24th COBEM - 2017

COBEM-2017-1422
METHODOLOGY FOR BURNER DESIGN - COMBUSTION OF PYROLYSIS GAS FROM CHARCOAL PRODUCTION

N.G.B. Gomes
J. V. Chávez
D. Medeiros Filho
D. J. Carvalho
R. G. dos Santos
W.A. Bizzo
University of Campinas, School of Mechanical Engineering, Campinas, Brazil
neil.gomes@fem.unicamp.br,jvillanueva@fem.unicamp.br,dmed22@fem.unicamp.br,liar@fem.unicamp.br,
roger7@fem.unicamp.br,bizzo@fem.unicamp.br

Abstract.This work presents a burner design methodology for pyrolysis gas emitted from charcoal production. Based on the variety of the existing burner concepts the flameless oxidation concept was chosen due to its high stability, energy recovery capability and possibility to deal with dirty gas with presence of tar. An analysis of the flammability limits of the pyrolysis gas showed that it is flammable most of the operation time. A design methodology was carried and a prototype is presented. The prototype is proposed to be placed on the top of the charcoal kiln chimney. Tests are due to be run by the end of this year at a biomass valorization plant in Minas Gerais, Brazil.

Keywords: Combustion, flameless oxidation, pyrolysis, gas, charcoal production

1. INTRODUCTION

Brazil uses in a large extent charcoal from planted forest in steel and pig iron industries (Lora and Andrade, 2009). In the process of pyrolysis wood, biomass is partially carbonized in a kiln to produce charcoal. The product has a higher energy content, lower humidity, and it can be used from direct combustion or associated with iron ore to produce steel. Methods for biomass utilization lead to production of some detrimental fuel by-products. In special tar production associated with biomass gasification/pyrolysis is considered to be one of the biggest challenges in utilization of biomass for power generation (Han and Kim, 2008).

The charcoal production process, slow pyrolysis, leads to emission of carbon monoxide, methane, tar, non methane organic compounds and particulate matter as well as incomplete combustion products (Pennise et al., 2001). Considering planted energy forests destined to energy use, mainly eucalyptus, the two main uses are cellulose and the charcoal production for pig iron industries in Brazil (Lora and Andrade, 2009).

In order to deal with the emission associated with the pyrolysis gas a methodology of burner design is presented in this work, based on existing burner concepts considering the goals of reducing toxic gas release, specially methane and tar. The concept aims to give flame stability during the longer period as possible and the smallest interference in the production i.e. no added pressure restriction for gas flow in the chimney.

Among the difficulties to burn non treated gas, in this particular case, is the presence of solid particles, condensible gas and tars that could potentially adhere to the internal surface of the burner. Another difficulty is the presence of premixed oxygen in the pyrolysis gas, low calorific value and high variability in composition and gas flow during the process (Vallourec & Mannesmann, 2011).

After an review of the available literature on low calorific gases, and considering the difficulties related to the type of fuel considered, we identified two burner concepts that have high potential of being used, the Costair and Flox. The Costair has been successfully adapted to deal with low calorific value gas from biomass such as gasification and wood gas (Al-Halbouni et al., 2006). A Flox burner was successfully tested with different LCV gases, both numerically and experimentally, with a range of concentrations of CH_4, CO, CO_2, N_2 and H_2 (Danon et al., 2010).

Both burner concepts, Costair and Flox, are based on intense recirculation of the mixed gas to reduce the flame temperature of the mixture. It also benefits from preheating the combustion air to give higher combustion stability and lower NOx emissions compared to conventional burners (Wang et al., 2007). It should be adapted to charcoal production and being associated with a pre existing kiln, the pressure loss is critical limitation for the process. The Flox concept has lesser limitations regarding pressure availability in the fuel and flow restriction acts in the combustion air, in comparison

