Production of Synthetic Gas (Syngas) by Gasification Process of Biomass

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Abstract: - **In a context of sustainable development challenges of our century. Improving the living comfort is inevitably accompanied by a significant increase in energy requirements. Thus there has been a steady growth in global energy demand. Given the depletion of fossil fuel resources and environmental problems caused by their consumption, the use of alternative energy sources is essential in order to continue to meet the growing energy demand and preserve the environment. New technologies based on renewable energy sources will be inducedto take a place of importance in energy production. The biomass sector because of the importance of its feedstock is considered as a promising way in the future. The biomass in relation to other renewable energies has a very flexible use in power generation plants; it is not dependent on weather conditions. The biomass resource is very diverse: it can come from energy crops industrial and agricultural solid wastes. The gasification of biomass is a thermochemical treatment that converts to carbonaceous solid into a combustible gas mixture, known as synthesis gas (syngas) containing hydrogen, carbon monoxide and methane. The aim of this work is to valorize the solid waste of agriculture, industry and households. The results showed that we can turn this waste into a synthesis of gas and fuel power stations by IGCC(Integrated Gasification Combined Cycle) for electrical energy production.**

Keywords: **Biomass, gasification, combustion, recovery of solid wastes**

I. INTRODUCTION

With the increasing concern about the decline in energy production and the protection of the environment, research into clean alternative fuels has drawn in recent years the attention of scientists and engineers [1]. In addition, increasingly stringent regulations on CO_2 emissions on the one hand and the depletion of fossil fuel reserves on the other hand, pushed the scientific community to find alternatives to these fuels. Indeed, the increase in the car fleet has led to an increase in the consumption of conventional fuels responsible for the continuous rise in pollutant emissions (carbon monoxide, unburned hydrocarbons, nitrogen oxides and particulates) and greenhouse gases greenhouse (GHG) [2]. During the 21st century, the biofuel economy will grow rapidly. In themodernized biomass energy contributes by 2050 about one half of total energy demand in developing countries [3].By 2020, the European Union has the goal to share a 10% of biofuels in the transport industry [4]; but by 2022 in the US, biofuels production is anticipated to reach 36 billion gallons [5]. Research in the fields of fuel quality and combustion will lead to a progressive reduction of pollutant emissions, increased protection of the environment and an improvement of the living environment. The use of biomass, a renewable resource and a balance sheet practically neutral from the point of view GHGs, is one of the most promising routes for replacing energy in the future fossils (petroleum, coal, gas, uranium,) [6]. Biomass can be converted into liquid and gaseous fuels through thermochemical and biological routes. Biofuel is a less-polluting, locally available, accessible, sustainable and reliable fuel obtained from renewable sources [7]. The thermochemical conversion (gasification) of vegetable raw materials (wood, straw, plants, herbaceous plants, household and industrial waste, agricultural waste ...) into a synthesis gas is possible through the use of gasifier. The gas of Product synthesis contains a significant proportion of hydrogen and carbon monoxide. The valorization of this gas is mainly done today in the cogeneration units, but the coupling possibilities with fuel cells or biofuel synthesis reactors by the Fischer Tropches process suggest a bright future for this sector [8].Gasification process occurs at temperatures between 1112º and 2732º F to produce a gas depending upon the process type and the operating conditions. Many different studies are underway to develop biomass gasification technologies to produce organic chemicals, hydrogen and ethanol for use as a transportation fuel in trucksand cars [9].

Guan et al. [10] investigated the gasification process of algae nanochloropsis in a supercritical water. The results showed that increasing the gasifier temperature leads to produce more carbon dioxide. In addition by reducing the gasifier operating temperature, the CO_2 mole fraction decreases and the quality of the produced synthetic gas was low. Yakaboylu et al. [11] reported the same trend in the gasification process of the dry starch as a biomass. Modelling of the biomass gasification process with supercritical water and thermodynamic assessment were conducted by Withag et al. [12]. The different components in gaseous products from the gasification process has been a popular subject of research. This is because carbon-containing fuels like biomass that have a different compositions of glucose, cellulose, lignin, glycerol, and phenolic [13-15].In this study, the simulation of a biomass-air gasification reactor was developed using of the software (EES-Equation Engineering Solver) using a model based on equilibrium thermodynamic. The calculation of thermodynamic equilibrium is independent of the design of

the gasifier and is therefore ideal for studying the influence of the nature of biomass and the conditions of operation on the performance of the gasifier. The chemical equilibrium is determined either by the equilibrium constants or by minimizing the Gibbs free energy. In the modeling of thermodynamic equilibrium, it is assumed that the biomass is dry and ashless, and contains the atoms C, H, O and N. Sulfur is not considered because biomass contains a quantity negligible for this species compared to carbon.

