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EVALUATION OF SPECIES BEHAVIOR IN A REDUCTION ZONE OF A FLUIDIZED BED BIOMASS GASIFIER IN STATIONARY STATE

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Abstract. *Gasification is a thermal process that produces gas, tar and char in a low oxygen environment. Steam can be used in the process. Tar and char suffer secondary reactions that produce the main products, hydrogen and carbon monoxide (Syngas). The Syngas fed a turbine-combined cycle in order to generate electric energy efficiently. Fluidized bed reactors have been used as gasifiers. Their advantages are: good gas solids contact, excellent heat transfer characteristics, better temperature control, large heat storage capacity, the high conversion efficiency and the quality of the gas produced. Sugarcane bagasse is a residue from the sugar and alcohol industries in Brazil. For this reason, it is widely used as fuel in gasification. However its low mass density cause feeding problems, then the fuel must be compacted in briquettes. Briquettes are more homogeneous and its mass density increases. In this paper, fluidized bed biomass gasifier presents a gaseous and a solid phase in countercurrent. The aim of this study was to develop a 1 dimensional stationary state model capable of describing the species concentrations in reduction zone (C, CO, H_2O, H_2 and CO_2). The model is based in species balance equations of each component. Successive over-relaxation method was used to solve the second order ordinary differential equations system.*

Keywords*: over-relaxation, fluidized bed, gasification, biomass, sugarcane bagasse.*

1. INTRODUCTION

The increasing energy demand cause several problems to environment and serious energy crisis. Fossil fuel burning releases toxic gases, CO_2, SO_2, NO_x, which causes global warming and acid rain. For this reason, several hydrogen production processes have been studied.

Hydrogen sources must be renewable, sustainable, efficient and insured. With this in mind, biomass gasification seems to be a promising process for producing energy, because it offers more attractive options for medium to large scale applications and it is a more friendly way of using biomass for energy purposes (Franco *et al.*, 2003). Biomass is the most important source of energy in developing nations, providing 35% of their energy (Dermibas *et al.*, 2004).

Carbon from biomass in the steam and oxygen (air) presence is converted to synthesis gas, a mixture of carbon dioxide and hydrogen. The weaker chemical bonds are breaking in the first gasification stage, named devolatilization, yielding tars, oils, phenols, and hydrocarbon gases. These products react to form hydrogen, monoxide carbon and dioxide carbon. The remainder fixed carbon in feedstock reacts with the oxygen and steam to produce the final gas (Stiegel and Ramezan, 2006).

Under normal conditions Brazil annually produces and processes more than 300 million metric tons of sugarcane which corresponds a quarter of the 1300 million tons grown worldwide in more than 100 countries (Hassuani *et al.*,

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2005). Sugarcane residues is used as fuel to satisfy the heat and electricity demand of the processing, however the process do not show economic feasibility.

The BIG/GTCC- technology (biomass integrated gasifier/gas turbine-combined cycle) offers a higher electric efficiency and a higher electricity-to-heat ratio than direct combustion steam turbine systems (Gómez *et al.*, 1999). Fluidized bed reactor is the reactor used in this case. This reactor has several advantages like: good gas solids contact, excellent heat transfer characteristics, better temperature control, large heat storage capacity, the high conversion efficiency and the quality of the gas produced (Sadaka *et al.*, 2002).

The aim of the study was to develop a 1 dimensional stationary state model capable of describing the species concentrations in reduction zone (C, CO, H_2O, H_2 and CO_2) and then calculate the better reactor length.

2. MATHEMATICAL MODEL DESCRIPTION

Mass balance can express the species behavior in the reduction zone length satisfactorily. The mathematical model obeys the following assumptions: isothermal process, one-dimensional model and steady-state operation.

