Emission control and determination of dry deposition of pollutants emitted by burning sugarcane bagasse used as industrial fuel

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The population density in urban centers is growing, increasing the need for manufactured products. This increase in demand is a benefit for the industry, however it becomes worrisome when we think about the environmental and social aspects, so waste management must seek more efficient processes, reducing the generation at the source and optimizing the use of the waste. In Brazil, the sugar-alcohol industry has sought to make the most of its resources, they use sugarcane as raw material, and its bagasse is fuel for energy generation (Freitas et al., 2021). In contrast to the energy benefits, the burning of biomass emits greenhouse gases and particulate matter (PM), which impact the climate and human health. Samae et al. (2021) showed sample results of PM from burning sugarcane bagasse, for diameter ranges between 1 and 2.5 µm, PM concentrations of (3.94±0.12) g/kg were found. Thus, it is observed that the replacement of fossil fuels by biomass becomes compensatory for the environmental impacts, because it reduces the emission of CO_2, but still emits a certain amount of gaseous and particulate pollutants, which can impact the health of the environment. Slapnig et. al (2018) observed high concentrations of PM2.5 related to increases in cases of infection and cardiorespiratory disease. Ferreira et al. (2016) observed that for $PM_{2.5}$ with higher concentrations of $SO_4{}^{2-}$ and NH_4^+ were related to a higher risk of circulatory diseases, and for $PM_{2.5\text{-}10}$, there was a relationship between respiratory diseases and SO_4^{2-}, and for circulation diseases SO_4^{2-}, NO_3^- and K^+ were related. Those particles with smaller sizes, known as fine particles, are transported by the air mass and will deposit far from the emission source, changing the atmosphere chemical composition from other regions and having harmful effects on its population health. Thus, it is evident that there is a need to reduce PM concentrations emitted from industrial processes for the safety of human health. In this context, there is the need for the use of industrial collection equipment, which are able to reduce the emission of gaseous pollutants and can be adapted according to the type of biomass and combustion characteristics (Bianchini et al., 2018). For alcohol and sugar industries, gas scrubbers are widely used, among the various types there are Venturi scrubbers, which reach a collection efficiency between 70 to 99% for particles of 1 µm aerodynamic diameter or smaller (Breitenmoser et al., 2021). The scrubbers remove the pollutants using a liquid scrubber inside the equipment, its working principle is the injection of liquid in the throat section, which is atomized due to the high velocity of the gas flow, and these droplets capture the particles through contact mechanisms. Thus, increasing the weight of the particles, and these being collected (Breitenmoser et al., 2021). The removal efficiency of PM from burning sugarcane bagasse was approximately 60% for Bianchini et al (2016) and Surjosatyo et al (2019). In the event that a pollutant is emitted to the atmosphere, the two most common natural removal mechanisms are dry deposition and wet deposition. Dry deposition is a natural removal process in which the particles are absorbed by the earth's surface, while in wet deposition the particles first need to be incorporated into water droplets and then reach the surface through precipitation. Studies relate dry deposition through deposition velocity, and it is a challenge to overcome to quantify the impact of pollutants on populations and the environment (Pellerina et. al, 2017). Several authors developed their research on the evaluation of the compound deposition flux in different surfaces through mathematical models that predict the phenomenon of the dry depositions from the determination of the deposition velocity (Buffa, et al., 2018 and 2019; Costa et al., 2021; Grøntoft, 2021). The accentuated use of biomass as industrial fuel and the need for efficient pollutant removal motivated the development of this work. The main objective was to evaluate the efficiency of a Venturi scrubber in the removal of PM2.5 emitted by the controlled burning of sugarcane bagasse under different operational conditions. The specific objectives were: to evaluate the chemical composition