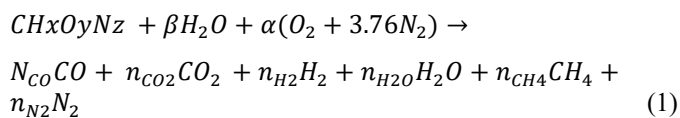## II. MODELING THE GASIFICATION OF BIOMASS

The gasifier simulation models can be classified as follows:

- Thermodynamic equilibrium.
- Chemical kinetics.
- Mechanics of digital fluids.
- Neural networks.

In this study the mathematical formulation of the thermodynamic equilibrium model is based on the following assumptions:

- The gasification process is considered adiabatic and stationary.
- The model is global and does not take into account axial and radial variations in temperature.
- The nitrogen present in the fuel or in the air is inert.
- Ashes are inert.
- Gaseous species from gasification are considered perfect gases.
- All reactions are in thermodynamic equilibrium.
- The gases are in equilibrium during flow through the coal bed.
- The pressure in the coal bed is atmospheric and constant.
- No gas is accumulated in the coal bed.
- There is no tar in the gasification zone.
- Carbon is converted to 100% CO and CO_2.
- The product gas includes only the following species: CO, H_2, CH_4, CO_2, H_2O, and N_2.

The chemical formula of biomass is given by $CH_xO_y\,N_z$ where x, y and z represent the numbers of oxygen atoms, hydrogen and nitrogen in the biomass corresponding to a single carbon mole. The global gasification reaction of biomass with air is given by[16, 17]:

$$CHxOyNz + \beta H_2O + \alpha(O_2 + 3.76N_2) \rightarrow$$
$$N_{CO}CO + n_{CO2}CO_2 + n_{H2}H_2 + n_{H2O}H_2O + n_{CH4}CH_4 + n_{N2}N_2 \qquad (1)$$

Where are the numbers of moles of air and water supplied per mole of fuel introduced into the gasifier respectively,

The main reactions that occur inside the reactor are as follows:

$$CO + H_2O \rightarrow CO_2 + H_2 \qquad (2)$$
$$C + 2H_2 \rightarrow CH_4 \qquad (3)$$

The equilibrium constants of these reactions are given by:

$$K_1 = \frac{P_{CO2}\,P_{H2}}{P_{CO}\,P_{H2O}} = \frac{n_{CO2}\,n_{H2}}{n_{CO}\,n_{H2O}} \qquad (4)$$

$$K_2 = \frac{P_{CH4}}{P_{H2}^2} = \frac{n_{CH4}\,n_{tot}}{n_{H2}^2} \qquad (5)$$

With

$$n_{tot} = n_{CO} + n_{CO2} + n_{H2} + n_{H2O} + n_{CH4} + n_{N2} \qquad (6)$$

The determination of these six unknowns (nH_2, nCO, nCH_4, nCO_2, nH_2O, nN_2) requires the writing of four other conservation equations of atoms.

$$C:\ n_{CO} + n_{CO2} + n_{CH4} = 1 \qquad (7)$$
$$H:\ 2n_{H2} + 2n_{H2O} + 4n_{CH} = x + 2\beta \qquad (8)$$
$$O:\ n_{CO} + n_{H2O} + 2n_{CO2} = y + \beta + 2\alpha \qquad (9)$$
$$N:\ 2n_{N2} = 2 * 3.76\alpha \qquad (10)$$

The equilibrium temperature reached inside the adiabatic reactor is determined from the conservation equation of energy.

$$H_{bio}^f + \beta \Delta H_{H2O}^v = N_{H2}H_{H2} + n_{CO}H_{CO} + n_{CH4}H_{CH4} + n_{CO2}H_{CO2} + n_{H2O}H_{H2O} + n_{N2}H_{N2} \qquad (11)$$