Gaseous components

$$D_{\beta,mix}\frac{d^2c_\beta}{dz^2}-\frac{Q_g}{A_S}\cdot\frac{dc_\beta}{dz}+R_\beta=0 \tag{1}$$

Boundary Conditions:

$$D_{\beta,mix}\frac{dc_\beta}{dz}\Big|_{z=0^+}=\frac{Q_g}{A_S}\left(c_\beta\Big|_{z=0^+}-c_\beta\Big|_{z=0^-}\right) \tag{2}$$

$$\frac{dc_\beta}{dz}\Big|_{z=L}=0 \tag{3}$$

Solid components (Carbon):

$$D_{C,mix}\frac{d^2(c_C)}{dz^2}-\frac{F_S}{A_S}\frac{d(c_C)}{dz}+3\frac{RT}{P}R_C=0 \tag{4}$$

Boundary Conditions:

$$D_{C,mix}\frac{d(c_C)}{dz}\Big|_{z=0^+}=\frac{F_S}{A_S}\cdot\left[(c_C)\Big|_{z=0^+}-(c_C)\Big|_{z=0^-}\right] \tag{5}$$

$$\frac{d(c_C)}{dz}\Big|_{z=L}=0 \tag{6}$$

Where D is the diffusivity of each component, A_S is the reactor surface area (m^{-1}), c is the species concentration ($mol.m^{-3}$), Q_g inlet gas flow ($m^3 s^{-1}$), F_S is the solid flow rate ($kg\ s^{-1}$), R is the gas constant $\left(atm\,m^3\,(mol\cdot K)^{-1}\right)$, R_i is the overall reaction rate and z the cartesian coordinate (m).

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3. KINETIC DESCRIPTION

In the Table 1, the corresponding rates for each one of the reactions in reduction zone were presented:

Table 1: Reaction kinetic rates

Reaction	Reaction Rate	Reference
$C + H_2O \rightarrow CO + H_2 \quad \Delta H = -131kJ/mol$ (7)	$r_1 = k_1 c_{H_2O}$	-
$CO + H_2O \rightarrow CO_2 + H_2 \quad \Delta H = +41kJ/mol$ (8)	$r_2 = k_2 c_{CO}\ ;\ k_2 = 10^6 \exp\left(-\frac{6370}{T}\right)$	(Corella and Sanz, 2004)
$C + CO_2 \rightarrow 2CO \quad \Delta H = -172kJ/mol$ (9)	$r_3 = k_3 c_{CO_2}\ ;$ $k_3 = 10^{-3} \times 4364 \times \exp\left(\frac{-29844}{T}\right) F_P$	(Chen *et al.*, 2001)

Fp is the specific internal surface area of the char (Chen *et al.*, 2001).

The total consumption and formation rates, R_i, for each component can be obtained using the equation follow (Xiu *et al.*, 2002):

$$R_i = \sum_{n=1}^{3} \upsilon_{in} r_n \tag{10}$$

Where, υ_{in} is the stoichiometric coefficient of compound *i* in the *n*th reaction. If υ_{in} refers to reactants, υ_{in} is negative, and for a product υ_{in} is positive. Then the overall reaction rate of each species is given to:

$$R_{CO} = r_1 - r_2 + 2r_3 \tag{11}$$

$$R_{H_2} = r_1 + r_2 \tag{12}$$

$$R_{H_2O} = -r_1 - r_2 \tag{13}$$

$$R_{CO_2} = r_2 - r_3 \tag{14}$$

$$R_C = -r_1 - r_3 \tag{15}$$

4. NUMERICAL METHODOLOGY

The differential equations, with the total consumption and formation rates, come in a system of ordinary differentials equations (ODE's). These equations are too complex for analytical solving. Then the ODE's were approximated by the finite difference method. The first boundary conditions were approximated by this method too, but by both forward and backward approximations. These two ways to write the boundary conditions equations were used to turn mass balance independent of forward and backward step.

Finally the equations form a linear system that was solved using the over-relaxation method.

