PLASMA-AIDED GASIFICATION OF BIOMASS STUDY OF A SELF-BLOWING GLIDARC

P. ESCOT BOCANEGRA*, J-M.CORMIER,

GREMI, PolyTech'Orléans, 14 rue d'Issoudun, BP 6744, 45067 Orléans Cedex 02, France
* pablo.escot@univ-orleans.fr

ABSTRACT

This paper talks about the plasma effect on different mixtures of oxygen and propane in a gas recirculation plasma reactor. In addition numerical results obtained from PFR simulation are used for discussion.. The plasma used in the reactor is made by three gliding atmospheric pressure arc discharges supplied independently by three direct current generators. The results show that the mixture composition influences the consumption of C_3H_8 and O_2 and the production of NO_x, CO and CO_2.

1.INTRODUCTION

There seems to be a general consensus that hydrogen may become "the fuel of the future". H_2 production from biomass is one of the most promising routes because of its CO_2 neutral character. The main goal of the research field is to optimize with a new approach the conversion of biomass (wood pellets) into biofuels to power engines or gas turbines (Combined Heat and Power). For that purpose, a unique two-stage set-up combining a gasification reactor (50kW) to a plasma reactor (3kW) was developed and used for the production of "clean" synthetic gas (syngas), and increase quality and amount of syngas produced.

The gasification reactor permits to convert the biomass pellets into gas with an exhaust flow rate between 30 and 40 $m^3.h^{-1}$and the plasma reactor acts as a purification stage by reducing tars production and simultaneously producing hydrogen rich syngas [1].

The main goal of research is to measure how the plasma can influence conversion of the gas mixture obtained from biomass gasification. To this aim, preliminary experiments are conducted with only gasification reactor to identify the chemical composition of the produced gases. Given the complexity of the mixtures (syngas, carbon dioxide, hydrocarbons, aerosols ...) from processing of biomass, we focused our study on the plasma conversion of hydrocarbons (C_3H_8) considered as representative molecules [2,3,4] and on the production of NO_x,CO and CO_2.

The mixtures composition investigated [O_2 (%) / C_3H_8 (ppm)] are respectively:
20 / 0;20 / 500; 20 / 1650; 5 / 1650.

Chemical analyses are performed online using temporal monitoring gas analyzer. The experimental chemical results are discussed using numerical simulation obtained with Plug Flow Reactor (PFR) with *GRI-Mech 3.0*.

2. EXPERIMENTAL SET-UP

The plasma reactor includes a particular fan that keeps constant the lengths of sliding discharges independently of the main stream; this why it is called "self blowing glidarc".

The plasma reactor is made of a ceramic tube with inside three peripheral electrodes and one in the center. This part of the reactor is placed in a vessel which permits gas recirculation (*Fig. 1*).

The plasma consists of three gliding arc discharges (*Fig. 2*) supplied independently by three direct current generators. The plasma reactor was supplied by sinusoidal high voltage generator (15 kV max, 2 A max).

In the experiments below the reactor operates in a closed loop, the input is directly connected to output. Propane is gradually converted by recirculation in the discharge. The inlet gas flow rate could be adjusted by using a high speed turbine together with gas recirculation in order to control the residence time of molecules in plasma that driving chemical conversions. The flow rate can be controlled by turbine frequency. The frequency range of 20 to 60 Hz permits to reach the reaction zone gas flow rate of 27 to 85$m^3.h^{-1}$ and gas velocity of 4 to 12 $m.s^{-1}$.

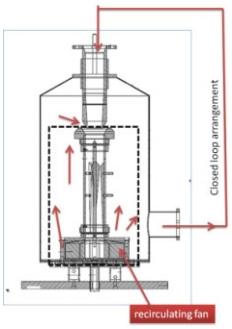

Fig. 1 Self blowing glidarc

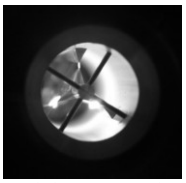

Fig. 2 Three gliding arc in plasma reactor

3. EXPERIMENTAL RESULTS

The experiments are performed with different gas mixtures consisting primarily of nitrogen and oxygen with a minor proportion of propane.
The turbine frequency is fixed at 30 Hz corresponding to gas flow rate of 42 $m^3.h^{-1}$ and gas velocity of 6 $m.s^{-1}$ in the plasma reactor (P=1atm). In these conditions a molecule remains in the reaction zone approximately 2 s when an experiment lasts 60 s. This flow rate is comparable to the exhaust flow rate of the gasification reactor (30-40 $m^3.h^{-1}$).
Figure 3 and 4 displays the consumption and the conversion rate of C_3H_8 as a function of time for different mixtures of O_2 and C_3H_8.
The figure 3 underlines that at the end of the experiment and whatever the mixture, the curves decrease to the same quantity of C_3H_8. It means that the plasma can't convert easily C_3H_8 when the limit of 250 ppm is reached. Moreover the content of O_2 doesn't influence the consumption of C_3H_8 before 50 s and then it's a very low difference.
These curves highlight two trends. First the conversion rate of C_3H_8 is higher for high content of C_3H_8 in the mixture. Then, decreasing the amount of O_2 in the mixture, increase the conversion rate of C_3H_8.
These trends have to be linked with Figure 5, which shows the consumption of O_2as a function of time for various mixtures of O_2 and C_3H_8.

