23rd ABCM International Congress of Mechanical Engineering
December 6-11, 2015, Rio de Janeiro, RJ, Brazil

STUDY OF COMBUSTION OF RICE HUSK AND ITS ATMOSPHERIC EMISSIONS

Prof[a]. Dr[a]. Juliana Esteves Fernandes Cieslinski
Prof[a] Dr[a]. Maria Angélica Martins Costa
Universidade Estadual Paulista "Júlio de Mesquita Filho" – UNESP – Campus de Itapeva e de Araraquara
jefernandes@itapeva.unesp.br
mangelica@iq.unesp.br

Abstract. *Biomass is a renewable energy source with great potential for growth in the coming years, both in Brazil and internationally. From biomass is possible to obtain electricity and thermal, in addition of biofuels such as biodiesel and ethanol. However, there is concern in investment in monitoring and control of air pollutants from the burning of biomass. Are the exhaust gases and fine particles known as particulates, which greatly contribute to the emergence of serious health problems to humans, in addition to the environmental damage. Therefore, this work aimed to carry out the monitoring and control of emissions from burning of the rice husk, a by-product of the processing of rice, of extreme importance in Brazil. The results showed that the particulate concentration values were higher than the air quality standards set by the World Health Organization and the largest concentrations of CO, CO2 and NOx were, respectively, 309 ppm (incandescent phase), 2.3% (flaming phase) and 48 ppm (flaming phase), demonstrating the need for the control of these emissions. Using a Venturi scrubber, maximum efficiencies of collecting particulate material, CO, CO2 and NOx were, respectively, 86.3%, 54%, 60% and 67%.The purpose of these instructions is to serve as a guide for formatting papers to be published in the Proceedings of the XXII COBEM. The abstract should describe the objectives, the methodology and the main conclusions of the paper in about 200 words. It should contain neither formulae nor reference to bibliography. The abstract will be included in a printed volume to be distributed to the symposium participants, whilst the full paper will be published in the proceedings.*

Keywords: *Biomass, particulates, exhaust gases, Venturi scrubber*

1. INTRODUCTION

Air pollution has been a theme intensely researched in recent decades and their reduction is a factor of great importance in the pursuit of preserving the environment and in the implementation of sustainable development, because its effects affect in many ways human health, ecosystems and materials.

Air quality management includes the following steps (PHILIPPI JR, 2005): the process of assessment of air quality-air quality monitoring; the strategic planning in the formulation of policies and decision-making and the development of a set of preventive actions and measures for pollution control.

The air quality monitoring can be accomplished by collecting data or systematic sampling of particulate matter and gaseous pollutants emitted into the atmosphere both in urban areas and industrialized regions (PHILIPPI JR, 2005).

Particulate matter, according to Chalvatzaki et al. (2012), consists of a mixture of solid particles and liquid droplets of various sizes and chemical compositions suspended in the atmosphere. In particular, toxicologists have paid attention in fine particles (PM2.5 particles with aerodynamic diameter – less than 2.5 μm) and ultrafine (particle size of approximately 0.1 μm in diameter or less) that cause adverse effects to human health, visibility and climate (BUONANNO et al., 2011 and CHALVATZAKI et al., 2010).

Second Philippi Jr. (2005), gaseous pollutants present in the molecular form, as for example, carbon monoxide (CO), carbon dioxide (CO_2), nitrogen oxides (NO_x), etc., and can be issued directly by the polluting sources (primary pollutants) or formed from photochemical reactions occurring in the troposphere between the primary pollutants (secondary pollutants).

The main air pollutants originate mostly from burning fuels, for shipping purposes and industrial production. Among the various types of fuel available for consumption, has been receiving increasingly highlight the biomass, because presents much smaller environmental impacts than fossil fuels, however still feature impacts not fully studied. The term biomass means the biodegradable fraction of products, waste and organic waste from agriculture, forestry and related industries, including fisheries and aquaculture, as well as the biodegradable fraction of industrial and municipal waste (BARBIERI et al., 2013).

For example, the use of rice husks for power generation can add value to the rice produced by industries, because the ash generated by the controlled burn of its bark can be used in various industrial branches, in addition to the hot gases emitted with the burning be used directly on rice drying (MAYER; HOFFMANN; RUPPENTHAL, 2006).

