Emission of carbon dioxide (CO_2) and other gases by burning sugarcane bagasse

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Abastract.
This study aims to quantify gas emissions, mainly CO_2, CO and NOx, from the sugarcane bagasse burning for different burner operating conditions and evaluate the emission control of these pollutants using a Venturi scrubber. CO_2, NOx and SOx are anthropogenic air polluting agents, these gases are emitted in the search for energy sources by the various industrial sectors. Although biomass burning is considered a mitigating measure, because its source is renewable, and also the formation and growth process of the plant are steps that capture CO_2 from the atmosphere, but the product of burning solid fuels is a mixture of various components, such as particulate materials, CO_2, CO, NOx, oxides, VOCs, among others, and may contain F, Hg and As. Part of this emission comes from the sugarcane bagasse burning, which is a waste product of the sugar and alcohol industry. CO_2 accumulation in the atmosphere brings negative effects to the environment, such as increased retention of solar energy, increasing the temperature of the planet, and reducing air quality. Material and Methods: The biomass used as fuel in the gas emission tests was sugarcane bagasse. The bagasse combustion process occurred in an experimental burner, comprising a rotary feeder, combustion chamber, exhaust gas chamber, Venturi scrubber, cyclone, blowers and exhaust ducts. The Venturi scrubber, located between the burner and the cyclone, has a rectangular geometry. For each gas velocity evaluated (3.4; 5.3; 7.0; 9 and 11 m/s), water flow rates between 2.5 L/min to 6.0 L/min were analyzed. The results showed that CO concentrations ranged from 34 to 311 ppp, and for NOx the concentrations were 8 to 80 ppm, NO_2 between 0.87 to 1.07, SO_2 values from 2.66 to 4.23, while those for CO_2 reached values from 6000 to 26000 ppm.

Keywords: CO_2 emission, biomass fuel, NOx emission, CO emission, pollutants control

1 Introduction

One problem society face is the increasing concentration of atmospheric CO_2 (which reached 407 ppm in 2018) and other greenhouse gases (GHGs) (Blunden and Arndt, 2019). The accumulation of CO_2 in the atmosphere brings negative effects to the environment, such as increased retention of solar energy, increased temperature of the planet, and reduced air quality. Studies have also observed a reduced rainfall effect (Julião, 2021). The global temperature is predicted to rise for the next few decades, even if humanity succeeds in stopping GHG concentration at the current level. To mitigate or reverse the anthropogenic contribution of CO_2 emissions (Hansen et al., 2017), significant reductions in GHG emissions from current economic activities and the simultaneous development of efficient technologies that can capture and or store or utilize CO_2 are of paramount importance (Dominic Bui Viet, et al., 2020). Capturing CO_2 from industrial sources does not represent a technological or scientific hurdle, but existing methods and technologies (including high-purity CO_2 recovery and liquefaction) remain very costly. Thus, monitoring, improvement and optimization of CO_2 capture units still represent important challenges (German Montes-Hernandez, et al., 2020).

Studies have shown the possibilities of reducing the emissions of these pollutants, in which the potential of each country, the possible exchange of fuels or different technologies for capturing pollutants were considered.

The substitution of fossil fuels by biomass becomes compensatory for the environmental impacts, because it reduces CO_2 emissions, but still emits a significant amount of gaseous and particulate pollutants, which can impact the health of the environment. Biomass is considered a renewable energy resource with CO_2 neutral balance, which can contribute to climate change mitigation. In recent years, bioenergy from biomass burning accounted for 10% of the total energy produced in the background, ahead of any other renewable energy source, such as solar and wind. Approximately 12% in biomass electricity generation system (Rokni et al, 2018). Biomass appears to be an alternative fuel that can provide technical, economic, and environmental benefits, but there are some critical issues that have limited the use of this resource source (Bianchini 2018; Cabrera et al, 2020).

The study conducted by Rokni et al (2018) analyzed the emission of carbon dioxide from some biomasses, obtaining as a result a mole fraction of 9% CO_2 in the output effluent for coal burning, 2.2% for corn husk and 5.5% for rice husk. In Brazil the sugar and ethanol industry has attempted to make the most of its resources, using sugarcane as raw material, and its bagasse is the fuel used for energy generation (Freitas et al., 2021). In return for the energy benefits, the burning of biomass emits greenhouse gases and particulate matter (PM), which impact the climate and human health. Amores et al. (2013) evaluated that for every 1 kg of bioethanol produced between 15 and 22.5 kg of CO_2 were emitted.

According to Antunes (2011), the burning of sugarcane straw, which is considered a disposable raw material, is one of the most critical points in the emission of greenhouse gases such as CO_2, because it drives the increase of air pollution by smoke and soot. Rokni et al (2018) in their study to analyze the emission of gases from the burning of biomass mixed with coal, because by mixing the fossil fuel to the renewable the total cost tends to decrease, but one should take aspects such as availability and cost of coal to perform this mixture of raw materials. The results showed a mole fraction of 9% CO_2 in the effluent output for coal burning, 2.2% for corn husk, and 5.5% for rice husk. The results showed that the emission of carbon dioxide is higher for samples containing roasted biomass compared to raw biomass. The carbon dioxide emissions from burning the two types of coal, were decreased in all the blends with biomass, with the reduction being more expressive for the blends of biomass and bituminous coal. The NOx emissions were also reduced using the biomass coal blends. Kazanc et al (2011) conducted a study analyzing the emissions from burning coal and bagasse in O_2/N_2 and O_2/CO_2 environments, and as a result obtained an emission, in mole fraction, of 15 to 18% CO_2, for burning coal, while the CO_2 emission for burning pure bagasse was between 0.6% to 1.4%, due to the lower concentration of carbon in biomass

Thus, it is evident that there is an urgent need to quantify, reduce PM concentrations and gases from industrial processes using biomass as an energy source for the safety of human health and the climate.

Methods for CO_2 capture

The most used methods for controlling and capturing CO_2 are the wash column and the droplet separator. In the wash column the gas comes into contact with the water flow, absorbing part of the carbon dioxide. In droplet separators, the pollutant is collected by means of inertial impaction and impact mechanism (Fang et al, 2020).