The first member of the equation represents the enthalpy of the products introduced into the reactor at the reference temperature of 298 K and the second member represents the enthalpy of the products of reaction. The set of equations from (4) to (11) represents a system of nonlinear equations comprising eight equations with eight unknowns (nH_2, nCO, nCH_4, nCO_2, nH_2O, nN_2). The resolution of this system is done automatically using the EES software that uses the residue method. The upper and lower heating value of the fuel determined as follows [1]:

$$P_{cs} = 0.3491 * \%C + 1.1783 * \%H - 0.1034 * \%O - 0.0151 * \%N \quad [\tfrac{MJ}{kg}] \qquad (12)$$

$$P_{ci} = P_{cs} - 9Y_H L_{H2O}^v \quad [\tfrac{MJ}{kg}] \qquad (13)$$

Complete and stoichiometric combustion gives off a heat of reaction equivalent to P_{ci} of fuel (biomass), therefore the enthalpy of fuel formation is equal to

$$\Delta H_{bio}^f = P_{ci} * M_{bio} + \Delta H_{CO}^f + \tfrac{x}{2} * \Delta H_{H2O}^f \qquad (14)$$

The equilibrium constants of reactions 2 and 3 are determined from the variation of enthalpy free from these reactions.

$$Ln\ (K_1) = -\frac{\Delta G_0^1}{RT} \quad ; Ln\ (K_2) = -\frac{\Delta G_0^2}{RT} \qquad (15)$$

$$\Delta G_0^1 = \Delta H_0^1 - T * \Delta S_0^1 \quad ; G_0^2 = \Delta H_0^2 - T * \Delta S_0^2 \qquad (16)$$

$$\Delta H_0^1 = H_{CO2}^0 + H_{H2}^0 - H_{H2O}^0 - H_{CO}^0 \ ; \ \Delta H_0^2 = H_{CH}^0 - 2 * H_{H2}^0 \qquad (17)$$

$$\Delta S_0^1 = S_{CO}^0 + S_{H2}^0 - S_{H2O}^0 - S_{CO}^0 \ ; \ \Delta S_0^2 = S_{CH}^0 - 2 * S_{H2}^0 \qquad (18)$$

The determination of the temperature reached inside the reactor is given by the following equation:

$$\Delta H_{bio}^f + \beta \Delta H_{H2O(g)}^f = \sum_{i=1}^{i=6} n_i H_i \qquad (19)$$

III. RESULTS AND DISCUSSIONS

This section presents the effect of humidity, moisture content and excess air on the produced fuel (syngas) and the calculations were made for solid waste. The mass composition of solid waste is shown in Table (1):

Table 1. Mass composition of fuel CH 1.5932 O 0.5758 N 0.0444

Element	Y k mass fraction%
VS	51.22
H	6.80
O	39.32
NOT	2.60

The coefficients α and β of the overall reaction (1) are deduced from the moisture content mc and from the excess air m according to the following relationships:

$$\alpha_{stoe} = \left(1 + \frac{x}{4} - \frac{y}{2}\right) \quad ; \alpha = m * \alpha_{stoe} \ ; \beta = \frac{M_{bio}}{18} * \frac{m_c}{m_c - 1}$$

$$x = 1.5932 \ ; y = 0.5758 \ ; z = 0.0444$$

3.1 Study the combined effect of moisture content and excess air

Fig.2 shows the combined influence of moisture content and excess air on the fuel (syngas) produced. The increase in the moisture content in the fuel makes considerably reduce the PCI and the temperature because the liquid water passes to the vapor state by absorbing a considerable amount of energy. The same evolution is noticed as regards the increase of the excess of air which reduces the PCI because the quantities of CO, H_2, CH_4 produced decrease more and more in favor of CO_2 and H_2O. Figure 3 shows, on the other hand, an increase in temperature at the high values of excess air, because we are closer to stoichiometry[18-20].