Since there are few studies involving the sampling of particles smaller than 2.5 μm from biomass burning and the control by a Venturi scrubber from biomass burning, this present study aimed to fill these gaps.

Therefore, this work tried to follow the guidelines for proper management of air quality, that is, perform the following steps:

1) To carry out the monitoring of emissions of gases and particulates into the atmosphere by burning of rice husk used by industry;

2) Analyze the data collected under national and international environmental legislation;

3) Analyze the control (corrective action) of pollutants emitted through a Venturi scrubber.

2. LITERATURE REVIEW

2.1 Biomass burning - emission of pollutants

The quantification of the emissions and particulate matter associated with biomass burning is essential for investigation of atmospheric processes, as well as governmental authorities which establish air quality standards. Currently there is still lack of consistent databases of emissions, making it difficult to climate modeling, photochemical modeling, emission inventories and the identification of emission sources (FERNANDES, 2009).

The biomass burning emits large quantities of carbon in the form of CO_2, CO, CH_4 and particulate pollutants and their concentrations depend on the type of burning biomass (chemical composition), and firing conditions (FERNANDES, 2009 and BARKER et al., 2007). When the combustion of the biomass is complete, the liberated substances are H2 O and CO_2, in addition to the heat. However, in practice, combustion is hardly complete and, therefore, there is also the release of particulate matter, CO and other products considered pollutants (SOARES, 1995). Emissions of these pollutants by incomplete combustion are largely influenced by the equipment and the process, that is, short residence time in the combustion chamber, low temperature combustion or poor fuel-air mixture (lack of oxygen).

With respect to the phase combustion (ignition, flame filament), emission (concentration) of particulate material reaches the maximum value during the call phase and decrease throughout the combustion process, with lower values for the filament phase addition addition, the greatest concentrations relate to smaller particle diameters (HOSSEINI et al., 2010 and COSTA et al., 2012). As for the gaseous pollutants produced by incomplete combustion (CH_4, CO, etc.) are mainly emitted in the filament phase, while most of CO_2 (products of complete combustion) is emitted during the call phase (SOARES NETO et al. 2011; OZGEN, CERNUSCHI and GIUGLIANO et al, 2013, and AMORIM et al, 2013). That is, the concentrations of pollutants from incomplete combustion increases as the concentration of CO_2 decreases (AMORIM et al., 2013).

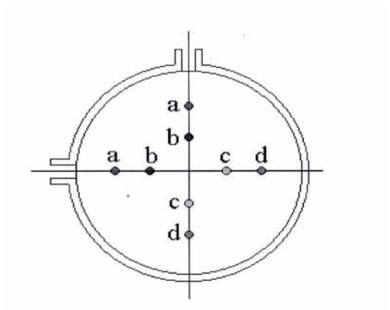
2.2 Biomass burning - particulate matter sampling

The particulate material in the source sample, in case of combustion (burning) of the biomass consists of collecting a sample volume of gas moving through the duct burner or chimney biomass to obtain a representative fraction of the total flow. The concentration within the instrument used to perform the measurement not necessarily have to be the same as that in the flow from which the sample is extracted. The sampling rate must be identical to the flow velocity, which features an isokinetic sampling (CARVALHO JR; LACAVA, 2003).

According Esmanhoto (2010), the sampling probe is to be entered section as perpendicular as possible to the flow. And, as in a duct there is no uniformity in the gas flow and hence non-uniformity of particle concentration, it is extremely important that the location of the sampling points to be selected carefully.

Environmental Company of the State of São Paulo (CETESB), through technical standard L9.221: 1990 indicates that for chimneys or circular section ducts, one should choose a cross section that is at least 8 internal diameters downstream and 2 internal diameters upstream from any flow disturbance as curves, expansion, contraction, inputs and outputs.

In addition to the cross section, attention should be paid to the sampling points in this section. For BSI Standards by standard BS 3405:1983, sampling should be done with 4 or 8 sampling points located at 2 or 4 sampling lines and points go from the center of 4 or 8 equal areas. The location of those points can be observed in Fig.1.