Post-combustion capture technology is the most developed and the processes of adsorption (surface gas binding), absorption, distillation, membrane separation, and gas hydrates have been determined to be potential mechanisms for CO_2 capture in this area of energy production. The selection of CO_2 capture is based on fuel composition, heat, the influence of water, the resulting partial pressure of the gas mixture, and the configuration of the power plant (Wenqiang Sun, et al., 2020 and Rao and Rubin 2002).

Recent studies seek to enable the use of scrubbers to reduce the emission of carbon dioxide, based on the assumption that, to optimize the absorption of CO_2, one must find the best operating conditions for this equipment (Khani et al, 2021). Scrubbers are equipment that have the function of controlling the pollution emitted into the atmosphere through the use of an atomized scrubbing liquid to drag the gases and particulate materials coming from a gas stream and, at the same time, are able to reduce the temperature of this stream. As scrubbers use a fluid against an air stream, scrubbers have the advantage over other pollution control equipment of reducing the temperature of the gas stream while removing solids, mists, and gases, and are a multi-disciplined device. As the gas composition that forms the effluent to be treated by the scrubber can change, it is possible to alter the liquid responsible for scrubbing so that it has more affinity with the pollutants you wish to remove from the gas stream (Wermac, 2021). Specifically Venturi-type scrubbers, the subject of this study, are highly efficient in removing small particles from gas streams and gaseous pollutants simultaneously (R. Bagheri, et al. 2019, M.K. Al Mesfer,et al., 2018 and Gregori, 2020).

Venturi scrubbers can remove gases and solid pollutants from the contaminated gas stream in a single process stage and are simple and small pieces of equipment (Gregori, 2020). The gases flow through the convergent section of the scrubber, where they are accelerated to enter the throat, where they reach their highest velocity, in the range of 30 to 150 m/s. In the throat normally occurs the injection of liquid, which will perform the washing of the gas flow (Gregori, 2020; Ferreira, 2018).

When entering the equipment, the liquid takes the form of jets, as there is a difference between the velocity of the liquid and the gas, a drag force arises on the drops. The pressure energy of the gas flow is transformed into kinetic energy, which acts on the liquid, atomizing it and generating the drops. When the liquid passes to the atomization state, its surface area increases considerably, in addition the gas velocity, and the turbulence of the flow provide the transfer of mass and heat between the two fluids (Gregori, 2020).

Finally, in the divergent section, the liquid with the collected contaminants leaves the scrubber and the gas is decelerated and with lower concentration of pollutants. After the divergent section, a cyclone can be added, which has the function of separating the drops of liquid that remained in the gas flow (Gregori, 2020; Bianchini et al., 2018).

Recent studies attempt to make feasible the use of scrubbers in general, and especially Venturi scrubbers, as a way to reduce the emission of particles and carbon dioxide. These studies seek to find the best fluids and operating conditions for this equipment, to optimize the absorption of CO_2 (Khani et al, 2021). We can highlight the works of M. Khani et al, (2021), Yeawan Lee, et al, (2022), Nur Fadhilah Idris, et al, (2022), Mujahid Farooq, et al, (2022), Samadi et al. (2014), Pineda et al. (2014), Bagheri et al. (2019), Augusto Bianchin, et al., (2016) and (2018), Sheng-Lun Lin, et al. (2021), N. Abbaspour, et al., 2020, Wenqiang Sun, et al., (2020).

One of these studies, in a spray tower, was conducted by Samadi et al. (2014) who used as washing fluid, a mixture of Fe_3O_4/water, with 0.024% volume of iron oxide (II, III). Two conditions were tested, one with the action of a magnetic field and another without the action of this field, and as a result it was found that the CO_2 absorption is 21% higher when there is the presence of the magnetic field.

Pineda et al. (2014), also aiming to increase the absorption rate of carbon dioxide, conducted a study using nano fluids of SiO_2/methanol and Al_2O_3/methanol, in a vertical scrubber column. And thus, the results showed that the absorption rate increased by 9.7% and 9.4%, respectively.

Another study by Bagheri et al. (2019) added carbon nanotube walls to a wash column, using pure water and methyldiethanolamine as fluids. The authors had a result an increase in CO_2 absorption, of 26.4% and 21%, respectively, for each fluid used.

The study conducted by Abbaspour et al. (2020), was conducted in a Venturi scrubber, equipped with a permanent magnetic field, were used as fluids: ferrofluid and water. As a result, an increase in efficiency of 17.56% was obtained using ferrofluids, and 8.61% for water.

Khani et al. (2021) conducted a Venturi scrubber study using ferrofluid and a uniform magnetic field generated by a solenoid. The tests showed that this composition improved the carbon dioxide absorption efficiency of the Venturi scrubber by 20.6%.

2 Objective

The main objective of this study was to quantify the fixed source gas emissions relating them to the burning of biomass used as fuel. The specific objectives are: 1) to sample and characterize the fixed source emission in terms of NOx, CO and CO_2 emitted by burning sugarcane bagasse used as fuel; 2) to obtain data on the emission concentration of gaseous pollutants emitted by biomass combustion; 3) evaluate the effect of burning temperature on gaseous emissions and 4) to preliminarily evaluate a Venturi scrubber to control gaseous pollutants using water as scrubbing liquid.

3 Material and Methods:

3.1 Materials

The biomass used as fuel for gas emission was sugar cane bagasse. This material was provided by the Santa Cruz sugar and ethanol mill belonging to the São Martinho group, located in the city of Américo Brasiliense, state of São Paulo. The bagasse was exposed to the open air under the presence of sunlight to promote its drying and reduce the moisture content. To calculate the moisture content of the sugarcane bagasse, the material was collected at three different points and then placed in a drying and sterilizing oven at a temperature of 105°C until its weight became constant.

3.2 Pilot burner system and detail of the Venturi scrubber

The process of bagasse combustion was carried out in an experimental pilot burner. The equipment, which can be seen in Fig. 1, is composed of a rotary feeder, combustion chamber, exhaust gas chamber, Venturi scrubber, cyclone, blowers and exhaust ducts.