with the Costair concept. There is existing data for a Flox burner adapted for LCV gas from biomass gasification that can deal with severe conditions of the fuel such as the ones prescribed for charcoal production (Schuster et al., 2007).
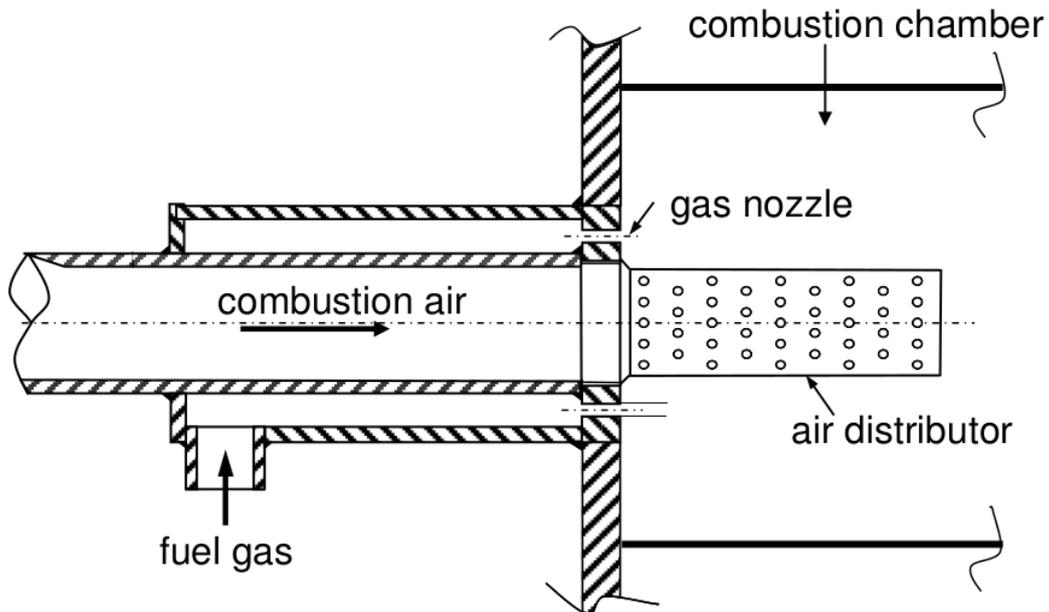

Figure 1: Costair combustion concept adpated for low calorific fuels. (Al-Halbouni et al., 2006)
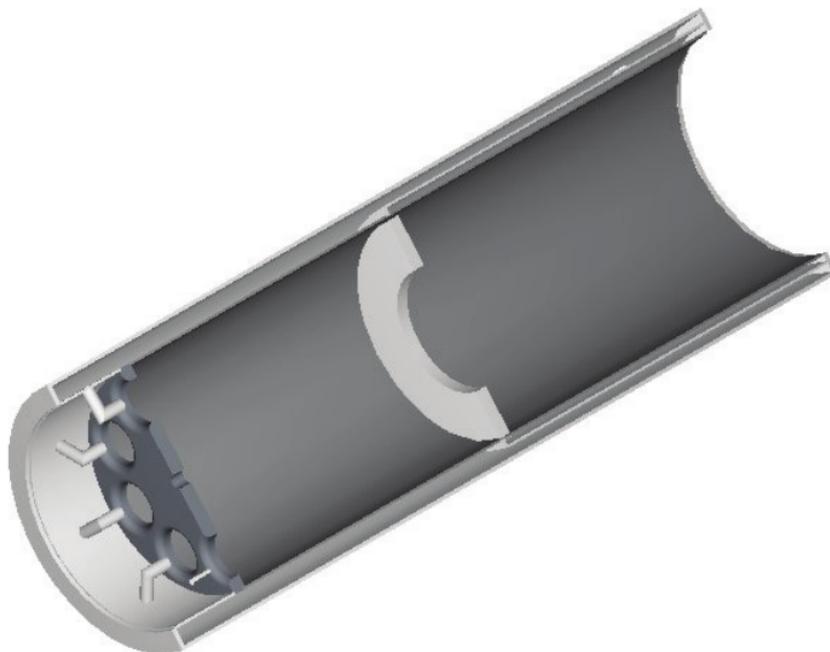

Figure 2: Modified flameless oxidation concept for biomass gasifier combustion. (Schuster et al., 2007)

An experimental analysis of the pyrolysis gas from the charcoal production was made by a Brazilian company that produces charcoal for pig iron and steel production – V & M Florestal (Vallourec & Mannesmann, 2011). The experiment was run according with the AM0041 methodology aiming the Clean Development Mechanism program. The data for a single run is presented in Table 1 bellow.

