an initial step for simulation process; and (ii) the secondary reactions involving the char conversion reactions and thermal cracking of heavier hydrocarbons in presence of steam and/or pure oxygen. Here, it is assumed that the pyrolysis process takes place instantaneously due

* email: wst2082@163.com

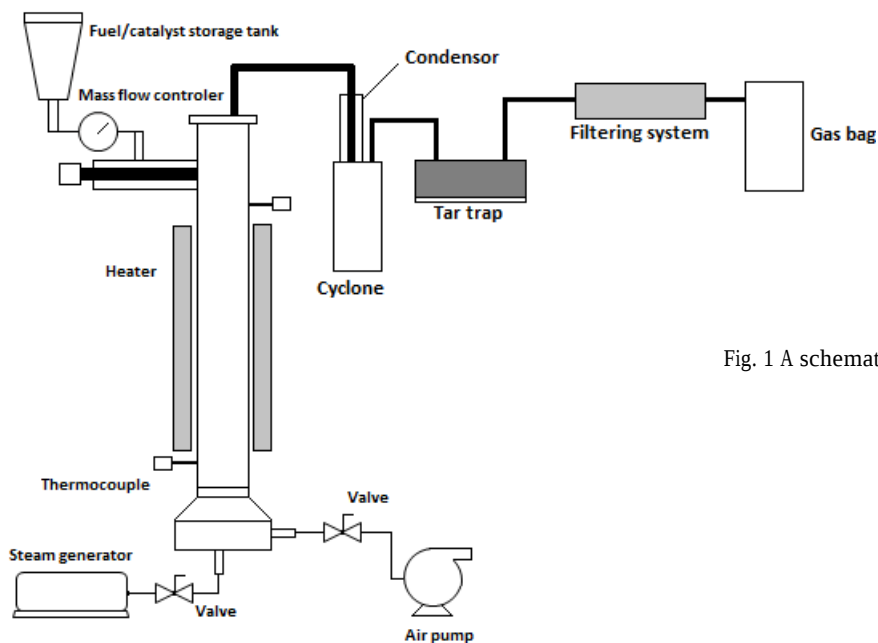


Fig. 1 A schematic diagram of fixed bed system

Proximate analysis (wt %)		Ultimate analysis (wt %)	
Moisture	08.16	C	44.18
Volatile	76.86	H	06.38
Fixed carbon	14.86	N	00.12
Ash	00.12	O ^a	49.32
^a Calculate by difference			

Table 1
THE ULTIMATE AND ELEMENTAL ANALYSIS
OF BIOMASS (LARCH)

Temperature (°C)	800	850	900	950	1000
<i>Product distribution (%)</i>					
Gas	75.2	80.4	87.5	90.3	92.8
Tar	6.4	4.2	2.9	2.1	1.6
Char	18.4	15.4	9.6	7.6	5.6
<i>Gas composition (mol%, dry basis)</i>					
H ₂	17.5	22.3	27.1	30.7	33.4
CO	20.1	23.9	25.4	26.2	28.8
CO ₂	38.5	36.1	34.7	32.2	30.7
CH ₄	23.9	17.7	12.8	10.9	07.1
<i>Gas characterization</i>					
Syngas (H ₂ +CO) (mol%, dry basis)	37.6	46.2	52.5	56.9	62.2
H ₂ /CO (mol/mol)	0.87	0.93	1.06	1.17	1.16
HHV (MJ/Nm ³)	14.3	12.7	11.7	11.6	10.7
Steam decomposition (%)	49.7	52.3	57.1	61.9	64.8
Carbon conversion efficiency, CCE (%)	60.1	66.3	70.4	74.7	79.0
Cold gas efficiency, CGE (%)	32.6	35.9	39.8	42.2	46.7
Product gas yield (Nm ³ /kg)	1.04	1.12	1.29	1.52	1.61
S/B = 1.0, ER= 0.15, Fe-MgO/biomass= 0.5					

Table 2
EFFECT OF
REACTOR
TEMPERATURE ON
GAS COMPOSITION
AND PERFORMANCE
INDICATORS

to high temperature operation. The cold gas efficiency (CGE) is defined as the ratio of the produced gas caloric value to the caloric value of the feedstock. The definition of carbon conversion efficiency (CCE) is also the ratio of the carbon content in the producer gas to the carbon content in the feedstock. The impacts of reactor temperature on gas composition and performance indicators at a steam/biomass ratio (S/B) of 1.0 were

studied as shown in table 2. As can be seen, the gas yield sharply increases with the increase of reactor temperature, while the tar and char yields slightly decrease. As reactor temperature increases from 800 to 1000°C, the tar and char yields decrease from 6.4 to 1.6 % and 18.4 to 5.6 %, respectively, while the syngas yield increases from 75.2 to 92.8 %. It can be inferred that thermal cracking of tars and char conversion reactions may simultaneously occur at