The system composed of the combustion chamber and container, properly insulated with rock wool in order to prevent the external side of the walls from reaching a temperature above 35°C, thus ensuring the safety of the operators.

After passing through the worm screw feeder, the bagasse is directed to the combustion chamber, where the burning process effectively takes place. After passing through the feeder, the sugarcane bagasse goes to the combustion chamber, where the burning process effectively takes place.

After the combustion starts, the fuel releases gases and particulate material, which goes to the gas receiver, while the residual ash remains in this chamber. For the combustion to occur continuously during the tests a fan was used to direct the external air to the burning system.

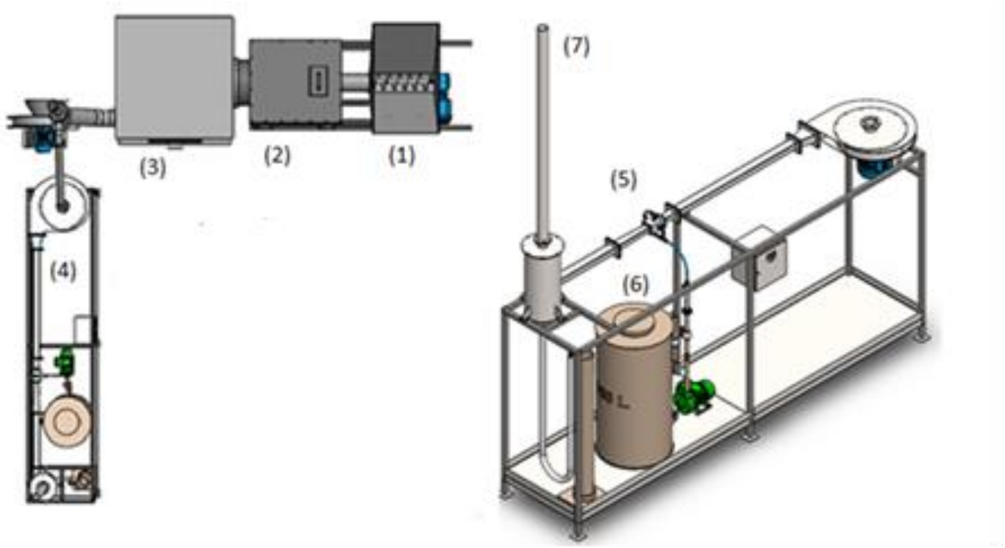
Knowing that the combustion chamber has the capacity to reach 900°C, for safety purposes, the system is controlled so that if the gases reach temperatures close to 400°C, the operation is automatically interrupted.

The temperature of the flames in the combustion chamber reached values above 900 C. According to Van Loo and Koppejan (2008) and Williams et al. (2012) for these temperature values occurred the processes of heating, drying (vaporizing the water present inside the raw material); the volatilization, in which occurs the thermal degradation of biomass, without the presence of an oxidizing agent, such as oxygen gas.

The first by-products begin to be formed, such as charcoal, carbon monoxide carbon dioxide; the combustion of volatiles and Combustion: the final process of fuel oxidation. The Venturi scrubber was used for the control of gas emissions and is located between the flaring system and the cyclone phase separator, as shown in the Fig. 2. Its dimensions are shown in table 1, while the subsequent figure exemplifies the profile of this equipment.

The gas stream, which contains particulate matter and gaseous pollutants, obtained after the burning of bagasse, is redirected to the Venturi scrubber by two blowers that pump this fluid, at velocities above 70 m/s. To ensure that the gaseous flow passes through the scrubber there are exhaust fans that perform this direction. The operating conditions, of the biomass burning, can be seen in table 2. Table 3 shows the gas velocities in the inlet, throat, and outlet pipes of the Venturi scrubber.

Fig 1. Pilot biomass burner scheme and control system feed chamber with a worm screw



Legend: (1) Feed chamber with an endless screw; (2) Combustion chamber; (3) Flame compartment; (4) Blower; (5) Scrubber Venturi; (6) Water tank and (7) Cyclone and Sampling chimney.

Fig 2. Collection system – Scrubber Venturi

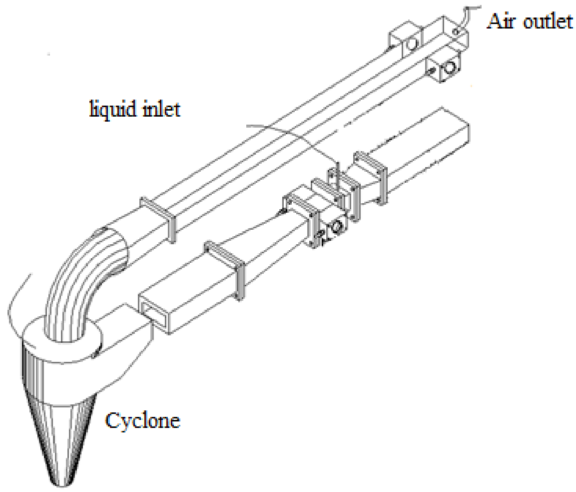


Table 1 - Venturi scrubber dimensions

Throat Length (L_{th})	11.7 cm	Convergent Length (L_C)	9.9 cm
Throat Width (W_{th})	2.4 cm	Convergent Width (W_C)	2.3 cm
Throat Height (H_{th})	3.5 cm	Convergent Height (H_C)	3.5 cm
Divergent Length (L_D)	28 cm	Injection Hole Diameter (Dh)	2.05 cm (x4)

Table 2. Operational conditions of the tests.

Parameter	**Values**
Water flow rate	2.5 L/min e 6.0 L/min
Rated power	0.36 MW
Combustion air flow	125 m^3/h
Biomass feed flow	18 kg/h
Biomass burnt per test	6 kg
Gas velocity at throat	88 m/s
Liquid/gas ratio	0,2 – 1,4 L/m^3
Number of orifices in a Venturi	4

Table 3. Gas velocities at the Venturi scrubber inlet, throat and outlet pipes.