Figs. 4, 5 and 6 show that the molar fractions of CO, H_2 and CH_4 respectively. From these figures it can be noticed that increasing the excess air leads to decrease the molar fractions of CO, H_2 and CH_4. This occurs because we are getting closer and closer to stoichiometry and the other products of the combustion such as CO_2 and H_2O become more and more prominent. The goal sought by the gasification is to produce a synthesis gas (syngas) rich in CO and H_2, for this it is preferable to operate in a lean mixture. The increase in the moisture content and consequently the amount of hydrogen contained in the water contained in the biomass, favors the formation of a large quantity of water in the gases burned at the expense of combustible gases (H_2 and CO). For methane evolution is opposite because the increase in the amount of hydrogen (moisture content) raises the percentage of methane contained in the flue gases.
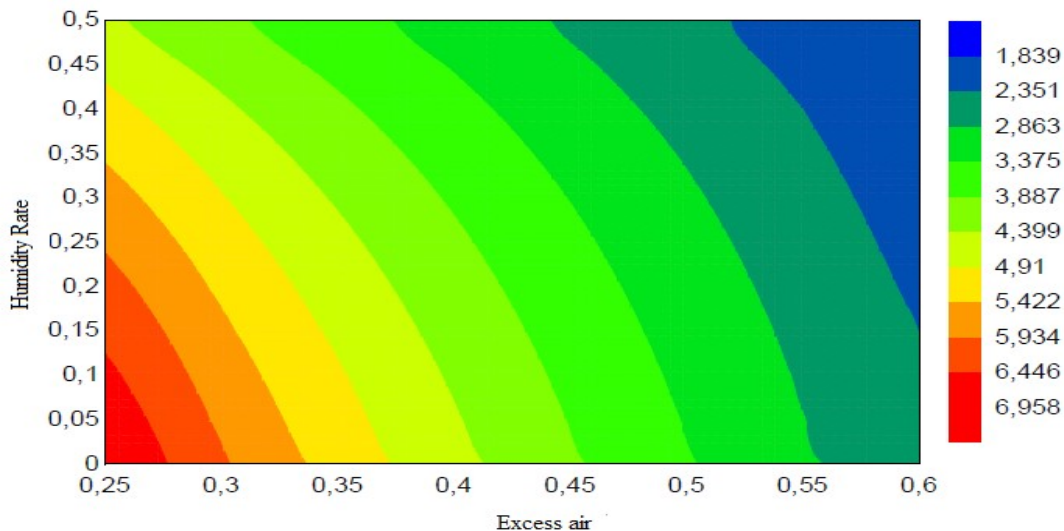
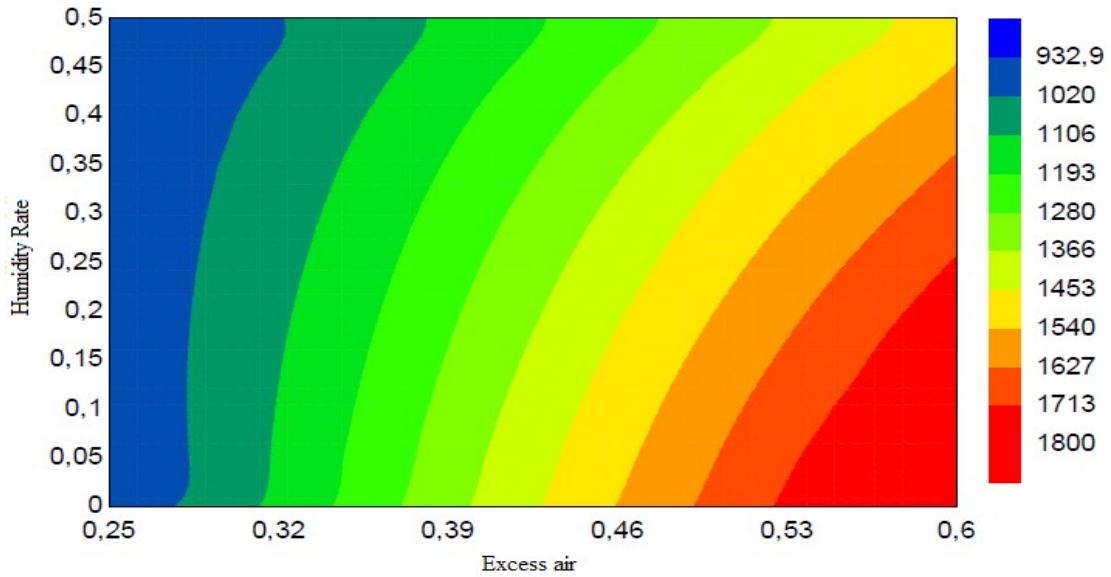