Table 1: Composition and volume of non condensible gas for a run in a charcoal production kiln. (Vallourec & Mannesmann, 2011)

Sample	%H_2	%O_2	%N_2	%CO_2	CO	%CH_4	%others
1	1.10	13.99	74.81	7.06	0.53	0.49	2.02
2	0.83	15.39	76.35	6.29	0.34	0.44	0.35
3	1.24	11.90	75.63	8.63	0.74	0.59	1.26
4	1.24	12.64	73.48	8.73	0.90	0.82	2.19
5	1.04	10.66	71.79	9.92	0.88	1.04	4.68
6	0.92	8.18	70.58	11.44	0.94	1.20	6.74
7	0.92	8.18	70.58	11.44	0.94	1.28	6.65
8	0.98	6.83	70.58	11.64	1.00	1.20	7.52
9	1.04	5.48	71.08	11.84	1.05	1.11	8.39
10	0.91	5.42	67.70	12.99	1.15	1.91	9.92
11	0.89	5.11	71.92	11.66	0.79	1.37	8.26
12	2.15	3.89	68.63	12.96	0.89	1.98	9.51
13	1.71	8.02	67.70	11.59	0.97	2.09	7.92
14	0.85	13.83	73.73	8.52	0.65	1.21	1.20
15	3.06	8.65	70.54	10.14	0.77	1.80	5.03
16	2.68	7.46	71.57	10.37	0.70	1.06	6.16
17	2.30	6.27	72.60	10.60	0.63	0.31	7.28
18	0.99	13.59	74.62	7.42	0.36	0.62	2.40
19	0.77	4.02	73.96	12.05	0.45	0.76	8.00
20	0.66	6.76	75.03	10.46	0.38	0.58	6.12
21	0.66	6.76	75.03	10.46	0.38	0.58	6.12

[1] Chemical Composition (%mol/mol gas)

In the data presented in the Table 1 special attention should be given for the significant presence of oxygen the pyrolysis gas, up to 15%. The presence of air in this quantities could allow the pyrolysis to be flammable by itself then allowing flash-back to occur. The last column presenting "others" refer to heavier hydrocarbons. Presence of condensible gas was measured and was accessed to be up to 34% of the pyrolysis gas mass (Vallourec & Mannesmann, 2011). The constituents of the condensible, however, were not specified.

Considering the examples of burner application in the literature for biomass gas, (Al-Halbouni et al., 2006),(Danon et al., 2010),(Schuster et al., 2007) and (Wang et al., 2007), also taking into account the limitations and problems of the current application the Flox concept was considered to be the most suitable. The most significant different in this case is that the mixing air shoudl also provide enough suction of the pyrolysis gas that do not have pressure availability as in a common combustion application.

2. METHODOLOGY

Given the scarcity of information available about the combustion properties of the biomass volatiles, this study was mainly based on classical studies and validated equations for gaseous mixtures and its flammability and burning characteristics. Based on composition data available in Table 1 tests in charcoal production sites, an analysis was made to evaluate the period in which the pyrolysis gas is actually flammable, its calorific value and the necessary information for combustion stoichiometry.

Based on the literature review a series of theoretical flammability correlations were considered. A classical method (Coward and Jones, 1952) presented the flammability of mixtures and also with the influence of inerts. Based on a specific mixture of flammable gases and the effect of each inert gas for a given temperature a range of flammability is calculated from lower to upper concentration of flammable gases. Inserting the actual porcentage of flammable gas in the mixture a curve is constructed. In that case if the actual flammable gas porcentage lies between the lower and upper limit, according to (Coward and Jones, 1952), the mixture is considered to be flammable. Using the data of the literature TABLE 1 a graph of flammability was constructed.

For the burner design, the main criteria were flashback, blowout and pressure distribution inside the chimney kiln for different operation points. Laminar flame speed was calculated using the correlations presented in (Turns, 2012). In order to evaluated the turbulent flame speed a turbulent relative intensity up to 15% was adopted.