Venturi frequency (Hz)	**V_{inlet} (m/s)**	**V_{outlet} (m/s)**	**V_{th} (m/s)**
20	49.3	3.4	88.1
30	76.6	5.8	136.9
40	97.3	6.0	173.9
50	121.3	8.8	216.8
60	146.8	10.3	262.4

3.3 Gas sampler

The gas sampler used will be the Chemist 500, consist of portable analyzers attached upstream of the Venturi scrubber and downstream of the droplet separator cyclone. It is a portable equipment, which works with electrochemical cells to measure the gases: O_2, CO, NO, NO_2, SO_2, CxHy and CO_2. Sampling will be performed by the sampling probe, attached to the thin wall nozzle and temperature and pressure gauge. The equipment probe will be inserted in the burner chimneys upstream and downstream of the scrubber, at the central point of the duct. In this sampler the gas sample is cleaned of moisture and impurities by a condensate filter positioned along the rubber hose that connects the probe to the analyzer. The gas is then analyzed for its components by electrochemical and infrared sensors. The sampling time was 5 min for evaluated variables, and 60 measurements were taken in this time. Seven batteries of tests were performed.

4 Results and discussion

4.1Characterization of sugarcane biomass

To obtain the sugar cane bagasse moisture, three samples of sugar cane bagasse were collected from different points of the amount exposed to open air to perform the drying, then they were placed in the oven at 105°C and weighed periodically until they reached a constant weight. Table 4 shows the biomass moisture values. The table 5 showed the elementary and immediate composition of sugarcane straw and bagasse.

Table 4 - Sugar cane bagasse moisture calculation.

Recipient	Total mass (g)	Mass of water (g)	Moisture (%)	Average humidity
Sample 1	1.761	0.100	5.68	5,9 %
Sample 2	1.776	0.109	6.14	
Sample 3	1.537	0.091	5.93	

Table 5. Elementary and immediate composition of sugarcane straw and bagasse.

Properties	**Straw**	**Bagasse**
Elemental Analysis (p%)		
Carbon (C)	44.50	45.45
Hydrogen (H)	5.63	5.53
Nitrogen (N)	1.1	0.74
Oxygen (O)	39.24	35.42
Sulfur (S)	1.26	1.24
H/C	0.17	0.12
O/C	0.88	0.78
Immediate Analysis (p%)		
Volatiles	80.03 ± 0.66	88.40 ± 2.16
Fixed Carbon	13.55 ± 0.96	9.12 ± 2.4
Ash	5.90 ± 0.55	2.31 ± 0.21
NCV* (MJ/kg)	15.17	15.96
CFS** (MJ/kg)	17.96	18.29

The results obtained from the sugarcane bagasse characterization analysis are in agreement with literature studies: K.R. Palma et al., 2021; Anh Tuan Hoang, et al., 2021). Wu et al. (2015) studied the influence of operational parameters, such as gasification temperature, equivalence ratio, feed rate and biomass water content on the performance of a bubbling fluidized bed gasifier operating with rice husk with 12 and 17 wt% moisture. The authors observed that, as expected, an increase in moisture led to a decrease in bed temperature, since water evaporation is an endothermic process. Finally, the authors advised moisture contents of up to 15 wt% to maintain a stable process. According to MARAFON et al., (2016) the higher calorific value PCS (MJ/kg) of sugarcane bagasse is comparable and higher than other biomasses, which encourages its use as a fuel. The PCS (MJ/kg) values of sugar cane bagasse, pine shavings, wheat straw, rice husk, olive pomace, cow manure, lignin, and cellulose are: 19.47, 20.23, 17.42, 16.3, 19,67, 17,36, 25 and 18.6 respectively. Telmo and Lousada (2011) report mn that increases in lignin content increase the heating value of the material. According to these authors, lignin is the component of plant cell walls that is richest in carbon and hydrogen, which are the main elements involved in heat generation. In biomass with high lignin content, combustion tends to be more efficient due to the higher heating value, as discussed by Telmo and Lousada (2011).

4.2 The emission concentration of gaseous pollutants emitted by biomass combustion

The flame temperatures in the combustion chamber were above 900 C and the combustion gases ranged from 125 to 340 C. Fig. 3 shows the emission concentration values for CO_2 for test batteries 2 and 3. Fig.4 shows the NOx and CO concentration values for battery 3. CO concentrations ranged from 34 to 311 ppp, and for NOx the concentrations were 8 to 80 ppm, NO_2 between 0.87 to 1.07, SO_2 values from 2.66 to 4.23, while those for CO_2 reached values from 6000 to 23000 ppm**.**