Fig. 2. Lower calorific value of syngas produced in MJ/Nm^3

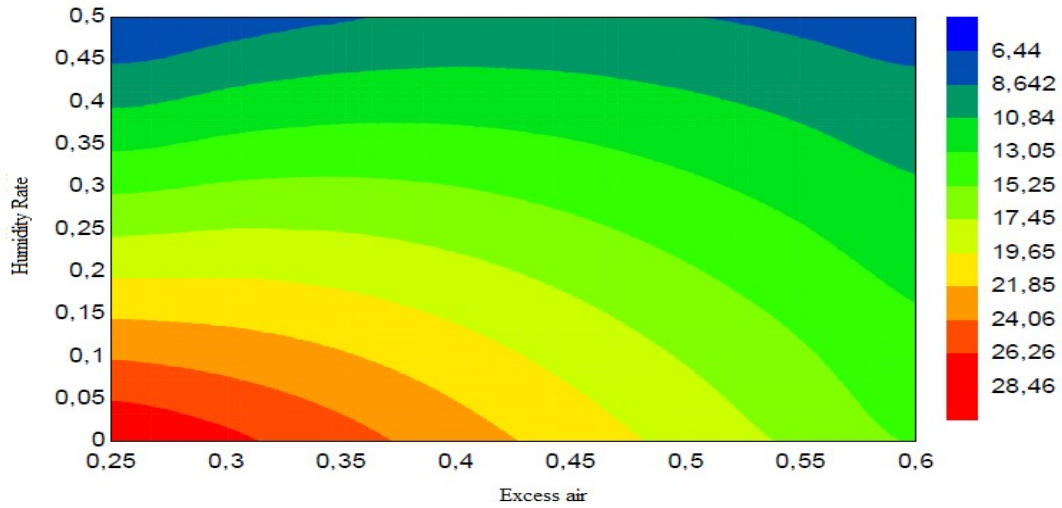Fig. 3. Adiabatic temperature reached in the reactor
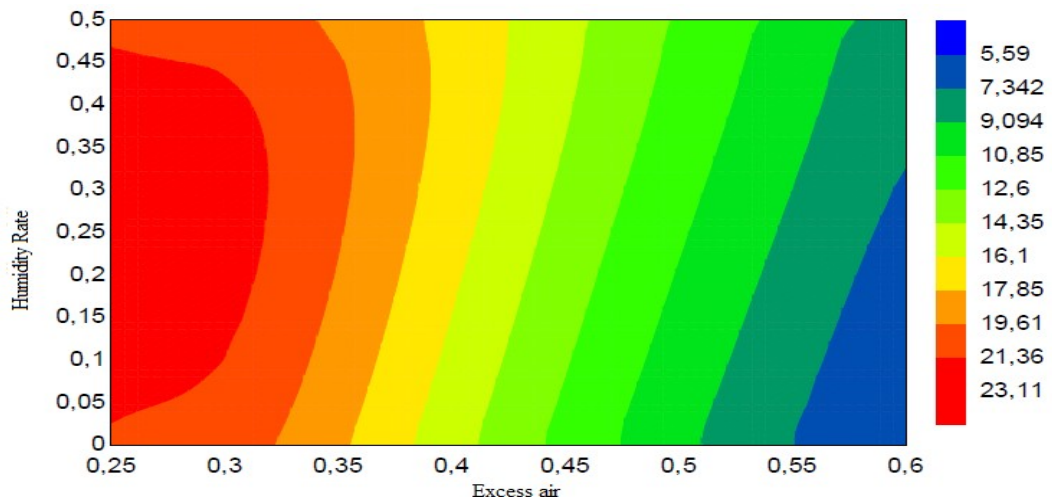