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4.1 Finite Difference Methods

For gaseous species:

$$D_{\beta,\,mix}\left(\frac{c_{\beta,\,j+1}-2c_{\beta,\,j}+c_{\beta,\,j-1}}{\Delta z^{2}}\right)-\frac{Q_g}{A_S}\left(\frac{c_{\beta,\,j+1}-c_{\beta,\,j-1}}{2\Delta z}\right)+R_\beta=0 \tag{16}$$

Forward boundary condition:

$$\frac{D_{\beta,mix}}{\Delta z}\left(c_{\beta,j+1}-c_{\beta,j}\right)=\frac{Q_g}{A_S}\left(\frac{c_{\beta,j}+c_{\beta,j+1}}{2}-c_\beta\Big|_{z=0^-}\right) \tag{17}$$

Backward boundary condition:

$$\frac{D_{\beta,mix}}{\Delta z}\left(c_{\beta,j}-c_{\beta,j\text{-}1}\right)=\frac{Q_g}{A_S}\left(\frac{c_{\beta,j}+c_{\beta,j-1}}{2}-c_\beta\Big|_{z=0^-}\right) \tag{18}$$

For solid species (carbon):

$$D_{C,\,mix}\left(\frac{c_{C,\,j+1}-2c_{C,\,j}+c_{C,\,j-1}}{\Delta z^{2}}\right)-\frac{F_S}{A_S}\left(\frac{c_{C,\,j+1}-c_{C,\,j-1}}{2\Delta z}\right)+R_C=0 \tag{19}$$

Forward boundary condition:

$$\frac{D_{C,mix}}{\Delta z}\left(c_{C,j+1}-c_{C,j}\right)=\frac{F_S}{A_S}\left(\frac{c_{C,j}+c_{C,j+1}}{2}-c_C\Big|_{z=0^-}\right) \tag{20}$$

Backward boundary condition:

$$\frac{D_{C,mix}}{\Delta z}\left(c_{C,j}-c_{C,j\text{-}1}\right)=\frac{F_S}{A_S}\left(\frac{c_{C,j}+c_{C,j-1}}{2}-c_C\Big|_{z=0^-}\right) \tag{21}$$

Concentration terms j+1 and j-1 in forward and backward boundary conditions approximations were isolated and substituted in the species equation approximation (Eq. 16 and 19). The equations are given in Tab. 2.

Table 2. Species equations approximation dependent on the term j.

$c_{CO_j}\left[\frac{D_{CO,mix}}{\Delta z^2}\left(\alpha_1^{-1}\alpha_2-2+\alpha_2^{-1}\alpha_1\right)-\frac{Q_g}{A_S}\cdot\frac{1}{2\Delta z}\left(\alpha_1^{-1}\alpha_2-\alpha_2^{-1}\alpha_1\right)\right]+c_{CO}\Big\|_{z=0^-}\left[\frac{D_{CO,mix}}{\Delta z^2}\left(-\alpha_1^{-1}\cdot\frac{Q_{gr}}{A_S}+\alpha_2^{-1}\cdot\frac{Q_g}{A_S}\right)-\frac{Q_g}{A_S}\cdot\frac{1}{2\Delta z}\left(-\alpha_1^{-1}\cdot\frac{Q_g}{A_S}-\alpha_2^{-1}\cdot\frac{Q_g}{A_S}\right)\right]+R_{CO}=0$	
$\alpha_1=\frac{D_{CO,mix}}{\Delta z}-\frac{Q_g}{2A_S}$	$\alpha_2=\frac{D_{CO,mix}}{\Delta z}+\frac{Q_g}{2A_S}$
$c_{H_2,j}\left[\frac{D_{H_2,mix}}{\Delta z^2}\left(\alpha_3^{-1}\alpha_4-2+\alpha_4^{-1}\alpha_3\right)-\frac{Q_g}{A_S}\cdot\frac{1}{2\Delta z}\left(\alpha_3^{-1}\alpha_4-\alpha_4^{-1}\alpha_3\right)\right]+c_{H_2}\Big\|_{z=0^-}\left[\frac{D_{H_2,mix}}{\Delta z^2}\left(-\alpha_3^{-1}\cdot\frac{Q_g}{A_S}+\alpha_4^{-1}\cdot\frac{Q_g}{A_S}\right)-\frac{Q_g}{A_S}\cdot\frac{1}{2\Delta z}\left(-\alpha_3^{-1}\cdot\frac{Q_g}{A_S}-\alpha_4^{-1}\cdot\frac{Q_g}{A_S}\right)\right]+R_{H_2}=0$	
$\alpha_3=\frac{D_{H_2,mix}}{\Delta z}-\frac{Q_g}{2A_S}$	$\alpha_4=\frac{D_{H_2,mix}}{\Delta z}+\frac{Q_g}{2A_S}$
$c_{H_2O_j}\left[\frac{D_{H_2O,\,mix}}{\Delta z^2}\left(\alpha_5^{-1}\alpha_6-2+\alpha_6^{-1}\alpha_5\right)-\frac{Q_g}{A_S}\cdot\frac{1}{2\Delta z}\left(\alpha_5^{-1}\alpha_6-\alpha_6^{-1}\alpha_5\right)\right]+c_{H_2O}\Big\|_{z=0^-}\left[\frac{D_{H_2O,\,mix}}{\Delta z^2}\left(-\alpha_5^{-1}\cdot\frac{Q_g}{A_S}+\alpha_6^{-1}\cdot\frac{Q_g}{A_S}\right)-\frac{Q_g}{A_S}\cdot\frac{1}{2\Delta z}\left(-\alpha_5^{-1}\cdot\frac{Q_g}{A_S}-\alpha_6^{-1}\cdot\frac{Q_g}{A_S}\right)\right]+R_{H_2O}=0$	
$\alpha_5=\frac{D_{H_2O,mix}}{\Delta z}-\frac{Q_g}{2A_S}$	$\alpha_6=\frac{D_{H_2O,mix}}{\Delta z}+\frac{Q_g}{2A_S}$