Using a CFD software tool, Star CCM+, for non reactive fluid flow was possible to simulate the pressure and velocity distribution inside the combustion chamber. The main objective was to preserve the pressure level of the pre existing chimney kiln by adjusting the exhaust mass flow and the combustor design. In this case the mixture velocity was also

compared with estimated flame speeds for the same given composition from TABLE 1 to avoid flash back.
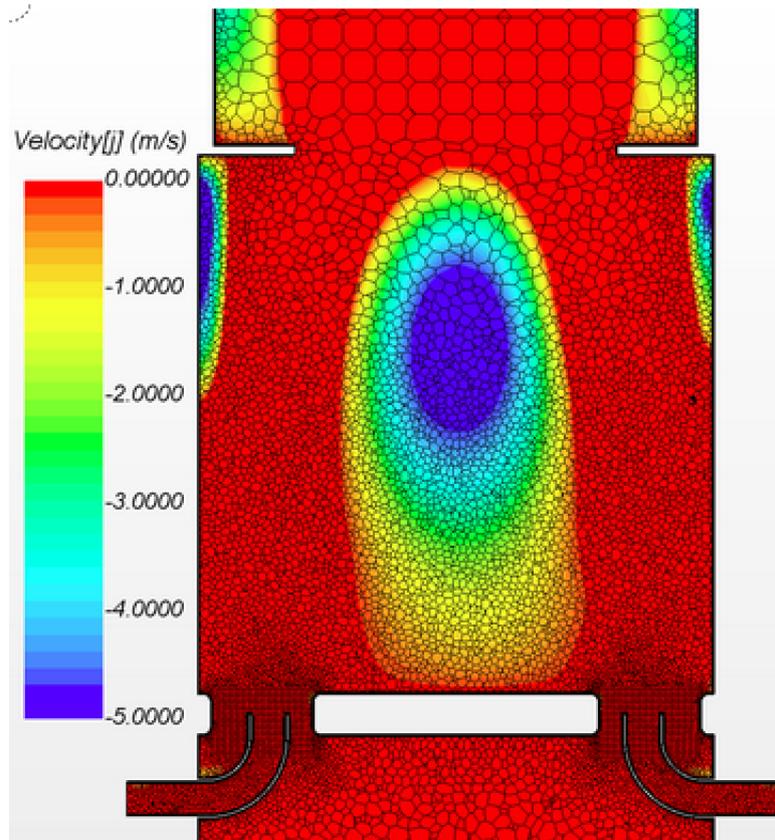

Figure 3: Non reactive CFD simulation of velocity distribution inside combustion chamber.

In Figure 3 it is visible the recirculation zone inside the combustor. The speed range is in the range from -5 to 0 m/s. According to (Schuster et al., 2007), where is also used a bluff body to increase recirculation inside the combustion chamber, the recirculation is one of the main important phenomena to allow the high burning efficiency of the project.
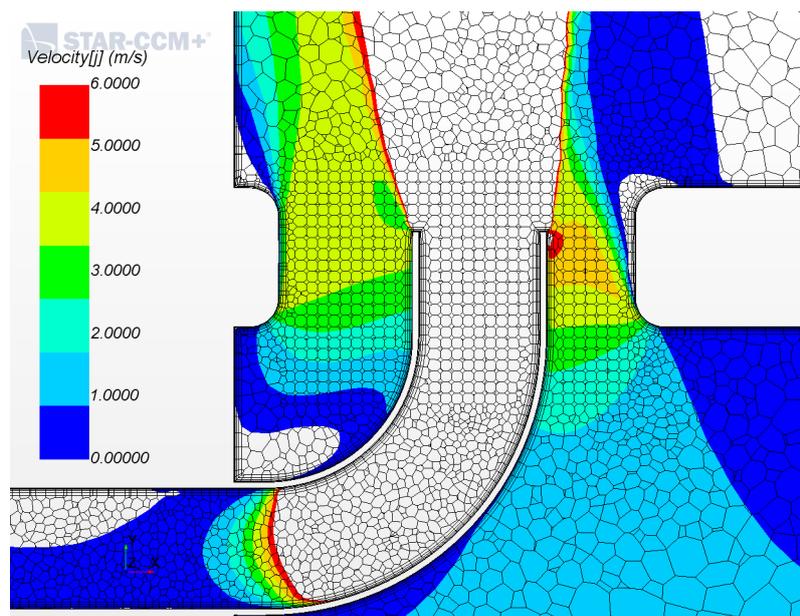

Figure 4: Non reactive CFD simulation of velocity distribution around the ejector area.