Fig. 4. Molar fraction of carbon monoxide CO

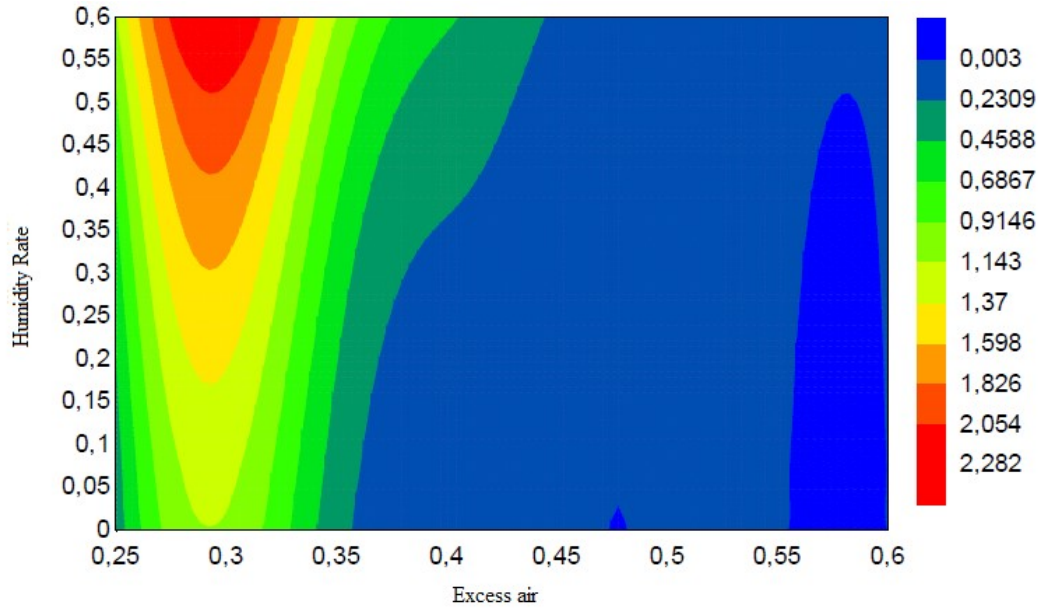Fig. 5. Molar fraction of H_2 hydrogen

Fig. 6. Molar Fraction of CH_4 Methane

3.2 Study the effect of humidity

Synthetic gas with good energy qualities can only be obtained with low proportions of the moisture content, because according to Figs. 7 and 8 the proportions of carbon monoxide and hydrogen is important for low humidity levels. This is possible using the drying techniques to reduce the significant quantities of water contained in the virgin biomass. In addition, as shown in Fig. 8, from 0 to 50% of moisture, about 300°C is lost temperature inside the fireplace and about 50% in PCI. So the optimal operating zone is therefore located towards the low values of the humidity rate.
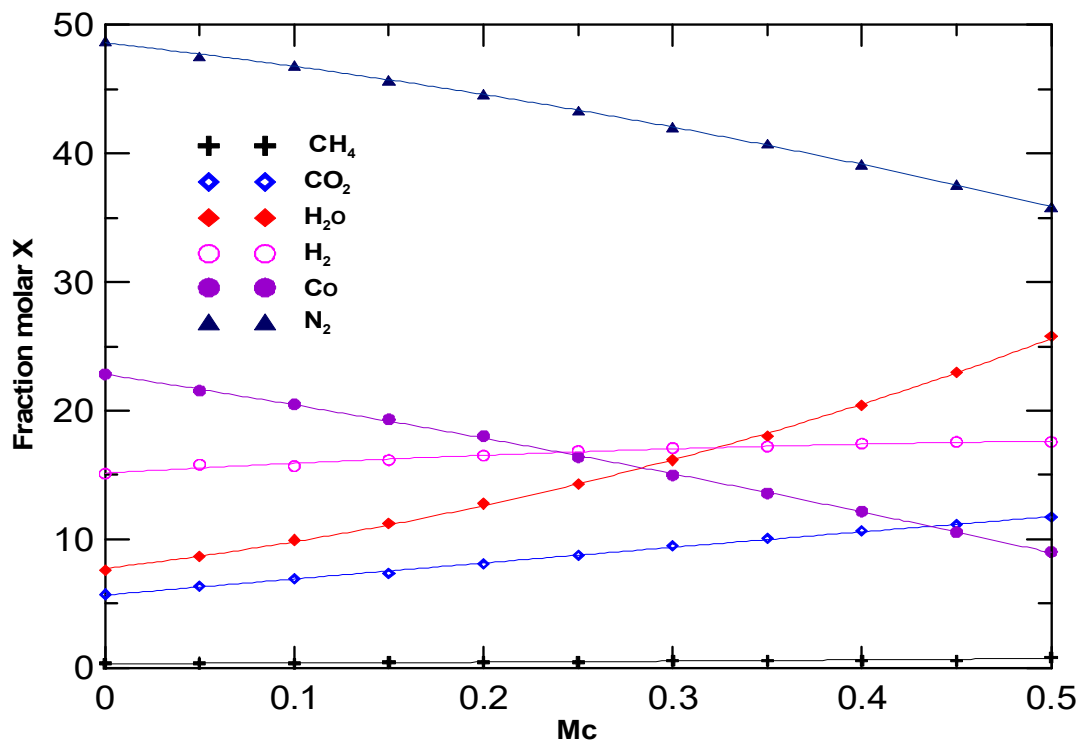