Fig.3. CO_2 and CO concentrations for different flue gas velocities

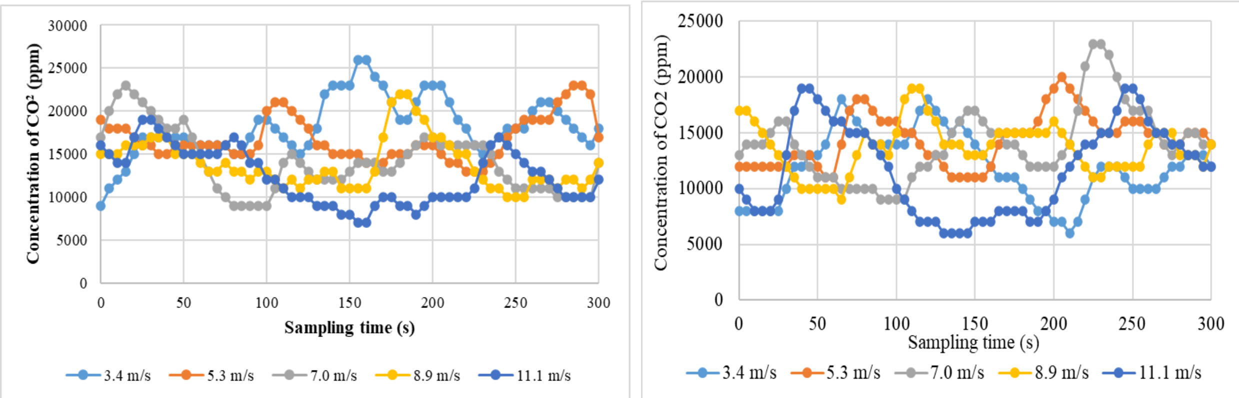
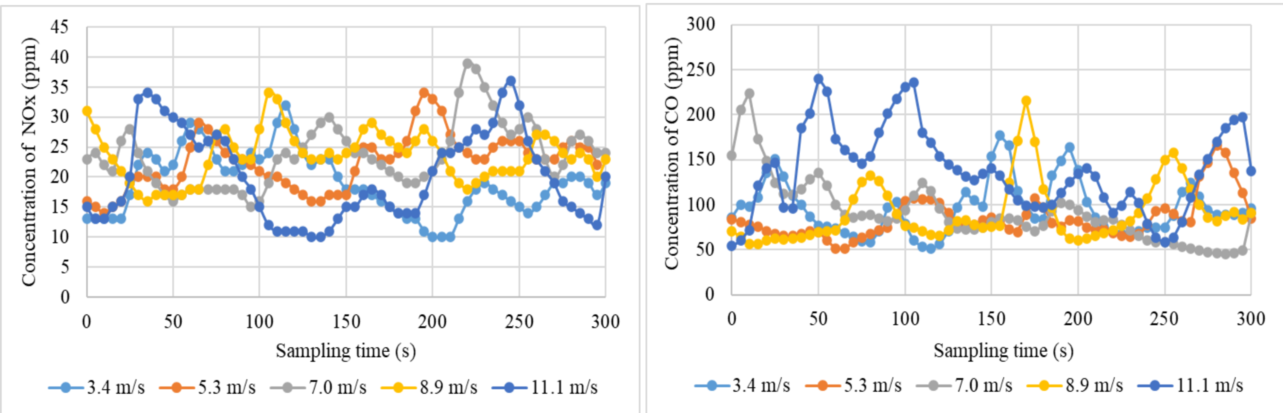


Fig.4. NOx and CO concentrations for different velocities of the flue gas outlet



Comparing the results obtained with other studies, with respect to CO, which in this study had an average concentration, of 44.40, for the first tests, and of 249.98 ppm, for the following ones, these numbers were close to the results of the author Marcondes (2015), who obtained an average concentration of 200 ppm for this gas during his experiment. The carbon dioxide emissions results were higher than those of Zajac et al (2017), who obtained values between 10000 and 13730, respectively, for wood and Virginia mallow pallets. The maximum concentration of SO_2 emitted, by bagasse burning, was 7 ppm, matching the concentration of 8 ppm, obtained by Marcondes et al., (2015).

However, Skopec et al (2014) and Zajac et al (2017) obtained a concentration of less than 1 ppm, when burning pallets of various types of wood. Skopec et al (2014) conducted a study to determine the emission of the gases, CO, NOx and SO_2, from burning biomass from wood pallets and straw, the values for CO and straw pallets were 3381 ppp and NOx of 240, higher values than using bagasse. The study by Cardozo et al. (2013) sought to compare emissions from burning commercial wood pallets with emissions from pallets made from sugarcane bagasse, sunflower husk, and Brazil nut shells. The results showed that bagasse emitted less than 100 mg/Nm^3 of NO, with 13% O_2, in tests on the burner with 12 and 13 kW of power. Under the same conditions, the bagasse emitted about 50 mg/Nm3 of CO, and about 45 mg/Nm3 of SO_2. The study by Amaral et al. (2013) sought to determine the concentrations of gases and particulate matter, emitted by sugarcane bagasse burning. The emission values for CO_2, CO, NOx and $PM_{2.5}$ were 23400 ppm, 1356 ppm, 17 ppm and 795.04 µg/m^3, respectively.

Regarding the legislation in force in the country (CONAMA Resolution No. 382/06), the emitted values of CO and NOx were above those allowed for stationary sources.

4.3 Results of burning temperature effects on gaseous emissions.

Figs. 5 to 7 show the values of the gas concentrations for the different biomass combustion situations. The results in fig 5 were obtained for a gas velocity in the duct of 8.9 m/s. In this test the highest temperature values and the highest CO2 emission values were achieved. The same behavior was identified for the gas velocities of 3.4,5.3, 7.0 and 11.1 m/s. CO2 concentrations for all gas velocities evaluated ranged from 2000 to 26000 ppm. In the biomass combustion process with the highest temperatures the highest concentrations of CO_2 and NOx are emitted.

Fig.5. CO_2 concentrations for different temperatures of the flue gas outlet (duct speed 8.9 m/s)

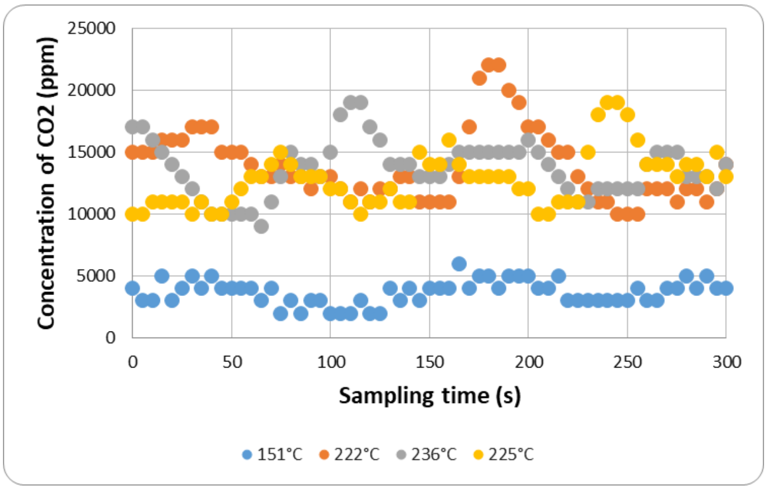
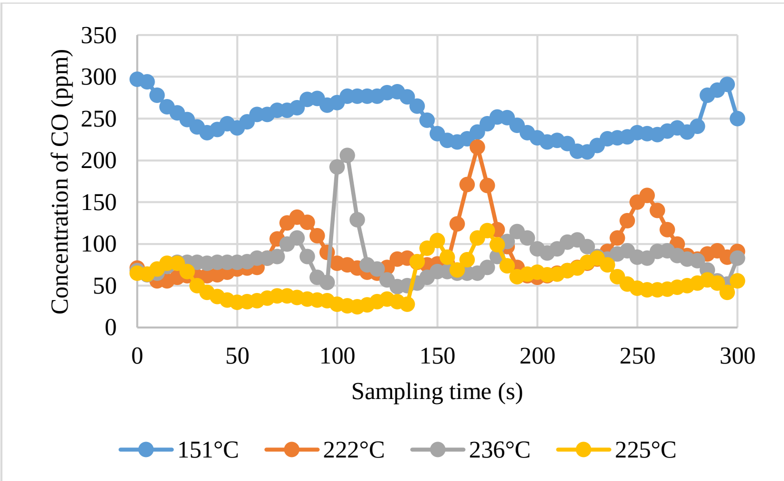