$c_{CO_2,j}\left[\frac{D_{CO_2,mix}}{\Delta z^2}\left(\alpha_7^{-1}\alpha_8-2+\alpha_8^{-1}\alpha_7\right)-\frac{Q_g}{A_S}\cdot\frac{1}{2\Delta z}\left(\alpha_7^{-1}\alpha_8-\alpha_8^{-1}\alpha_7\right)\right]+c_{CO_2}\Big\|_{z=0^-}\left[\frac{D_{CO_2,mix}}{\Delta z^2}\left(-\alpha_7^{-1}\cdot\frac{Q_g}{A_S}+\alpha_8^{-1}\cdot\frac{Q_g}{A_S}\right)-\frac{Q_g}{A_S}\cdot\frac{1}{2\Delta z}\left(-\alpha_7^{-1}\cdot\frac{Q_g}{A_S}-\alpha_8^{-1}\cdot\frac{Q_g}{A_S}\right)\right]+R_{CO_2}=0$	
$\alpha_7=\frac{D_{CO_2,mix}}{\Delta z}-\frac{Q_g}{2A_S}$	$\alpha_8=\frac{D_{CO_2,mix}}{\Delta z}+\frac{Q_g}{2A_S}$
$c_{C,j}\left[\frac{D_{C,mix}}{\Delta z^2}\left(\alpha_9^{-1}\alpha_{10}-2+\alpha_{10}^{-1}\alpha_9\right)-\frac{F_S}{A_S}\cdot\frac{1}{2\Delta z}\left(\alpha_9^{-1}\alpha_{10}-\alpha_{10}^{-1}\alpha_9\right)\right]+c_C\Big\|_{z=0^-}\left[\frac{D_{C,mix}}{\Delta z^2}\left(-\alpha_9^{-1}\cdot\frac{F_S}{A_S}+\alpha_{10}^{-1}\cdot\frac{F_S}{A_S}\right)-\frac{F_S}{A_S}\cdot\frac{1}{2\Delta z}\left(-\alpha_9^{-1}\cdot\frac{F_S}{A_S}-\alpha_{10}^{-1}\cdot\frac{F_S}{A_S}\right)\right]+R_C=0$	
$\alpha_9=\frac{D_{C,mix}}{\Delta z}-\frac{F_S}{2A_S}$	$\alpha_{10}=\frac{D_{C,mix}}{\Delta z}+\frac{F_S}{2A_S}$