Sampling point*	Distance from wall according to standard*	Wall distance (cm) for this study **
a	0,065 D	1,1
b	0,250 D	4,4
c	0,750 D	13,2
d	0,935 D	16,4

Figure 1. Sampling points in the cross section according to the standard BS 3405:1983*. For this paper D = 17.54 cm**

2.3 Recent studies on the issue and sampling particulate matter

Estrellan and Lino (2010) conducted a compilation of actual data from studies and simulations of pollutant emissions from open burning (open) of different types of biomass (burning of agricultural waste, burning of household waste and wood for heating and cooking , forest fires, etc.) and came especially to the following conclusion regarding the burning of agricultural residues. The open burning of waste from agriculture is a low-cost method to control insects, diseases and the invasion of weeds. However, as the economic and practical benefits of burning such wastes is apparent, environmental and health risks of this activity need to be recognized. Open burning of waste samples of various agricultural products such as rice and sugarcane showed a variety of pollutant emissions such as particulate matter, carbon monoxide, methane, volatile organic compounds, etc. For example, sampling of particulate material from the burning of the rice crops in Taiwan made by Cheng et al. (2009) showed a significant increase in PM2.5 and PM10 concentrations in the air during such burning. The amount of fine particles (PM2.5) increased from 32.61 $g.m^{-3}$ (non-burning period) to 123.61 $g.m^{-3}$ (burning period). These figures are well above the WHO - World Health Organization - standard (25 $mg.m^{-3}$ for 24 hours of sample) as well as the authors mention, the standard set by the US Environmental Protection Agency (EPA) (35 $mg.m^{-3}$ for 24 hours sampling).

Hossain et al. (2012) observed the burning characteristics of rice husk and concluded that the largest concentrations of particles (3.5×10^5 $g.cm^{-3}$) occurred to around 0.15 μm diameter on flame combustion phase i.e. ultrafine particles. These concentrations also exceeded the maximum limit of 25 $\mu g.m^{-3}$ established by WHO. To the three conditions of combustion (flame, glowing and open burning) distributions of particle diameters for the burning of the rice husk resulted in unimodal distributions (140.7 nm, 88.2 nm and 53.3 nm, respectively). A reason for this descending order of distribution may be due to volatile organic carbon fractions being influenced by different temperatures in different conditions of burning (227ºC, 193ºC and < 193ºC, respectively). The order of the distributions of diameter was the same as the order (descending).

2.4 Biomass burning - gas sampling

As the concentration of the combustion gas components provides a number of important information to the combustion process and, in general, instruments that perform this measurement values provide on a dry basis, i.e. without water. Water may become liquid within the analysis instrument interfering in its measurement system (CARVALHO JR and LACAVA, 2003).

The sampling and conditioning of gas to be analyzed can be done continuously or discontinuously, by extracting a fraction of these gases and direction to the analyzing equipment or directly on site (flare stack biomass) in continuous measurement process (ALMEIDA FILHO, 2008).

2.5 Recent studies on the issue and gas sampling

Fernandez et al. (2012) conducted a comparison of the six most common types of biomass (almond hulls, rice husk, rice straw, bagasse wine, wood pellets, charcoal) in the Spain which could be used as combustible fuels substituents fossils. Such biomass were characterized (morphology, composition) and subsequently burned for analysis of the emitted gases (O_2, CO, CO_2, NO_x, SO_2) using the gas analyzer Testo 350 XL Testo 454 Testo Brazil Ltda. With regard to CO emission, coal plant biomass and wood pellets showed the highest values during firing: 2000 and 6000 ppm, respectively. The authors explain that some biomasses, such as almond bark, need a very low air supply for complete combustion, while samples as wood pellets and charcoal have the worst combustion rates (need lot of air). Rice husk had issued around 600 ppm. The relationship between CO and CO_2, coal plant biomass and wood pellets showed the highest values, again suggesting that the use of these biomass as fuel is disposed. The higher the ratio CO/CO_2, the worse the rate of combustion. The wood pellets, besides the high concentration of emitted CO, also showed high NO_x concentration during firing (near 100 ppm), while the other biomass such as rice hulls, issued around 10 to 20 ppm.

2.6 Biomass burning - control particulates and gases

There are various equipment used to control particulate emissions emitted by industries, including cyclones, filters, electrostatic precipitators, sedimenters, etc. One such option is the adoption of gas scrubbers, also known as scrubbers.