Fig.6. CO concentrations for different temperatures of the flue gas outlet (duct speed 8,9 m/s)

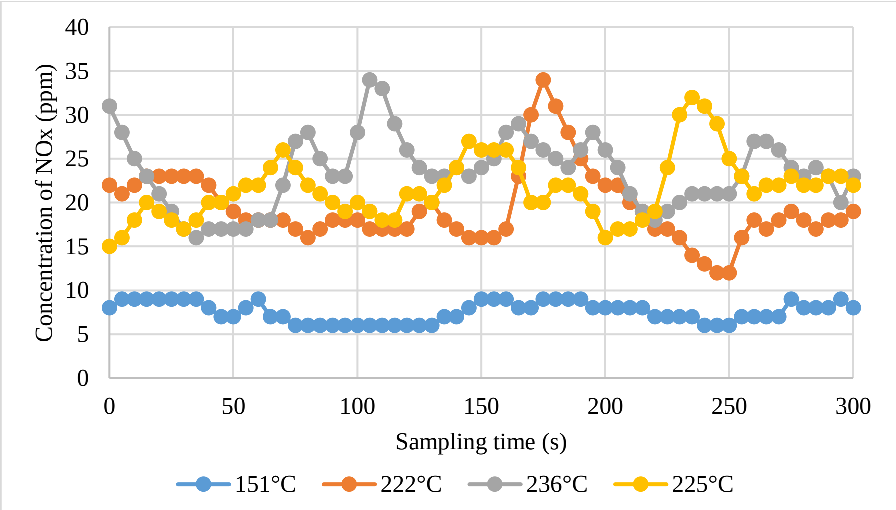


The flame phase is also characterized by high variation in fuel mass, as described by (Amorim et al., 2013). According to the results of Amaral, et al., 2014 high burning rates are associated with high temperatures.

Burning peaks were observed during the combustion phase. This is caused by the predominant burning of volatile compounds. Amorim et al. (2013) reported that the mass change is higher during the burning phase.
The maximum instantaneous EF value for CO_2 was expected in the burning phase because higher concentrations of this compound are emitted in this phase. The CO_2 emission values followed the temperature variations.
The results showed that there is a peak concentration of CO_2 and NOx during the flame phase of combustion and reduction during the smoldering phase (Amaral, et al., 2014).
According to Soares Neto et al. (2011), CO_2 emissions factor really is much lower in the flaming phase than in the smoldering phase. They concluded that this is mainly due to the predominant burning of volatile substances in the flaming phase, which includes compounds other than carbon.

The results for CO emissions had the opposite behavior to CO_2 and NOx with respect to temperature variation as expected for the combustion process. The highest emissions were observed for the lowest temperature values. The values ranged from 23 to 302 ppp, with the highest emission being for Vg = 11.1 m/s

Fig.7. NOx concentrations for different temperatures of the flue gas outlet (duct speed 8,9 m/s)



The CO emission factor was lower for biomass that had higher lignin content. NOx emission may be related to elemental chemical composition (N_2 content) in the fuel and not just to lignin content.
Os valores de NOx para os testes realizados variam de 5 até 40 ppm, sendo que os menores valores foram para as menores temperaturas (138, 148, 151 and 158 C).

Burling et al. (2010) also noted that the emission factor of NOx is mainly drive by nitrogen content in the fuel. Their results showed that emission factors of compounds containing elements other than carbon (e.g., N, S, Cl) may be highly dependent on the elemental composition of the fuel. El May et al. (2013) observed that the highest NOx emission rates are obtained with samples having the highest fuel nitrogen contents. The lignin content seems to influence the emission of carbon-based compounds, such as CO_2 and CO, due to its elemental composition (carbon, hydrogen and oxygen). The emission of NOx may be related mainly to nitrogen-based extractives. The CO concentration is at its lowest during the flame phase of combustion and increases during the smoldering phase.

For gases generated in the combustion phases, larger amounts of compounds such as CO_2 and NOx were generated in the flaming phase. During the smoldering phase, CO emissions predominated, this compounds resulting from incomplete combustion.

4.4 Preliminary results of the evaluation of a Venturi scrubber to control gaseous pollutants using water as the scrubbing liquid.

Preliminary results were obtained of the performance in the process of collecting the gases emitted by biomass combustion by means of a rectangular Venturi scrubber. The washing liquid was only water, even knowing that we would have low collection efficiencies, but thinking about having possible satisfactory situations to motivate the control in distilleries and industries that use this equipment. Liquid flow rates of 300 and 400 L/h and velocities of 5.3 and 7.0 m/s were evaluated.