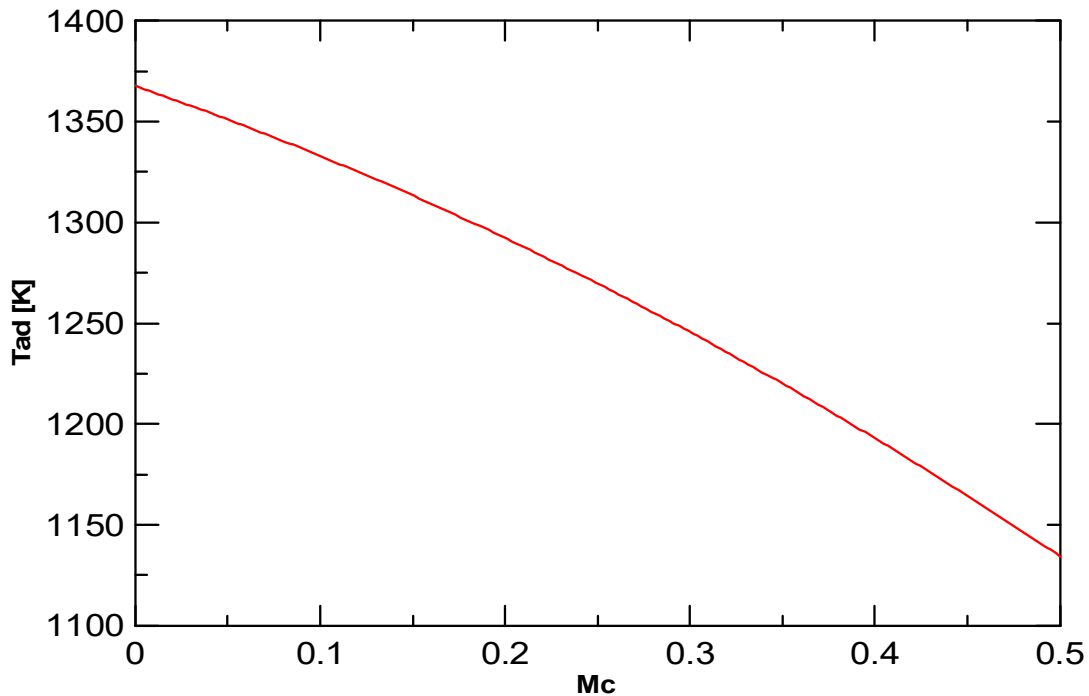Fig. 7. Evolution of the molar fractions of flue gases for m = 0.4

Fig. 8. Evolution of the adiabatic reactor temperature for m = 0.4

3.3 Study the effect of excess air

Increasing the excess air, although it increases the adiabatic temperature inside the gasifier, but it reduces the proportions of gases that form the synthesis gas. The area optimum operation would then be in an area with a moisture content of about 30% and an excess of air of the same order of magnitude. From Figs. 9 and 10,it is clear that the reduction of the moisture content by the drying technique will cost increasingly expensive compared to the expected gain of gasification synthesis gas production biomass from the economic point of view.
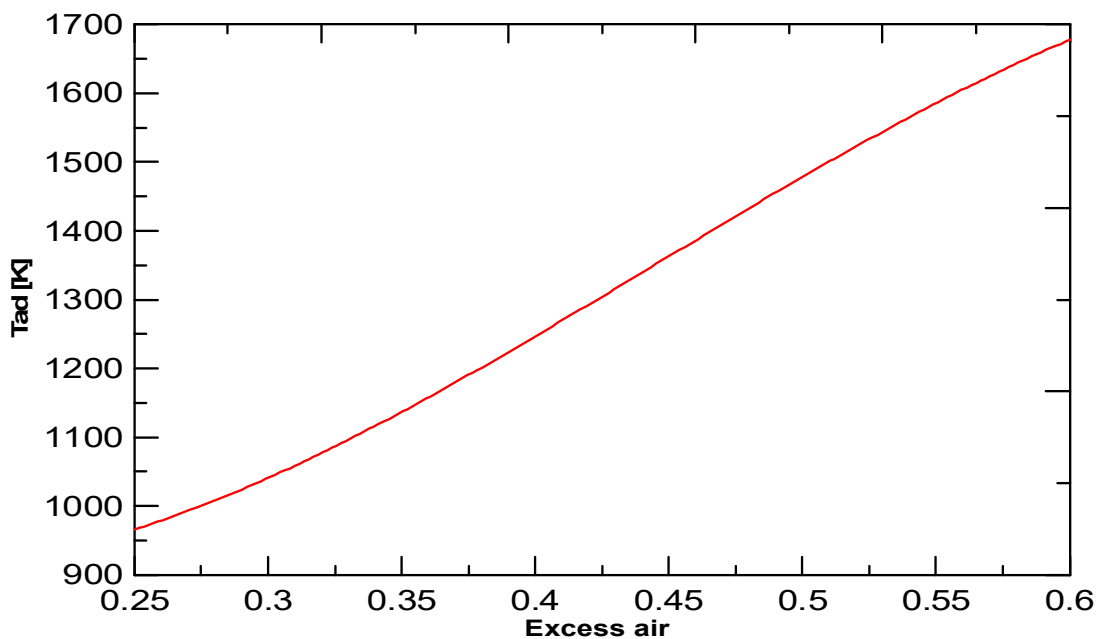