The scrubbers are used not only as particulate pollution control equipment, but also gaseous pollutants (COSTA, 2002 and PHILIPPI JR, 2005). The cleaning elements are the droplets formed from the injection of a liquid, usually water, gas containing contaminants (GUERRA, 2009).

Therefore, this type of equipment, the gas carrying particles is forced through a spray of water droplets with which the particles collide and are deposited in them by increasing size and allowing for collection (PHILIPPI JR 2005).

2.7 Recent studies on the particulate matter collection efficiency and pollutant gas into a venturi scrubber

Costa et al. (2008) used two Venturi scrubbers, a rectangular section and another circular section, on a laboratory scale, for the control of particulate matter from biomass burning arising out of a timber industry. The variables studied were the liquid flow rate (QL) (0.4, 0.6 and 0.8 L / min), the gas velocity (Vg) (20 and 22 m / s) and the length of neck 90 mm. The sampling system consisted of a vacuum pump for sucking gas stream a mass flow meter, a system of nozzles and isokinetic sampling probe. The particles (17 um of diameter) were suctioned by the probe located at the center of the duct through the vacuum pump and dust retained in the filter membrane was then analyzed (mass of particles) to obtain the overall efficiency by Eq. (1) in each test. The equation parameters are: E = particulate matter collection efficiency (%); Ci = concentration at the entrance (ug.m^{-3});Cf = Concentration at the exit (g.m^{-3})

$$E = \frac{C_i - C_f}{C_i} \times 100 \tag{1}$$

Collection efficiencies obtained were greater than 96% in all tests conducted by Costa et al. (2008), and the rectangular Venturi showed the highest values. The collection efficiency increased with increasing gas velocity in the throat for both geometries washer. The liquid flow rate of 0.6 L / min provided the highest efficiency among the tests, except for the Venturi circular with gas velocity in the throat of 22 m / s with the highest efficiency for liquid flow rate of 0.8 L / min.

Pourmohammadbagher et al. (2011), unlike the previous authors conducted a study on the simultaneous removal of gaseous pollutants (NO, NO_2, SO_2 and CO_2) using a venturi scrubber and with the liquid water and a solution 2% v / v NaOH. The liquid flow rate (QL) were 1.5, 4, 6.5, 9 and 11.5 L / min and the gas stream (Qg) were 3.3, 5, 6.6 and 8.3 m3 / min. The collection efficiency was calculated based on the difference between the concentrations of pollutant gases at the inlet and outlet of the Venturi according to Eq. (1) using a gas sampler based on the electrochemical method of pollutant gas concentration measurement.

The lower collection efficiencies occurred due to NO to NO is relatively insoluble in water. NO_2, SO_2 and CO_2 had a small decrease in efficiency with increasing gas flow. was also observed an increase in collection efficiency of all gases with the use of the solution 2% v / v NaOH, and SO_2 was completely removed from the gas stream (overall efficiency of collection of 100%). Increasing the liquid flow led to an increase in all pollutants collection efficiency to a maximum extent, subsequently decreasing with increases in the fluid flow. These results show the importance of liquid-gas contact, because with higher liquid flow contact between this and the gas is impaired and collection efficiencies decrease.

3. MATERIALS AND METHODS

In this study It was used rice husk as biomass. The burning of biomass were carried out with the aid of a biomass burner coupled to a biomass feeder (Fig. 2). The gases emitted by burning were directed to the exhaust chimney, with inner diameter of 17.54 cm. The particulate matter sampling was made in a crosssection to 8 diameters downstream internal (8 D) and 2 internal diameters upstream (2 D) of disturbances found in the chimney of the biomass burner (Fig.3) as the technical norm CETESB L.9221 (1990). Were observed sampling points a, b, c, d in two axes in cross-section chosen, according to standard BS 3405 (1983) (Fig. 1).