Fig. 8 shows the values of emitted CO_2 concentrations without the use of the Venturi scrubber (no scrubber) in the collection and with the scrubber operating with two liquid flows (300 and 400 l/min) to Vg = 5.3 m/s. Observing only the plotted data on the graphs, we can intuit that they had satisfactory particle collection efficiencies. In some moments of the biomass combustion process it was observed very encouraging values of collection efficiency, above 20 %. In some moments of the biomass combustion process it was observed very encouraging values of collection efficiency, above 20 %. The best values would be for a liquid flow rate of 300 L/h. This ratio of liquid flow by gas flow would really provide a good collection situation for the Venturi, considering the distribution of the drops inside the venturi and the penetration of the jet. According to Khani, et al., (2021) CO_2 concentration in the base fluid in the absence of a magnetic field. It is clear that by increasing the air velocity and water flow rate, the mass transfer efficiency enhances. In packed columns, an increasing gas flow reduces the contact time, so mass transfer decreases. However, in the venturi scrubber, by increasing the air velocity, the liquid droplets break into smaller droplets, so the contact surface between the gas and liquid phases increases, and the absorption rate increases.

However, in a combustion process, the observation of the burning temperature should always be carefully observed. Fig.9 shows the values of the temperature variation during these tests. Observing the temperature fluctuations during the tests one notices the same behavior as the CO_2 emissions, i.e. the higher temperatures of the burning process raised CO2 emissions, which could have resulted in these differences in emissions and not in the collection efficiency.

Fig. 8 Results of CO_2 concentrations for Vg = 5.3 m/s

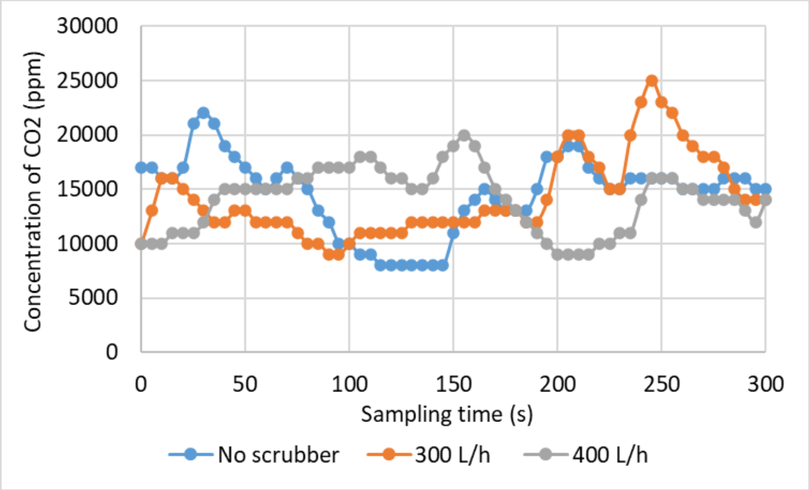


Fig. 9 Values of the temperature variation for Vg = 5.3 m/s

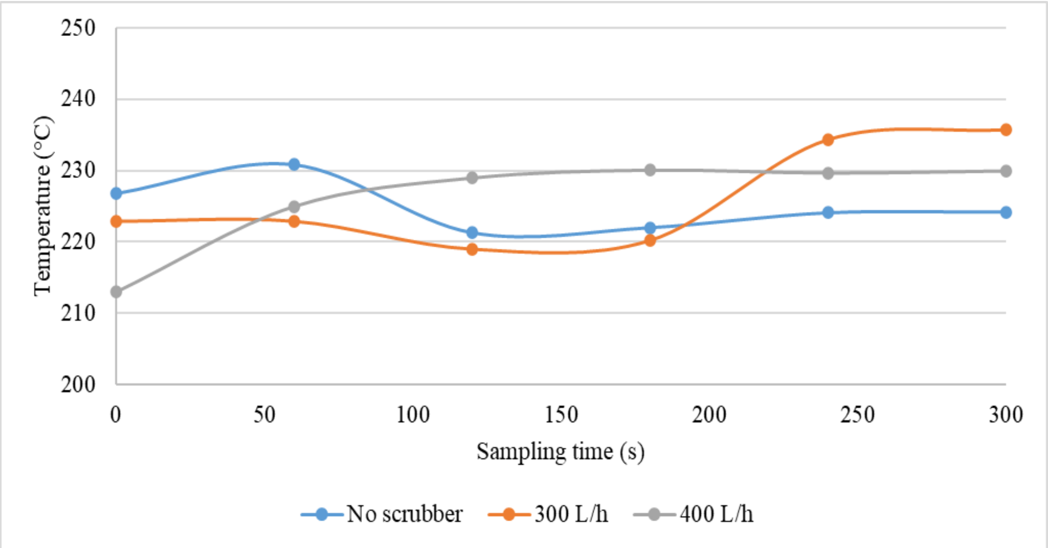


Fig.10 shows the values of the temperature variation during the tests with Vg = 7.0 m/s and Fig.11 shows the values of the temperature variation. In the region between the sampling times of 60 and 155 (s) a good CO_2 capture situation is observed. Observing the temperature curves for the 300 L/h flow rate we cannot safely say that the temperature rise was responsible for the higher emission rates.

For CO and NOx gases the effect of process temperature was observed. Lower firing temperatures raised the emissions of CO and inversely for NOx. These preliminary results necessarily need to be repeated using only water and subsequently a suitable liquid solution for CO_2 capture.

More attention should be given to sampling at stationary industrial sources and to calculations of gaseous pollutant collection efficiencies if water-only scrubbers are used as the sequestration liquid. The results of pollutant emission for the demonstration of efficiency or reduction of CO_2 emission should always be related to the temperature of the combustion process.

