Simulation of Adiabatic Gasification of Corn Straw using Air-Steam Blends as an Oxidizing Agent

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Abstract

Due to the increase of consumption in the world of energy and the pollution caused by fossil fuel combustion processes, it is necessary to generate new technologies for the use of alternative fuels, allowing to reduce the dependence on fossil fuels such as oil, gas and coal. In general, the combustion processes of fossil fuels produce greenhouse gases which increase the temperature of the environment and the deterioration of the ozone layer. Chemical equilibrium was used to estimate the species produced by adiabatic gasification with different air-vapor mixtures. By running the NASA CEA software (chemical equilibrium with applications), a thermochemical simulation was performed under two parameters: the equivalence ratio (ER) defined as stoichiometric air/air supplied to the reactor (1.5-6) and the steam-fuel ratio (0-1). Thus, the syngas composition showed the following ranges: CO (0% -14.7%), H2 (0% - 36.7%), CH4 (0% -4.3%), CO2 (17% -22.7%). The calorific value of the gases and the energy conversion power were also calculated with the composition of the gases. Then, The Higher Heating Value (HHV) was calculated whose values aim to conclude that syngas generated can be classified as a poor fuel gas since the HHV ranged between 1992 kJ/SATP m^3-7537 kJ/SATP m^3.

Keywords: Chemical balance; Gasification; Calorific value; Corn straw

Introduction

The current and growing consumption of energy and the increase of toxic NOx, SOx and greenhouse gases produced from the combustion of fossil fuels, are problems that require effective solutions that meet the energy needs of society in a sustainable manner. Fuel biomass, which includes energy crops and a wide range of municipal, agricultural and animal waste, serves as renewable resources for energy conversion processes in thermal energy conversion processes such as complete combustion and gasification. The use of biomass in the above mentioned processes does not increase the concentration of CO_2 in the atmosphere because biomass is a carbon neutral fuel resource. For combustion processes, it is advisable to use biomass with high calorific value and low ash content. Biomass with low calorific value results in poor and unstable combustion whereas biomasses with high ash content cause problems in burners and boilers due to the slag and dirt produced. Complete combustion and gasification of biomass with air have been deeply studied during the last decades [1-16].

The biomass gasification is a thermal process to produce syngas which can be an alternative solution since biomass is a neutral fuel in the production of CO_2 [10]. Additionally, biomass can also be used as fuel in combustion processes for power generation; however, these processes usually occur at high temperatures that favor the formation of NOx and SOx [17-19]. The use of biomass (energy crops, agricultural and municipal waste, etc.) as fuel in gasification processes for power generation not only alleviate the high demand for energy but also avoids pollution caused by fossil fuels and inadequate management of waste.

Materials & Methods

The biomass samples of corn straw were analyzed under ultimate and proximate analysis. Thus, preparation was performed under the ASTM D2013 standard for proximate analysis, which were carried out under the following standards: (ASTM D3302), (ASTM D3175/D7582), (ASTM D4239), (ASTM D3172), (ASTM 2492), (ASTM D5865). The elemental analysis of carbon, hydrogen, and nitrogen (ASTM D5373) as follows: (ASTM 2492), (ASTM D3174-12 / D7582-15). The results of these analyses are shown in Table 1.

Table 1: Proximate and Ultimate analysis on a dry basis.

Volatile material (%)	74.5
Fixed Carbon (%)	16.4
Ash	9.1
C (%)	48
H (%)	5
O (%)	43.5
N (%)	0.5
Empirical	$CH_{1.44}O_{0.78}N_{0.0103}S_{0.0027}$
Formula	
HHV (MJ/kg)	16
LHV (MJ/kg)	14.7

Then the software CEA (Chemical equilibrium and applications) provided by NASA was used to estimate the adiabatic composition of the species produced (about 150 species). This software makes use of chemical equilibrium libraries to calculate the molar fractions of the species generated by the process.