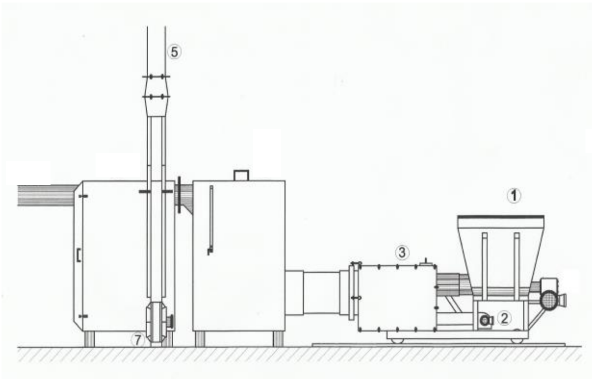


Figure 2. Feeder and biomass burner and chimney: (1) feeder of biomass; (2) air feed controller;(3) biomass burner; (5) chimney; (7) blower

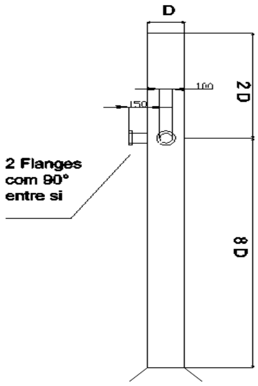


Figure 3. Scheme of sampling holes positions in the chimney

The instrument used for sampling of particulate matter was DataRAM 4, model DR-4000. It was designed to measure the concentration of particulate matter (liquid or solid) in spraying in the air, as well as the average particle size, temperature and humidity of the gaseous flow, providing discrete and continuous reading, as well as the electronic record of this information. Sampling of gases emitted by the burning of biomass was held at the same location where sampling was made of particulate matter (fig. 3). The UniGas 3000 + sampling equipment was installed in the same horizontal line sampling point of particulate matter. This instrument has electrochemical sensors that make reading the internal concentrations of oxygen (O_2), carbon monoxide (CO), nitrogen oxides (NO_x) and sulfur dioxide (SO_2). The temperature of gas and air are used in conjunction with the analysis of gas to calculate efficiency, excess air and the concentration of carbon dioxide (CO_2).

4. RESULTS AND DISCUSSION

4.1 Sampling of particulate matter

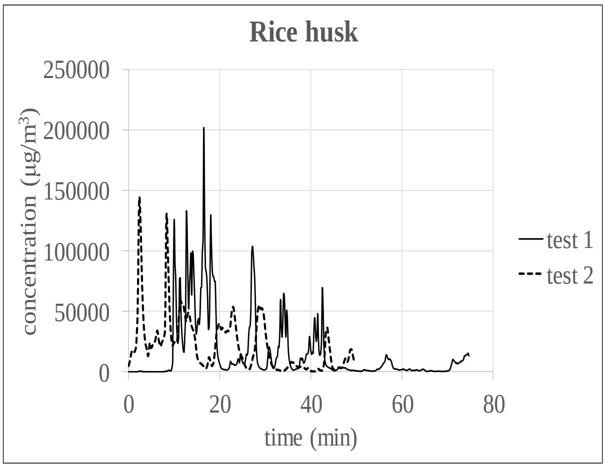


Figure 4. Concentration of PM2.5 as a function of burning time – rice husk

The concentration of particulates reaches a maximum during the stage of the flame and decreases throughout the combustion process (peak concentrations) (filament layer), as also observed for the work of Hosseini et al. (2010) and Costa et al. (2012). The average concentrations in the two phases were combustion cited: 25327.75 g.m^{-3} (Test 1 - Flame phase) and 3244.99 g.m^{-3} (Test 1 - filament phase); 23551.11 mg.m^{-3} (test 2 - called phase) and 22829.51 ug.m^{-3} (test 2 - Incandescent phase). The adequacy of the standard air quality established by WHO for fine inhalable particles of 2.5 mg.m^{-3} for a 24-hour sampling, we found that in almost all tests with rice husk this value was exceeded (concentration average for test 1 = 15983.15 g.m^{-3} and average concentration for testing 2 = 23322.93 g.m^{-3}).