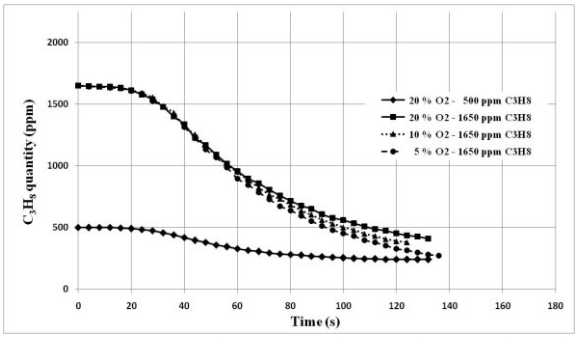

Fig. 3 C_3H_8 amount at the reactor outlet as a function of time for different mixtures

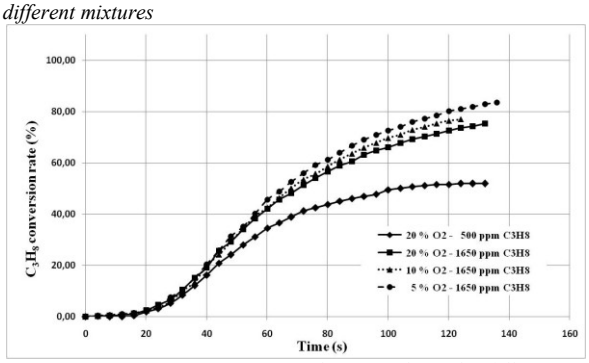

Fig. 4 C_3H_8 conversion rate as a function of time for different mixtures

As in figure 3, figure 4 emphasizes the same trends. After 10 s the consumption rate of O_2 increase with both the increasing amount of C_3H_8 and the decreasing amount of O_2 in the mixture. Moreover the consumption rate of O_2 is higher when the mixture is composed of O_2 and C_3H_8 and not only of O_2.

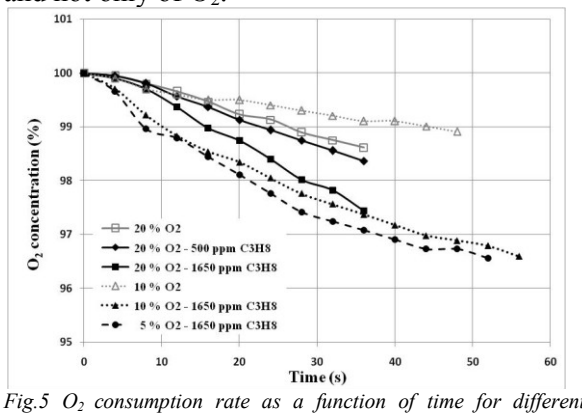

Fig.5 O_2 consumption rate as a function of time for different mixtures

Figure 6 shows the NO_x production versus time for various mixtures of O_2 and C_3H_8.
The NO_x rate production is more important when the quantity of O_2 increase in the mixture. But C_3H_8 do not influence the NO_x production because of the small amount of propane in air.
(Remarks concerning the simulation of this production will be done in the "simulation" section).

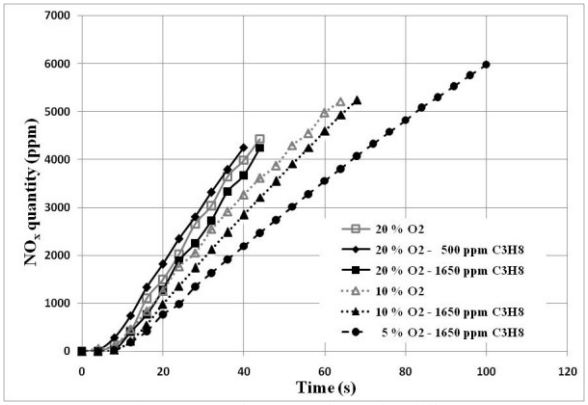

Fig. 6.NO_x production as a function of time for different mixtures

The CO production is directly function of the quantity of C_3H_8, the figure 7 reports the production of CO as a function of time for various mixtures of O_2 and C_3H_8.