On the other hand Figure 4 shows the positive axial speed inside around one of the ejectors. This analysis was important to garantee that the air speed was high enough to avoid flash-back. The range of speed aroung the ejector was

compared with the laminar and turbulent speed of the mixture. As a safety measure the air speed around the ejector should be higher than the flame speed to avoid flash-back.

3. RESULTS AND DISCUSSION

There are some preliminary results regarding the flammability limits, flame speed and pressure distribution. Using the correlations presented in the literature (Coward and Jones, 1952) was clear that the pyrolysis gas was flammable most of the operation time. Regarding the burner design a side and perspective view is presented in the Figure 6 bellow. It is similar to the concept presented in (Schuster et al., 2007) with the necessary adjustment for the project mass flow rate, flame speed and pressure distribution in the kiln chimney.

Considering the method presented in (Coward and Jones, 1952) the pyrolysis gas from TABLE 1 is flammable inside the lower and upper limit, the actual mixture composition in shown in green in the graph bellow. According to this analysis the gas is flammable most of the time, more precisely from day 2 when the drying process is ending and the temperature has a great increase showed by the abrupt expansion of the flammability range.
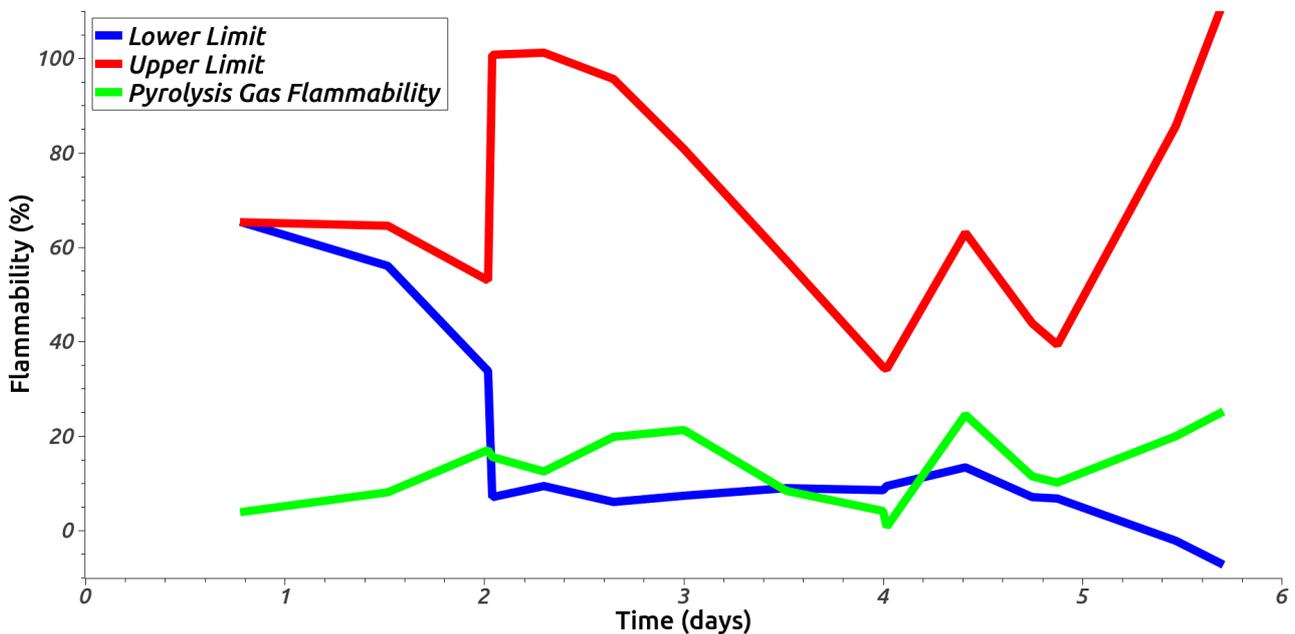