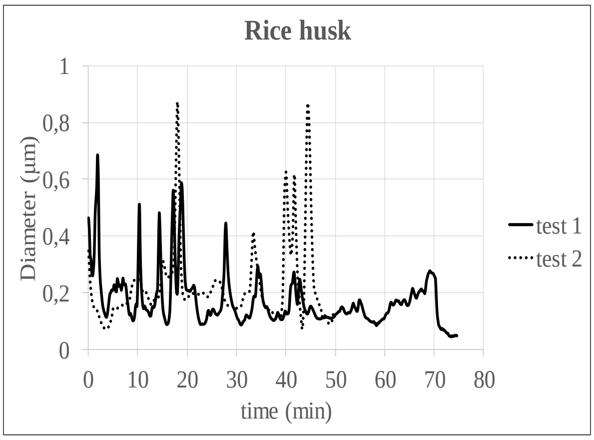


Table 1. Minimum and maximum diameters - rice husk

	Average diameter (µm)			
	Flame phase	Incandescente phase	Minimum diameter (µm)	Maximum diameter (µm)
Test 1	0,1983	0,1379	0,0425	0,6868
Test 2	0,2180	0,2190	0,0709	0,8737

Figure 5. Particle diameter as a function of time – rice husk

In Fig. 5, the interfaces between the phases and flame filament, there was inverted peaks (smaller diameters) for two tests (0.1578 µm - test 1 and 0.0746 um - test 2), as also observed by Costa et al. (2012).

It can be observed from Fig. 5 and Tab. 1 that the filament phase there was a decrease in the diameter of collected particles (average filament diameter in the smaller phase stage in the flame), and test 2 had almost the same average in the two phases due to the filament phase it has been extended for less time (test stopped). According to Hossain et al. (2012), one reason for the decreasing order of diameters between phases of flame and glowing (conduct contrary to other biomasses studied that showed increasing order of diameters between phases of flame and glowing), it may be due to the basic nature of particles together with volatility. Particles emitted from the rice husk during glowing stage were completely volatilized by heating at 150 ° C, while the majority of the particles in the flame phase were retained up to 250ºC. That is, according to Hays et al. (2005), the fractions of volatile organic carbon present in the burning of rice hulls are composed of over 200 compounds have melting points in the range of 0 ° C to 250 ° C. Therefore, the different combustion conditions (temperatures for different phases) may act differently for the different particles (distinct melting points), potentially facilitating the fastening process with other particles, resulting in an increase in diameter (the higher the point melting, lower volatilization and therefore greater attachment between the particles and larger diameter, which happened in the flame phase).

4.2 Sampling of gases

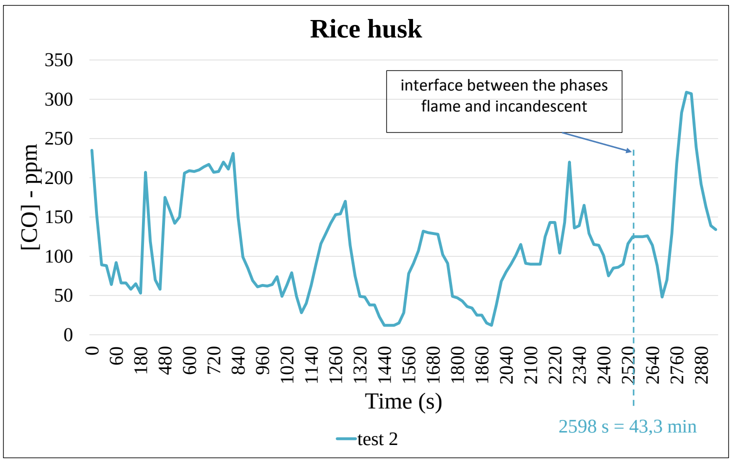


Figure 6. CO concentration versus burning time - rice husk - Test 2

The observation of Fig. 6 and in particular the stages of combustion bounded by interface demarcated in the same figure, show a tendency to increase in CO concentration along the incandescent phase.

Regarding the stages of combustion, their concentrations at the stage of flame and incandescent, respectively, were 235 ppm and 309 ppm. These values are consistent with those observed by Soares Neto et al. (2011) and Hossain et al. (2012) who concluded that maximum CO concentrations appear in the incandescent phase. Even Hossain et al. (2012) observed in their study that the CO relationship between phases of flame and incandescent resulted 1: 2.6.