4.2 Over-relaxation method

Each equation balance dependent on concentration terms j was a line in a matrix. This gives us a linear equation system that was solved using the over relaxation method. The method was modified for this problem so the species consumed appear with a subtraction mark. In each iteration the step in length increases too. The matrix elements are given in Tab. 3

$$a_{11}\left(c_{CO}\right)_j+a_{12}\left(c_{H_2}\right)_j+a_{13}\left(c_{H_2O}\right)_j+a_{14}\left(c_{CO_2}\right)_j+a_{15}\left(c_C\right)_j=b_{11} \tag{22}$$

$$\left(c_{CO}\right)_j^{K+1}=(1-w)\left(c_{CO}\right)_j^K+\frac{w}{a_{11}}\left[b_{11}-\left(a_{12}\left(c_{H_2}\right)_j^K+a_{13}\left(c_{H_2O}\right)_j^K+a_{14}\left(c_{CO_2}\right)_j^K+a_{15}\left(c_C\right)_j^K\right)\right] \tag{23}$$

$$a_{21}\left(c_{CO}\right)_j+a_{22}\left(c_{H_2}\right)_j+a_{23}\left(c_{H_2O}\right)_j+a_{24}\left(c_{CO_2}\right)_j+a_{25}\left(c_C\right)_j=b_{21} \tag{24}$$

$$\left(c_{H_2}\right)_j^{K+1}=(1-w)\left(c_{H_2}\right)_j^K+\frac{w}{a_{22}}\left[b_{21}-\left(a_{21}\left(c_{CO}\right)_j^{K+1}+a_{23}\left(c_{H_2O}\right)_j^K+a_{24}\left(c_{CO_2}\right)_j^K+a_{25}\left(c_C\right)_j^K\right)\right] \tag{25}$$

$$a_{31}\left(c_{CO}\right)_j+a_{32}\left(c_{H_2}\right)_j+a_{33}\left(c_{H_2O}\right)_j+a_{34}\left(c_{CO_2}\right)_j+a_{35}\left(c_C\right)_j=b_{31} \tag{26}$$

$$\left(c_{H_2O}\right)_j^{K+1}=(1-w)\left(c_{H_2O}\right)_j^K-\frac{w}{a_{33}}\left[b_{31}-\left(a_{31}\left(c_{CO}\right)_j^{K+1}+a_{32}\left(c_{H_2}\right)_j^{K+1}+a_{34}\left(c_{CO_2}\right)_j^K+a_{35}\left(c_C\right)_j^K\right)\right] \tag{27}$$

$$a_{41}\left(c_{CO}\right)_j+a_{42}\left(c_{H_2}\right)_j+a_{43}\left(c_{H_2O}\right)_j+a_{44}\left(c_{CO_2}\right)_j+a_{45}\left(c_C\right)_j=b_{41} \tag{28}$$

$$\left(c_{CO_2}\right)_j^{K+1}=(1-w)\left(c_{CO_2}\right)_j^K-\frac{w}{a_{44}}\left[b_{41}-\left(a_{41}\left(c_{CO}\right)_j^{K+1}+a_{42}\left(c_{H_2}\right)_j^{K+1}+a_{43}\left(c_{H_2O}\right)_j^{K+1}+a_{45}\left(c_C\right)_j^K\right)\right] \tag{29}$$

$$a_{51}\left(c_{CO}\right)_j+a_{52}\left(c_{H_2}\right)_j+a_{53}\left(c_{H_2O}\right)_j+a_{54}\left(c_{CO_2}\right)_j+a_{55}\left(c_C\right)_j=b_{51} \tag{30}$$

$$\left(c_C\right)_j^{K+1}=(1-w)\left(c_C\right)_j^K-\frac{w}{a_{55}}\left[b_{51}-\left(a_{51}\left(c_{CO}\right)_j^{K+1}+a_{52}\left(c_{H_2}\right)_j^{K+1}+a_{53}\left(c_{H_2O}\right)_j^{K+1}+a_{54}\left(c_{CO_2}\right)_j^{K+1}\right)\right] \tag{31}$$

Table 3. Matrix elements.