Figure 5: Flammability Limits calculate for the Pyrolysis Gas composition.
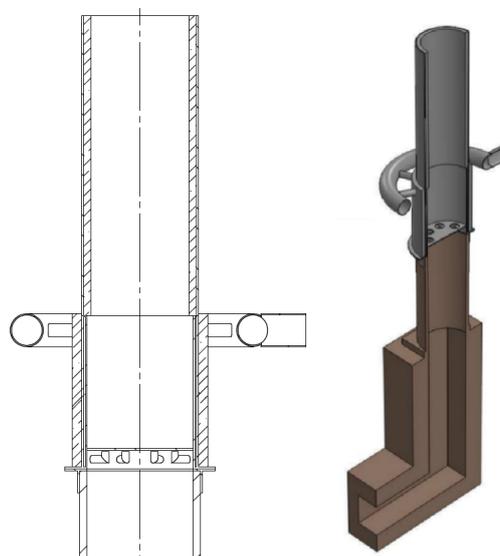

Figure 6: Design of the combustor and proposed set up on top of the chimney. Exhaust air for combustion and suction is inserted in the tube in the right.

The project proposed a burner design attached to the top of the process chimney. The solution should also maintain the current flow rate of the process. In this concept was difficult to deal with flash-back, because flame could propagate back throught the chimney and back to the kiln. It was not possible to use a flame arrestor due to the high pressure loss and the presence of incondensable gases in the pyrolysis process. So, the exhaust air alone need to be sufficient to carry the flame away in case of emmergency. In Figure 4 we garantee that the speed is above 4m/s which is the scale of flame speed in this condition.

In figure 6 is a plane and 3D perpective of the burner adapted to the top of the process chimney. With adjusted geometry using the CFD tool and the specification of a exhaust with enough air flow to assure both air to combustible mixture and air suction by the ejectors the prototype is expected to meet all requirements.

4. CONCLUSIONS

The work aims to do an adaptation of the Flox burner concept to a kiln of an charcoal kiln. Using the correlation in the literature the pyrolysis gas was flammable most of the operation time. CFD simulations were carried out and indicates, for non reactive flow, the recirculation behaviour of the gas inside the combustion chamber and safe air speeds around the ejectors to avoid flash-back in the test.

Nonetheless there's still ongoing analysis and points to be discussed such as the ignition device or emmergency routines in case of flash-back to the kiln. A more precise flammability evaluation of the pyrolysis gas and comparison with different methodologies as well as the calculated flame speed is still being made for the final project report. The prototype is in its late stage of developement and tests are due to happen by the end of this year and are expected to give more detailed data for the combustion performance of the burner.

5. ACKNOWLEDGEMENTS

6. REFERENCES

Al-Halbouni, A., Rahms, H., Görner, K., An efficient concept for low calorific gases, (2006) 1-6.

Danon, B., Jong, W. de, Roekaerts, D. J. E. M., Experimental and numerical investigation of a flox combustor firing low calorific value gas, Combust. Sci. and Tech (2010) 1261-1278.

Coward, H. F., Jones, G. W., Limits of flammability of gases and vapors, Bureau of Mines Bulletin 503 (1952).

Han, J., Kim, H., The reduction and control technology of tar during biomass gasification/pyrolysis: An overview, Renewable and Sustainable Energy Reviews Vol 12 (2008) 397-416.

Lora, E. S., Andrade, R. V., Biomass as energy source in Brazil, Renewable and Sustainable Energy Reviews (2009) 780-787.

Pennise, D. M., Smith, K. R., Kithinji, J. P., Rezende, M. E., Raad, T. J., Zhang, J., Fan, C., Emissions of greenhouse gases and other airborne pollutants form charcoal production in Kenya and Brazil, Journal of Geophysical Research Vol 106 (2001) 143-155.

Schuster, A., Zieba, M., Scheffknecht, G., Optimization of conventional biomass combustion system by applying flameless oxidation, 15th IFRF Member's Conference (2007) 1-13.

Turns, S. R., An introduction to combustion: concepts and applications, third ed, Mc Graw Hill, New York, 2012.

Vallourec & Mannesmann Florestal, Projeto Carbonização - Mitigação de Emissões de Metano na Produção de Carvão Vegetal da Vallourec & Mannesmann Florestal, Versão 1, Minas Gerais, Brasil (2011) Anexo 1.

Wang, Y. D., McIlveen-Wright, D., Huang, Y., Hewitt, N., Eames, P., Rezvani, S., McMullan, J., Roskilly, A. P., The application of FLOX/COSTAIR technologies to reduce NO x emissions from coal/biomass fired power plant: A technical assessment based on computational simulation, Fuel 86 (2007) 2101-2108.

7. RESPONSIBILITY NOTICE