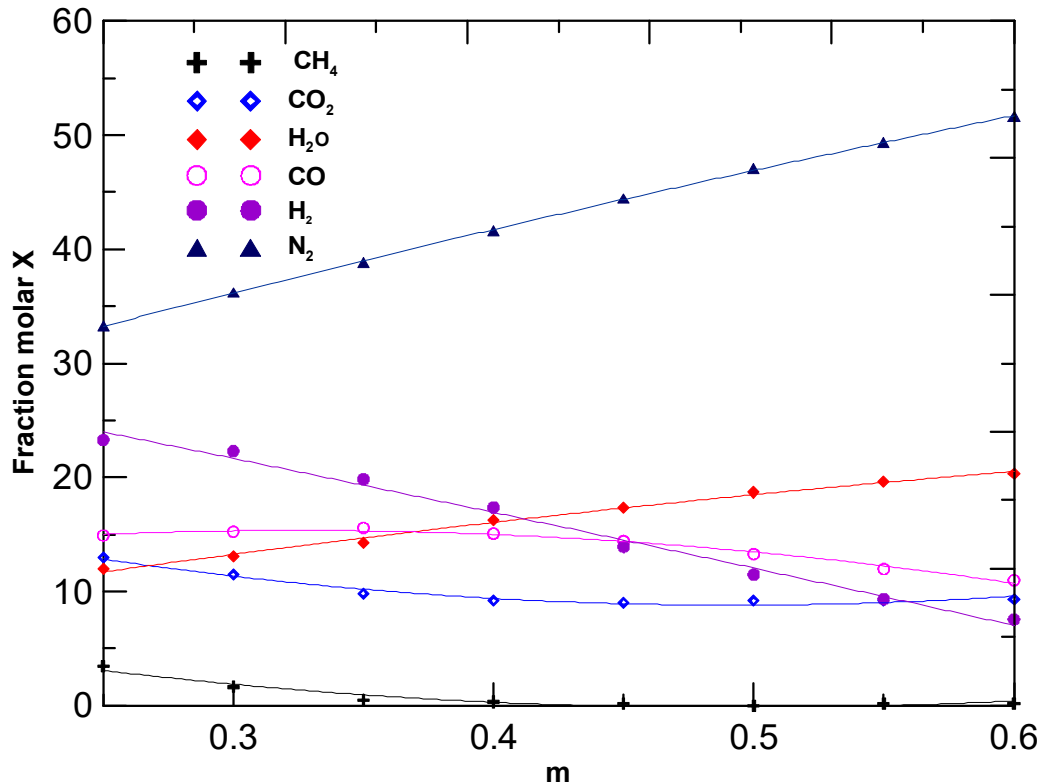Fig. 9. Evolution of the adiabatic reactor temperature for mc = 0.3

Fig. 10. Evolution of the molar fractions of the flue gas for mc = 0.3

IV. CONCLUSIONS

In a context of sustainable development, controlling global energy consumption is one of the major challenges of our century. The improvement of the comfort of life is accompanied ineluctably a significant increase in energy needs. In this way, we record steady growth in global energy demand. With regard to the depletion of resources fossil fuels and environmental problems caused by their consumption, the use of alternative energy is essential to continue to meet the demand constantly growing and preserving the environment. New technologies based on energy sources renewables will have to take a more and more important place in the production of energy.The biomass sector because of the importance of its deposit is considered a pathway promising in the future. Biomass with respect to other renewable energies, presents a very flexibility because it does not depend on weather conditions. The biomass resource is highly diversified: it can come from energy crops, by-products of the wood, industrial solid waste and agriculture.The gasification of biomass is a thermochemical treatment that converts a carbonaceous solid into a fuel gas mixture called syngas (synthesis gas) containing hydrogen, carbon monoxide and methane. The aim of the work is to valorize the solid waste coming from agriculture, industry and households. The results obtained show that we can transform this waste into syngas and feed IGCC (Integrated Gasification Combined cycle) for the production of electrical energy.According to the results

obtained, the nitrogen contained in the air is heated unnecessarily during the gasification reaction, the operation with oxygen would make it possible to improve the efficiency of gasification by omitting to heat the inert gases. The optimal area of functioning is in the zone of low values of the moisture content and for excessive of the order of 30%. In perspective an experimental study is launched for the realization of a prototype of gasifier for the production of synthesis gas and its subsequent transformation into Fischer-Trophces technique in second generation fuel.

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