$a_{11} = \frac{D_{CO,mix}}{\Delta z^2}\left(\alpha_1^{-1}\alpha_2 - 2 + \alpha_2^{-1}\alpha_1\right) - \frac{Q_g}{A_S}\cdot\frac{1}{2\Delta z}\left(\alpha_1^{-1}\alpha_2 - \alpha_2^{-1}\alpha_1\right) + k_2$	$a_{12} = 0$	$a_{13} = k_1$
$b_1 = c_{CO}\big\|_{z=0^-}\left[-\frac{D_{CO,mix}}{\Delta z^2}\left(-\alpha_1^{-1}\frac{Q_{ar}}{2A_S} + \alpha_2^{-1}\frac{Q_{ar}}{A_S}\right) - \frac{Q_{ar}}{A_S}\frac{1}{2\Delta z}\left(-\alpha_1^{-1}\frac{Q_{ar}}{A_S} - \alpha_2^{-1}\frac{Q_{ar}}{A_S}\right)\right]$	$a_{14} = 2k_3$	$a_{15} = 0$
$a_{22} = \frac{D_{H_2,mix}}{\Delta z^2}\left(\alpha_3^{-1}\alpha_4 - 2 + \alpha_4^{-1}\alpha_3\right) - \frac{Q_g}{A_S}\cdot\frac{1}{2\Delta z}\left(\alpha_3^{-1}\alpha_4 - \alpha_4^{-1}\alpha_3\right)$	$a_{21} = k_2$	$a_{23} = k_1$
$b_2 = c_{H_2}\big\|_{z=0^-}\left[-\frac{D_{H_2,mix}}{\Delta z^2}\left(-\alpha_3^{-1}\frac{Q_g}{2A_S} + \alpha_4^{-1}\frac{Q_g}{A_S}\right) - \frac{Q_g}{A_S}\frac{1}{2\Delta z}\left(-\alpha_3^{-1}\frac{Q_g}{A_S} - \alpha_4^{-1}\frac{Q_g}{A_S}\right)\right]$	$a_{24} = 0$	$a_{25} = 0$
$a_{33} = \frac{D_{H_2O,mix}}{\Delta z^2}\left(\alpha_5^{-1}\alpha_6 - 2 + \alpha_6^{-1}\alpha_5\right) - \frac{Q_g}{A_S}\cdot\frac{1}{2\Delta z}\left(\alpha_5^{-1}\alpha_6 - \alpha_6^{-1}\alpha_5\right) - k_1$	$a_{31} = -k_2$	$a_{32} = 0$
$b_3 = c_{H_2O}\big\|_{z=0^-}\left[-\frac{D_{H_2O,mix}}{\Delta z^2}\left(-\alpha_5^{-1}\frac{Q_g}{2A_S} + \alpha_6^{-1}\frac{Q_g}{A_S}\right) - \frac{Q_g}{A_S}\frac{1}{2\Delta z}\left(-\alpha_5^{-1}\frac{Q_g}{A_S} - \alpha_6^{-1}\frac{Q_g}{A_S}\right)\right]$	$a_{34} = 0$	$a_{35} = 0$
$a_{44} = \frac{D_{CO_2,mix}}{\Delta z^2}\left(\alpha_7^{-1}\alpha_8 - 2 + \alpha_8^{-1}\alpha_7\right) - \frac{Q_g}{A_S}\cdot\frac{1}{2\Delta z}\left(\alpha_7^{-1}\alpha_8 - \alpha_8^{-1}\alpha_7\right) - k_3$	$a_{41} = k_2$	$a_{42} = 0$
$b_4 = c_{CO_2}\big\|_{z=0^-}\left[-\frac{D_{CO_2,mix}}{\Delta z^2}\left(-\alpha_7^{-1}\frac{Q_g}{2A_S} + \alpha_8^{-1}\frac{Q_g}{A_S}\right) - \frac{Q_g}{A_S}\frac{1}{2\Delta z}\left(-\alpha_7^{-1}\frac{Q_g}{A_S} - \alpha_8^{-1}\frac{Q_g}{A_S}\right)\right]$	$a_{43} = 0$	$a_{45} = 0$
$a_{55} = \frac{D_{C,mix}}{\Delta z^2}\left(\alpha_9^{-1}\alpha_{10} - 2 + \alpha_{10}^{-1}\alpha_9\right) - \frac{F_S}{A_S}\cdot\frac{1}{2\Delta z}\left(\alpha_9^{-1}\alpha_{10} - \alpha_{10}^{-1}\alpha_9\right)$	$a_{51} = 0$	$a_{52} = 0$
$b_5 = c_C\big\|_{z=0^-}\left[-\frac{D_{C,mix}}{\Delta z^2}\left(-\alpha_9^{-1}\frac{F_S}{2A_S} + \alpha_{10}^{-1}\frac{F_S}{A_S}\right) - \frac{F_S}{A_S}\frac{1}{2\Delta z}\left(-\alpha_9^{-1}\frac{F_S}{A_S} - \alpha_{10}^{-1}\frac{F_S}{A_S}\right)\right]$	$a_{53} = -\frac{3RT}{P}k_1$	$a_{54} = -\frac{3RT}{P}k_3$