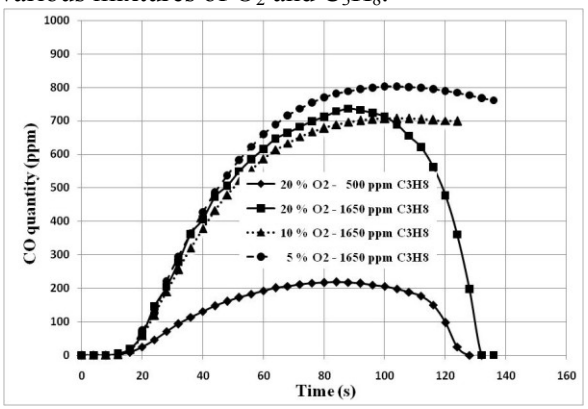

Fig. 7 Influence of O_2 and C_3H_8 initial quantity on CO production.

For 20% of O_2 in the mixture, CO increase to a maximum at 90 s and then decrease. The level of the maximum is function of quantity of C_3H_8, if the quantity of $C_3H_8$is higher, the value of the maximum will be higher too. For less quantity of O_2 in the mixture, the production of CO increase, stabilize and then decrease slowly. The figure 8 displays the production of CO_2 as a function of time for two amount of O_2.

Figure 8 demonstrates that the production of $CO_2$is similar whatever quantity of O_2 in the mixture.

Figure 9 represents the evolution of the main species CO, CO_2, C_3H_8 as a function of time for 20 % O_2 and 1650 ppm C_3H_8 in the mixture. The increasing quantity of CO is due to the decomposition of C_3H_8 and its oxidation into CO. Then the decreasing concerns oxidation of CO into CO_2.

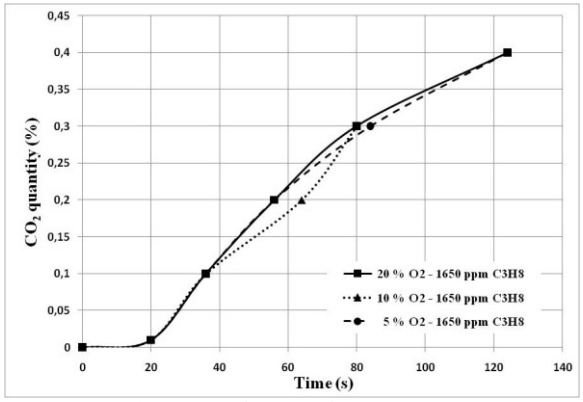

Fig. 8 CO_2 production as a function of O_2 quantity

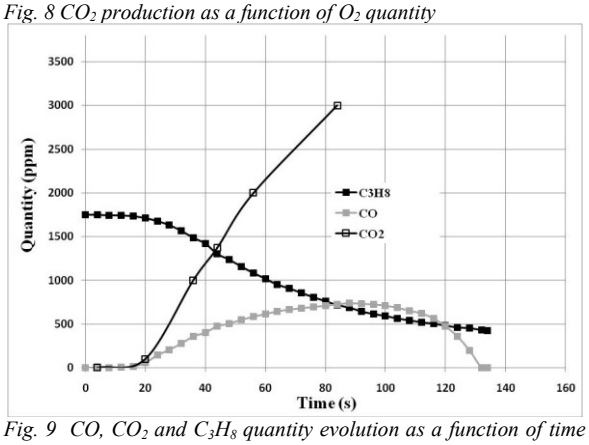

Fig. 9 CO, CO_2 and C_3H_8 quantity evolution as a function of time for 20 % $O_2$and 1650 ppm C_3H_8

4.**SIMULATION** RESULTS AND DISCUSSION

PFR simulation is performed using the "*Kintech-Lab-Kurtchatov"*chemical software called:*Chemical Workbench (CW).*

Fluid going through the PFR may be modeled as flowing through the reactor as a series of infinitely "plug", each with a uniform composition. As flow down the PFR, the residence time is a function of the plug position.

Concentrations obtained from "CW" are expressed as a function of the plug position. The total length of reaction (Lr) is corresponding to the residence time (τ) in the reactive zone. The time to cross reaction volume is corresponding to a conversion distance in the plasma zone.

Experimental concentrations are corresponding to a residence time after recirculation.

The parameters used to simulate the conversion of C_3H_8in PFR are: length (Lr) of 10 cm, cross-section of 19 cm^2, flow rate of 42 $m^3.s^{-1}$, admission gas temperature of 400K and reaction temperature of 1290 K (*GRI-Mech 3.0)*.

Figure 10 presents the simulation results for consumption rate of C_3H_8 versus distance for different mixtures.