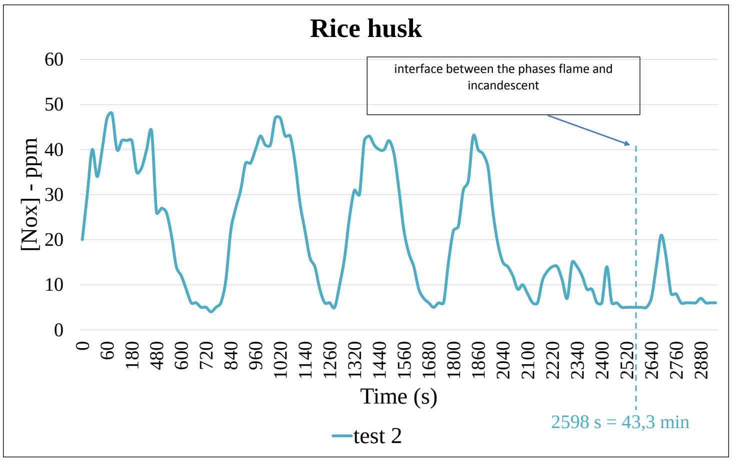


Figure 7. NOx concentration as a function of burning time - rice husk - Test 2

Through Fig. 7 it can be seen that NOx emissions decreased to flame phase to incandescent phase.

Table 2. Average overall efficiency of particulate matter collection, penetration of the liquid jet and liquid-gas ratio - rice husk

Eficiência global média de coleta de material particulado (%)	Penetração do jato (l*) (mm)	Penetração máxima da linha central do jato (l**) (mm)	L/G (L/m^3)
86,3	3,7	5,6	0,068

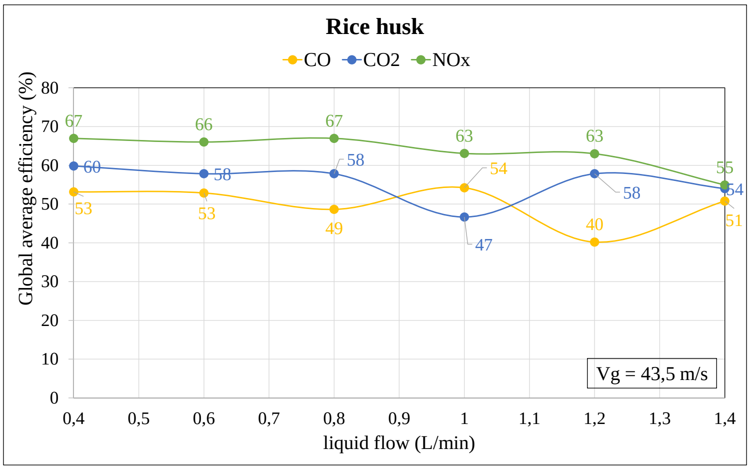


Figure 8. Overall average collection efficiency of gas vs liquid flow - rice husk

By Fig. 8 we observed that the maximum NO_x collection efficiency for the rice husk was 67% for liquid flow rate of 0.8 L / min. The higher the gas velocity, the higher the collection efficiency.

The maximum efficiency of collection of CO_2 was achieved for the smaller flow of liquid (0.4 l / min) with a tendency to decrease as the liquid flow rate was increased, as also observed Pourmohammadbagher et al. (2011).

CO_2 collection efficiencies were higher than CO for all fluid flow except to 1.0 L / min. To measure this flow CO_2 concentration was higher (0.25%), and therefore, had the lowest efficiency (47%), since the greater the concentration of gas is lowest collection efficiency.

5. REFERENCES

ALMEIDA FILHO, F. *Monitoramento e controle de emissão de material particulado em uma fonte estacionária*. 2008. 131 f. Dissertação (Mestrado) – Programa de Pós-Graduação em Engenharia Química, Universidade Federal de São Carlos, São Carlos, 2008.

AMORIM, E. B. et al. Influence of specimen size, tray inclination and air flow rate on the emission of gases from biomass combustion. *Atmospheric Environment*, v. 74, p.52-59, 2013.

BARBIERI, L. et al. Management of agricultural biomass wastes: Preliminary study on characterization and valorisation in clay matrix bricks. *Waste Management*, p. 2307-2315, 2013.

BARKER, T. et al. *Mudança do clima: Mitigação*. Reino Unido: Editora da Universidade de Cambridge, 2007.

BSI STANDARDS. *BS 3405: British Standard Method*. Measure of particulate emission including grit and dust (simplified Method), 1983.

BUONANNO, G. et al. Chemical, dimensional and morphological ultrafine particle characterization from waste-to-energy plant. *Waste Management*, p. 2253-2262, 2011.