5. RESULTS AND DISCUSSION

Figure 1 shows the species concentration at a temperature 800K. Carbon and dioxide carbon are all consumed in the process. Hydrogen was produced more than monoxide carbon because of the first and second reaction (Eq. 7 and 8).

All the species concentrations stabilize in the 0.3 m of the reduction zone length. So a reduction zone length more long is unnecessary since the reactions are complete and the main products were produced in a good amount.

The concentrations data in each iteration were plotted with the reactor zone length.

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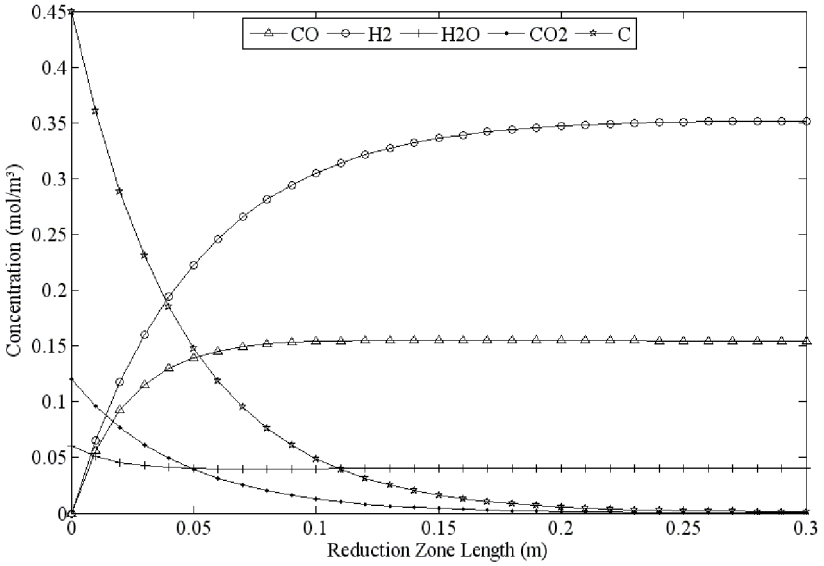

Fig. 1: Species concentration in the reduction zone length at 800K.

Initial steam concentration is related to the amount of monoxide and hydrogen produced, Fig. 2 and Fig. 3. The increase of initial steam concentration helps the first two reactions, directly the first one. Thus the steam initial concentration analysis is responsible to the purpose of producing more Syngas (hydrogen and carbon monoxide), the main product of this process. These gases are the fuel to the gas turbine that will produce energy.