Results & Discussion

The empirical equation and the enthalpy of biomass formation can be determined using mass conservation and proximate and ultimate analysis. The results and the simulation parameters are presented in Table 1 and Table 2 respectively.

**Table 2:** Operating conditions for the model.

Parameters	
Fuel	Corn Straw
Pressure (atm)	1
Air Temperature (ºC)	25
Vapor Temperature (ºC)	100
ER	1,5-6
SF	0-1

The dry basis molar fraction vs. ER of the species produced and studied during the process is presented in Figure 1.

Figure 1: Effect of ER on the production of combustible gases. S:F=0.6.
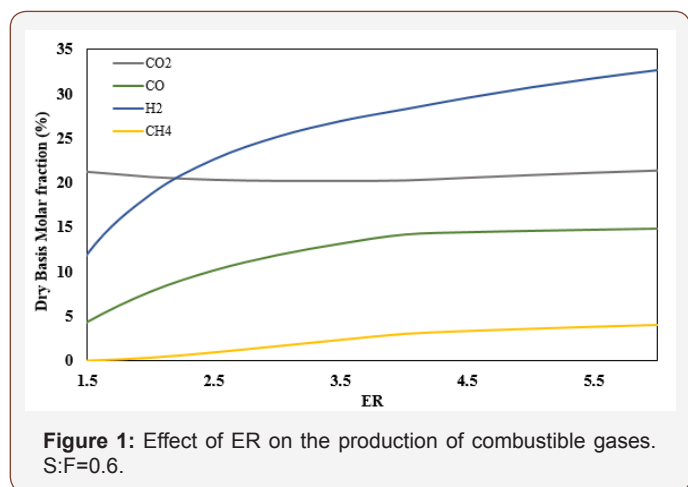
Figures 2 & 3 show the effect of ER and SF in the production of CO_2 and CO respectively. The CO_2 curves show a similar behavior for any SF value, but for ER values range (1-3), CO_2 concentration tends to decrease and for ER between 3-6, the production of CO_2

increases. The CO curves keep a similar shape for any SF, but for ER values from 1.5 to 2.5 they have a higher slope than that of those curves for ER values ranging (2.5-6).
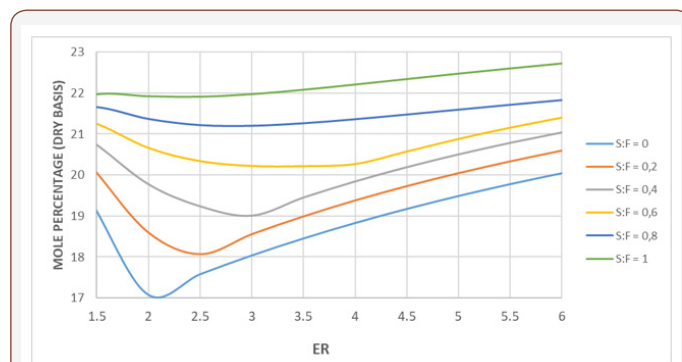
Figure 2: Effect of ER and SF on the production of CO_2.
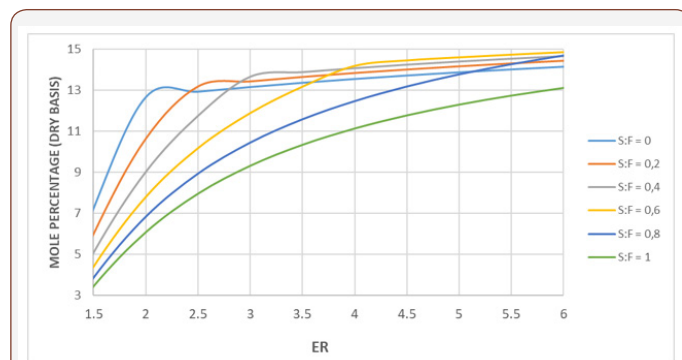
Figure 3: Effect of ER and SF on the production of CO.
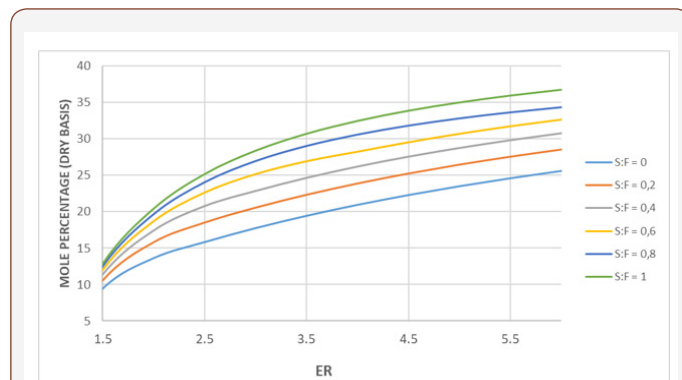
Figure 4: Effect of ER and SF on H_2 production.