CARVALHO JR, J. A.; LACAVA, P. T. *Emissões em processos de combustão*. São Paulo: Editora da Unesp, 2003. 137 p.

CETESB. *L9.221: Dutos e chaminés de fontes estacionárias*. Determinação dos pontos de amostragem, 1990.

CHALVATZAKI, E. et al. Aerosol technology, properties, behavior and measurements of airborne particles. *Waste Management*, p. 2456-2468, 2012.

CHALVATZAKI, e. et al., Measurements of particulate matter concentrations at the landfill site (Crete, Greece). *Waste Management*, p. 2058-2064, 2010.

CHENG, M. T. et al. Particulate matter characteristics during agricultural waste burning in Taichung city, Taiwan. *Journal of Hazard Mater*, v. 165, p. 187-192, 2009.

CORTEZ, L. A. B.; LORA, E. E. S.; GÓMEZ, E. O. (Org.). *Biomassa para energia*. Campinas: Editora da Unicamp, 2008. 736 p.

COSTA, M. A. M. et al. Controle da emissão de poluente particulado emitido pela queima de biomassa usada como combustível. In: *Congreso Interamericano AIDIS*, 31., 2008, Santiago. Anais...

COSTA, M. A. M. et al. Real-time sampling of particulate matter smaller than 2.5 um from Amazon forest biomass combustion. *Atmospheric Environment*, v. 54, p.480-489, 2012.

ESTRELLAN, C. R.; LINO, F. Toxic emissions from open burning. *Chemosphere*, v. 80, p. 193-207, 2010.

FERNANDES, A. P. S. *Emissão de PM2,5 e gases em sistemas domésticos de queima de biomassa*. 2009. 67 f. Dissertação (Mestrado) – Programa de Pós-Graduação em Engenharia do Ambiente, Universidade de Aveiro, Aveiro, 2009.

FERNÁNDEZ, R. G. et al. Study of main combustion characteristics for biomass fuels used in boilers. *Fuel Processing Technology*, v. 103, p. 16-26, 2012.

GUERRA, V. G. *Investigação do efeito de injeção de líquido por orifícios múltiplos na formação de gotas em um lavador Venturi*. 2009. 154 f. Tese (Doutorado) – Programa de Pós-Graduação em Engenharia Química, Universidade Federal de São Carlos, São Carlos, 2009.

HAYS, M. D. et al. Open burning of agricultural biomass: physical and chemical properties of particle-phase emissions. *Atmospheric Environment*, v. 39, p.6747-6764, 2005.

HOSSAIN, A. M. M. M. et al. Volatility and mixing states of ultrafine particles from biomass burning. *Journal of Hazardous Materials*, v. 205-206, p. 189-197, 2012.

HOSSEINI, S. et al. Particle size distributions from laboratory-scale biomass fires using fast response instruments. *Atmospheric Chemistry And Physics*, v. 10, p.8065-8076, 2010.

MAYER, F. D.; HOFFMANN, R.; RUPPENTHAL, J. E.. Energy, economic and Environmental Management of the residue of rice husk in small and medium-sized agro-industries of rice. In: *Symposium on production engineering*, 13, 2006, Bauru. Anais ....

OZGEN, S.; CERNUSCHI, S.; GIUGLIANO, M. Experimental evaluation of particle number emissions from wood combustion in a closed fireplace. *Biomass & Bioenergy*, p.1-10, 2013.

PHILIPPI JR, A. *Sanitation, health and environment: foundations for sustainable development*. Barueri: Manole, 2005.864 p.

POURMOHAMMADBAGHER, A. et al. Simultaneous removal of gaseous pollutants with a novel swirl wet scrubber. *Chemical Engineering and Processing: Process Intensification*, v. 50, p. 773-779, 2011.

SOARES, R.V. Queimas Controladas: Prós e Contras. In: *Fórum Nacional sobre Incêndios Florestais*, 1., 1995, São Paulo. Anais...São Paulo, p. 6-10.

SOARES NETO, T. G. et al. Laboratory evaluation of Amazon forest biomass burning emissions. *Atmospheric Environment*, v. 45, p. 7455-7461, 2011.

WHO. Air quality and health. Disponível em: <www.who.int/mediacentre/factsheets/fs313/en/index.html>. Acesso em: 05 set. 2012.