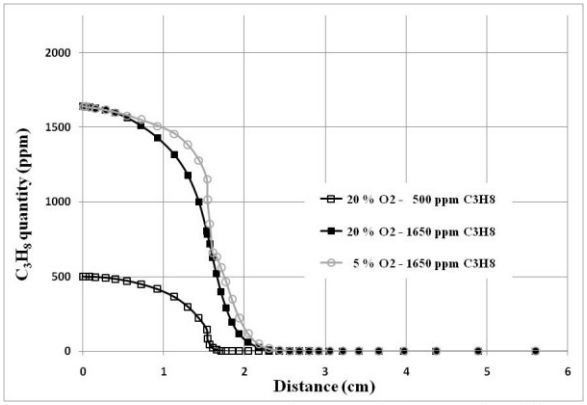

Fig. 10 Conversion rate as a function of distance for different mixtures

The quantity of O_2 in the initial mixture is not significant in these proportions to see an important effect on the C_3H_8 consumption.

TheC_3H_8 consumption is slightly delayed when the amount of oxygen decreases.The increasing C_3H_8 quantity in the initial mixture induces a modification on the conversion rate of C_3H_8 and on the distance of total conversion. If the amount of C_3H_8 decreases, both the conversion rate and the distance of total conversion of C_3H_8 will decrease. The same trends appear for experimental results in figure 3. Increasing the quantity of C_3H_8 in the mixture decreases the conversion rate and the time to reach the limit. The simulation with PFR is in accordance with our experimental results concerning the consumption trends of C_3H_8.

The figure 11 shows the evolution of the main species CO, CO_2, C_3H_8 and H_2 as a function of time for 20 % O_2 and 1650 ppm C_3H_8 in the mixture.

The concentrations evolution can be compared to the experimental ones shown in the figure 9.

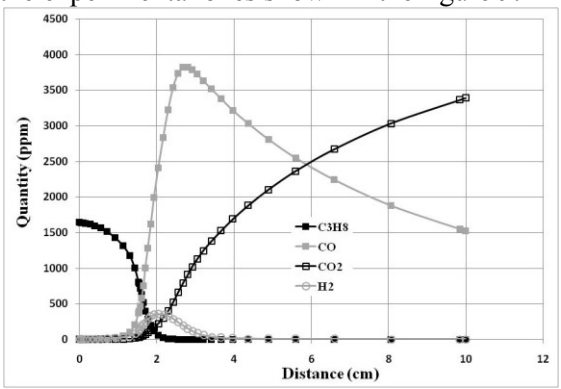

Fig. 11 CO, CO_2 and C_3H_8 quantity as a function of distance for 20 % O_2 and 1650 ppm C_3H_8

The trends of the curves are similar in both figures. In PFR simulation, the CO produced is higher than CO_2. Quite the reverse, in the experiment CO produced is lower than CO_2. The explanation lie to conversion of C_3H_8, total for the PFR and not for experiment. During experiment not enough $C_3H_8$is converted to increase the quantity of CO and at the same time the quantity of CO_2 increase. The production of H_2 is possible on a short distance with a low production. It should be noted additionally that the mechanism is not suitable for simulation of NOx production.

The analysis of all species produced from the GRI-Mech mechanism shows that intermediate species appear which are later oxidized. This is the case of $H_2$and C_2H_4. The analysis of more extensive experimental results will help validation of simplifying modeling assumptions and also to improve the model by introducing pla*sma specificities.*

5. CONCLUSION

Experiments demonstrate that plasma converts C_3H_8 mainly into CO and CO_2 and H_2O. Simplified simulation allows to highlight generation of many other species, and specially hydrogen. These species will be targeted in future trials to improve the plasma reactor model. In case of experiments with gasifier and plasma coupling, heavy molecules must be converted. Chemical kinetics of these molecules is clearly very different from that of propane. However, experiments with propane are a very useful reference to verify the proper functioning of the plasma reactor. These tests should also allow further modelling of the plasma reactor which is difficult in case of heavy hydro carbons and specially molecules obtained from biomass treatment.

REFERENCES

[1] J. Luche, Q. Falcoz, T. Bastien, J.P. Leninger, K. Arabi, O. Aubry, A. Khacef, J.M. Cormier and J. Lédé. "Plasma treatments and biomassgasification". IOP Conf. Ser.: Mater. Sci. Eng. 29 01 2011

[2] J. Luche, O. Aubry, A. Khacef, J. M. Cormier. "Syngas production from methane oxidation using a non-thermal plasma: Experiments and kinetic modeling", Chem. Eng. J., (2008).

[3] O. Aubry, J.M. Cormier."Improvement of the diluted propane efficiency treatment using a non-thermal plasma". Plasma Chemistry and Plasma Processing, 29 (1), 13, 2009

[4] A. Khacef, K. Arabi, O. Aubry, J.M. Cormier, IEEE Transactions on Plasma Science, 39 (11), 2914-2915 (2011)