The inflection points in Figure 2 indicate that for any ER points the effect of temperature on CO_2 production begins to be more important than the CO yield. The reaction $C + O_2 \rightarrow CO_2$ is favored at low temperatures while the reaction $C + 1/2\ O_2 \rightarrow CO$ is important at high temperatures [10]. Figure 4 shows the effect of ER and SF on the production of H_2. Increasing the ER for constant SF values, means more H atoms available for the C vapor reactions. As a result of this, H_2 production is increased while CO production tends to decrease especially at high ER. By increasing the SF maintaining the ER constant, the production of CO_2 and H_2 increases but the production of CO decreases. This is due to the fact that by increasing SF the gasification process occurs in an environment rich in H_2O that favors the reactions that produce mixtures rich in H_2 and CO_2. It can

be observed that the production of H_2 is more sensitive to changes of ER than that of SF. The calorific value of the gases is presented in Table 3 as a function of the ER and SF. As the ER increases, the HHV of the gases increases because of the increase of the production of H_2, CO, and CH_4. The gases produced at high SF are rich in H_2 which makes them very attractive from the environmental point of view since the combustion of H_2 produces heat and H_2O, i.e at SF= 0.8 and an ER=6, it is found the highest calorific value obtained in the gasification process.

Table 3: The calorific value of the combustible gases generated (KJ/m^3).

ER	SF					
	0	0.2	0.4	0.6	0.8	1
1,5	2060	2037	2021	2009	2000	1992
2	3472	3440	3389	3350	3319	3295
2,5	3869	4362	4412	4339	4281	4235
3	4225	4756	5214	5117	5028	4958
3,5	4548	5106	5580	5754	5634	5539
4	4841	5420	5904	6289	6139	6018
4,5	5108	5701	6191	6602	6566	6423
5	5353	5955	6447	6856	6934	6768
5,5	5578	6186	6678	7083	7255	7068
6	5785	6396	6886	7287	7537	7331

High values of ER (ER> 4) imply low oxygen supplied to the reactor therefore there is not enough oxygen for the combustion of fixed carbon (FC) and pure carbon begins to appear as a by-product. In other words, at ER> 4 the process tends to be pyrolysis that produces carbon, gases, and ash.

In general, mixtures rich in H_2 and CH_4 have a better conversion efficiency due to their high calorific values, compared with that of CO.

Conclusion

- To obtain mixtures of gases rich in hydrogen it is necessary to carry out the process in an environment rich in water vapor.

- The best conditions to obtain mixtures rich in hydrogen are with high values of the ER.

- In general, the production of different combustible gases is more sensitive to variations in the ER than to variations in the SF.

- To obtain a maximum calorific value and a higher HHV of corn straw, it is important to work with an ER 6 and an SF between 0.6 and 1.

Acknowledgment

Conflict of Interest

This manuscript has not been published and is not under consideration for publication elsewhere. Moreover, we declare having no conflicts of interest to disclose.

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