of the emitted pollutants and the determination of the velocity and dry deposition flux of the main quantified chemical species. **Material and Methods:** Sugarcane bagasse was used as fuel, which was ground and pre-dried by natural convection to a moisture content of 7% (wet basis). The sugarcane bagasse, about 6 kg in total, was transported into the combustion chamber via a worm screw. Then the primary air was induced by a fan and the flow rate controlled and quantified. The gaseous fluxes were quantified, as well as the temperature profiles during the burning tests. The concentrations of PM and chemical species present in the emitted particulate matter were determined for each diameter range of the samplers. The sampling was performed with two samplers: an 8-stage Andersen Cascade Impactor (diameter ranges 0 - 10 µm) and a 12-stage Moudi sampler (diameter ranges 0.056 to 18 µm). Particulate matter was collected on Teflon (Moudi) and glass fiber (Andersen Impactor) filters, which were arranged in the stages of the samplers. These filters were previously weighed and stored for later chemical analysis of ions present in the particulate material. An Ion Chromatograph (Thermo Scientific), model ICS 5000 analytical was used to determine water-soluble ions in the PM. The analyzed species were anions (fluoride (F^-), acetate (HCH_3COO^-), formate ($HCOO^-$), chloride (Cl^-), nitrite (NO_2^-), nitrate (NO_3^-), sulfate (SO_4^{2-}), oxalate ($C_2O_4^{2-}$), phosphate (PO_4^{3-}) and cations (sodium (Na^+), ammonium (NH_4^+), potassium (K^+), magnesium (Mg_2^+) and calcium (Ca_2^+)). The determination of dry deposition velocity was obtained by the parameterization of Zhang et al (2001), using the land use categories (LUC) of the model, LUC 6 (grass), 7 (plantations and mixed crops) and 15 (urban). And the seasons of the year (SC): 1 (summer solstice), 2 (autumn), 3 (late autumn) and 5 (spring). With the concentrations of each ionic species contained in each stage of the samplers and the respective gas velocity, the deposition velocity and dry deposition flux were obtained (Zang et al. 2001), focusing on nitrate, phosphate, and sulfate ions. **Results and discussions.** Gas velocities (Vg) in the outlet stack were from 2 to 10 m/s with wash liquid flow rates of 2.5 to 6 L/min. For $PM_{>1.0}$ µm the highest efficiencies were 87%, 76% and 89% for Vg of 2, 3 and 8 m/s, respectively. While for $PM_{0.056µm}$ the collection efficiencies were 70, 43 and 68%, respectively. Overall, for PM<1.0 µm the efficiency reached value of 70.4% these values are in agreement with the results presented by Bianchini et al (2016) and Surjosatyo et al (2019). The deposition velocity reached a minimum value for particles with a diameter close to 1 µm, increased to a maximum for particles with a diameter smaller than 1 µm, and also increased for particles with a diameter larger than 1 µm. The highest deposition velocities were obtained at LUC 6 and 7 at SC stations 1 and 2, and stations 3 and 5 have a small difference more evident at lower wind speeds. The results of the chemical analysis of the samples collected by the Cascade Impactor showed the presence of NO3-, K+ and SO42-, with the highest concentration of K+ for fine PM, and for particles with aerodynamic diameter between 0 and 0.4 µm the highest concentrations of NO3- and SO42- were found. The data collected agreed with the results of Alvarez et al (2018), who obtained for burning sugarcane bagasse, high concentrations of potassium and low concentrations of sodium, magnesium, calcium, and ammonium. The results of the chemical analysis with the use of the Venturi scrubber showed a significantly lower amount of NO3- and SO42- for PM10 and PM2.5. The dry deposition flux results showed that LUC 6 and 7 at station SC5 have the same deposition values, which are similar to SC1 and SC2 for coarse particulate matter and similar to SC3 for fine particulate matter. Compared to LUC 15 (urban), which has the same values regardless of the SC, the deposition fluxes are higher at LUC 15 than for LUC 6 and 7 at stations 3 and 5. It is concluded that without the use of the Venturi scrubber, there is a deposition of sulfate and nitrate ions compared to the potassium ion, for the fine and coarse particulate. With the Venturi scrubber in operation in the cleaning process, the dry deposition fluxes of nitrate and sulfate ions are lower, especially for the fine particulate.

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