Fig.10 Results of CO2 concentrations for Vg = 7.0 m/s

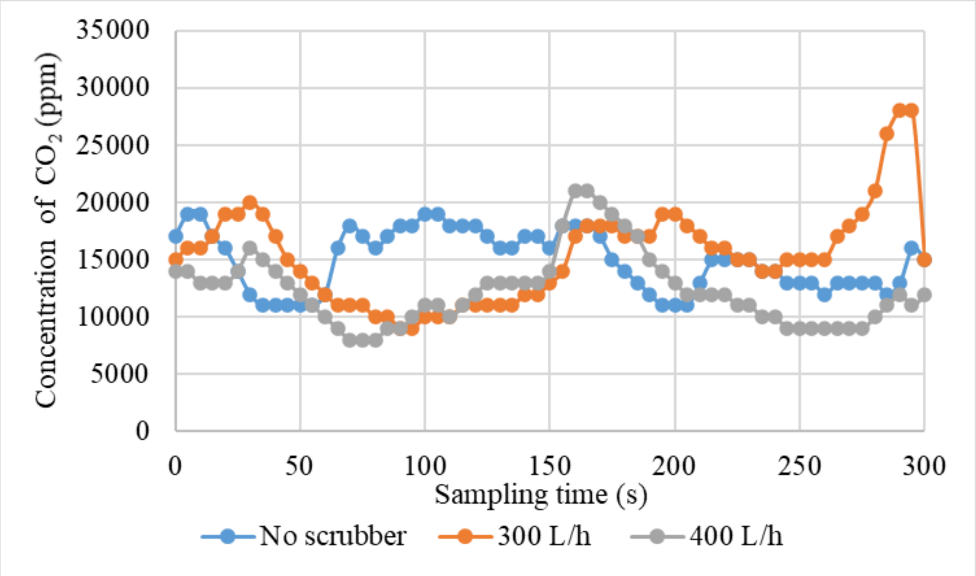


Fig. 11 Values of the temperature variation for Vg = 7.0 m/s

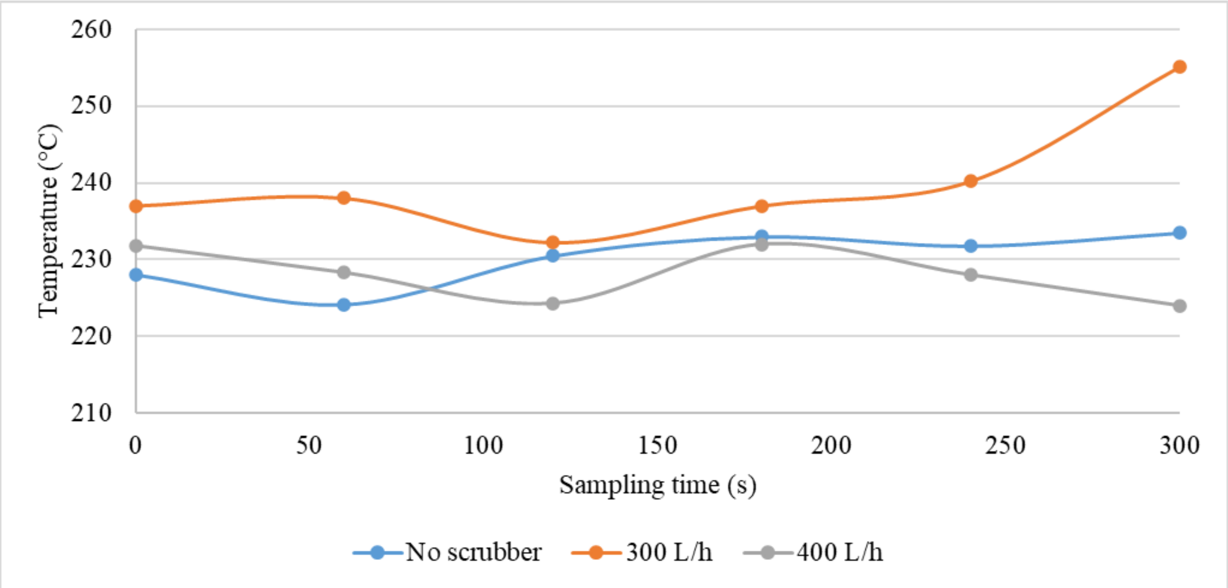
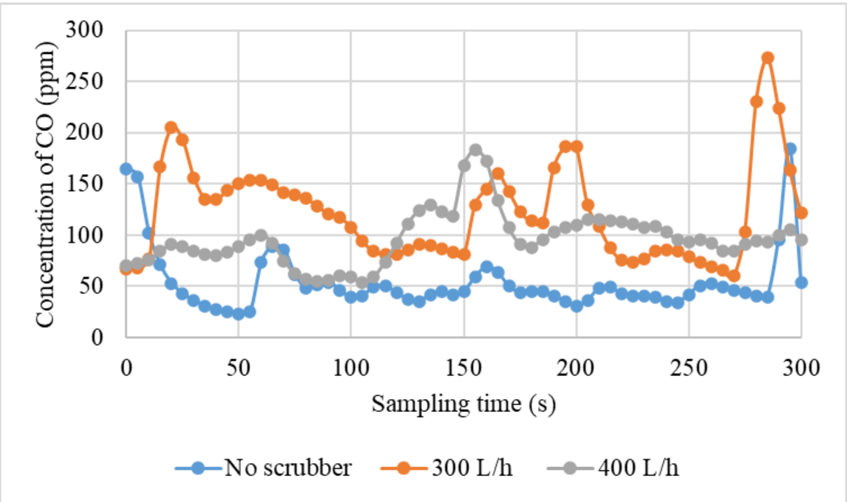


Fig.12 Results of CO concentrations for Vg = 7.0 m/s



5 Conclusion

The use of sugarcane bagasse is a fuel indicated to replace fossil fuels; gas emissions should be monitored and controlled by the industries; The values emitted by burning this fuel are high compared to other studies with different biomasses and the CO_2 values are high and should be included in the legislation for industries and emissions in stationary sources. CO concentrations ranged from 34 to 311 ppp, and for NOx the concentrations were 8 to 80 ppm, NO_2 between 0.87 to 1.07, SO_2 values from 2.66 to 4.23, while those for CO_2 reached values from 6000 to 23000 ppm**.** In the biomass combustion process with the highest temperatures the highest concentrations of CO_2 and NOx are emitted. For gases generated in the combustion phases, larger amounts of compounds such as CO_2 and NOx were generated in the flaming phase. During the smoldering phase, CO emissions predominated, this compounds resulting from incomplete combustion.

Acknowledgment

This work was supported by FAPESP (Fundação de Amparo à Pesquisa do Estado de São Paulo), Project n° 2016/23209-0, Project 2019/27754-1 and 2018/00697-5).

Compliance with Ethical Standards

Conflict of interest

The authors declare that they have no conflict of interest.

Ethical approval

This article does not contain any studies with human participants or animals performed by any of the authors.

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