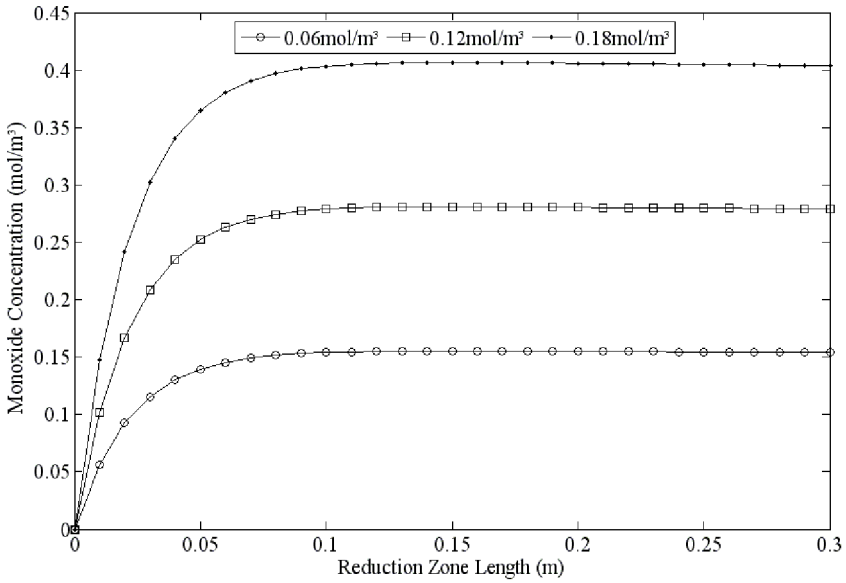

Fig. 2: Monoxide concentration in the reduction zone length with different steam initial concentrations.

There is more hydrogen production than carbon monoxide in the process. This is caused by the first two reaction kinetic rates. The Reaction 7 and 8 presents the higher kinetic constants, but the second reaction consumes carbon monoxide, it helps the decrease of monoxide concentration in relation to hydrogen.

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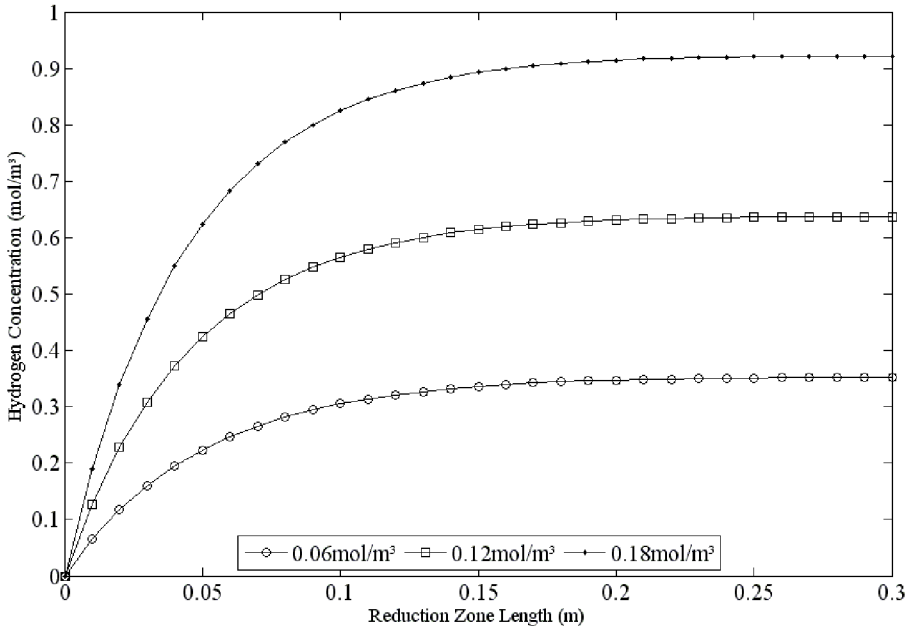

Fig. 3: Hydrogen concentration in the reduction zone length with different steam initial concentrations.

6. CONCLUSIONS AND FUTURE ESSAY

The evaluation of species behavior in a reduction zone shows some important results: the method used to solve the linear system was able to find the better reduction zone length. The steam initial concentration is crucial for increasing the products yield. The over-relaxation method can be a good method for systems with linear reaction kinetics. The gasification kinetic rates hardly are linear. In this paper the kinetic rates were linear and give us satisfactory results.

In the future essay, a heat balance will be done. It is important to study the relations between temperature and the reaction development, it could increase the products yield too. Other numerical Methods as Crank Nicolson and Method of Line (MOL) could be used to range non linear problems (non-linear kinetic rates).

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