S/B (wt/wt)	0.50	0.75	1.00	1.25	1.50
<i>Product distribution (%)</i>					
Gas	91.4	92.1	92.8	93.7	94.5
Tar	2.5	2.1	1.6	1.2	0.8
Char	6.1	5.8	5.6	5.1	4.7
<i>Gas composition (mol%, dry basis)</i>					
H ₂	28.2	30.7	33.4	37.2	40.4
CO	33.7	30.1	28.8	22.1	18.9
CO ₂	26.4	29.7	30.7	34.4	35.6
CH ₄	11.7	09.5	07.1	06.3	05.1
<i>Gas characterization</i>					
Syngas (H ₂ +CO) (mol%, dry basis)	61.9	60.8	62.2	59.3	59.3
H ₂ /CO (mol/mol)	0.83	1.02	1.16	1.68	2.13
HHV (MJ/Nm ³)	12.5	11.5	10.7	10.0	09.6
Steam decomposition (%)	57.4	60.1	64.8	68.2	71.7
Carbon conversion efficiency, CCE (%)	85.0	83.1	79.0	77.3	74.5
Cold gas efficiency, CGE (%)	51.8	48.2	46.7	42.6	40.7
Product gas yield (Nm ³ /kg)	1.75	1.69	1.61	1.54	1.47
T = 1000 °C , ER= 0.15, Fe-MgO/biomass= 0.5					

Table 3
EFFECT OF S/B ON
GAS COMPOSITION
AND PERFORMANCE
INDICATORS

higher reactor temperatures because higher temperature favors tar and char destruction and the increase of the gas yield. As expected, the concentrations of CH₄ and CO₂ decrease slightly with the increase of reactor temperature which is related to the extension of the water-gas shift reaction. As can be seen in table 2, as the reactor temperature increases, the produced gas caloric value (HHV) slightly decreases because an increase of reactor

temperature causes a decrease of CH₄ concentration; however, the CCE and CGE increase due to a significant increase in the syngas yield.

Table 3 presents the influence of S/B on gas composition and performance indicators at 1000°C. It is found that the gas yield increased with an increase of S/B from 0.5 to 1.5 wt/wt, whereas the char and tar yields decreased to 4.7 and 0.8 %, respectively. The addition of steam favors tar destruction mainly resulting from steam reforming of

Fe-MgO/biomass ratio	0.1	0.25	0.5	0.75	1.00
<i>Product distribution (%)</i>					
Gas	90.1	91.7	92.8	93.5	93.2
Tar	2.9	2.5	1.6	1.2	0.8
Char	7.0	5.8	5.6	5.3	6.0
<i>Gas composition (mol%, dry basis)</i>					
H ₂	27.2	30.1	33.4	39.2	44.8
CO	34.3	31.6	28.8	26.5	24.7
CO ₂	35.4	33.8	30.7	25.1	20.4
CH ₄	03.1	04.5	07.1	09.2	10.1
<i>Gas characterization</i>					
Syngas (H ₂ +CO) (mol%, dry basis)	61.5	61.7	62.2	65.7	69.5
H ₂ /CO (mol/mol)	0.79	0.95	1.16	1.47	1.81
HHV (MJ/Nm ³)	09.0	09.6	10.7	12.0	12.8
Steam decomposition (%)	69.8	67.3	64.8	61.2	58.4
Carbon conversion efficiency, CCE (%)	64.4	71.1	79.0	85.8	91.5
Cold gas efficiency, CGE (%)	40.6	43.8	46.7	49.5	52.3
Product gas yield (Nm ³ /kg)	1.47	1.54	1.61	1.67	1.72
T = 1000 °C , S/B = 1.0, ER= 0.15					

Table 4
EFFECT OF FE-MGO/BIOMASS RATIO
ON GAS COMPOSITION AND
PERFORMANCE INDICATORS

condensable fractions; however, the addition of more steam demands additional energy. A clear increase of H_2 with S/B is observed, which can be due to several reasons: (i) as S/B increases, the heating rate increases, so greater generation of H_2 can be achieved in the initial devolatilization step; (ii) the increase of S/B improves the endothermic nature of steam reforming/cracking reactions of condensable fractions; (iii) the usage of more steam promotes the water gas shift reaction, which produces H_2 and CO_2 . At higher S/B ratios, the hydrogen concentration remained nearly constant probably due to heat and mass transfer limitations.

Table 4 shows the product gas composition and gas performance parameters as a function of Fe-MgO/biomass (C/B). In the present work, C/B varies from 0.1 to 1.0, while the S/B and reactor temperature are kept constant. With the increase of C/B from 0.1 to 1.0, it can be found that the H_2 concentration increased by 39% while the CO_2 concentration decreased from 35.4 vol% to 20.4 vol%, indicating that direct gasification of biomass in presence of Fe/MgO favors hydrogen production with in situ CO_2 capture. This can explain that the steam added into the gasifier would react with the condensable fractions (volatiles and char residues) to generate more hydrogen.

Conclusions

In this work, an experimental work done on air-steam gasification of biomass in presence of Fe/MgO for hydrogen rich gas production and CO_2 reduction. As reactor temperature increased from 800 to 1000°C, the tar and char yields decreased from 6.4 to 1.6 % and 18.4 to 5.6 %, respectively, while the syngas yield increased from 75.2 to

92.8 %. With the increase of C/B from 0.1 to 1.0, H_2 concentration increased by 39 % while the CO_2 concentration decreased from 35.4 vol% to 20.4 vol%.

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