A Produção do Conhecimento na Engenharia Química

Carmen Lúcia Voigt
(Organizadora)

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APRESENTAÇÃO

A Engenharia Química, devido preocupação em desenvolver produtos e processos de produção, é responsável por pesquisas e projetos em relação aos materiais que passam por mudanças físicas e químicas, adquirindo outras características. A manipulação de compostos e substâncias para se criar novos produtos é o foco da Engenharia Química. Estes produtos proporcionam uma melhoria na qualidade de vida humana, pois além de pesquisas relacionadas, existe a preocupação em viabilizar as invenções, criar métodos baratos e eficientes de fabricação em massa, implementar processos químico-industriais cada vez melhores, mais econômicos e mais ecológicos.

O mercado de trabalho na área da Engenharia Química volta-se, por exemplo, para as áreas de energias renováveis (biocombustíveis), para a extração de óleos vegetais e para a produção de ração animal. Há espaço nas indústrias de tintas prediais e automotivas (máquinas agrícolas), nas indústrias têxteis, de cosméticos e higiene pessoal, assim como nas indústrias de tratamento de superfícies metálicas e não metálicas. Os profissionais também podem atuar nas indústrias de transformação dos polímeros, de gemas e joias, de erva-mate, frigoríficas e em laticínios, bem como nas indústrias farmacêuticas e de medicamentos.

Neste volume, organizado para você, apresentamos a produção de conhecimento na Engenharia Química através da realização de pesquisas diversas que abrangem desde nanomateriais na indústria de fármacos, métodos para degradação de poluentes, recuperação e purificação de compostos tanto de origem orgânica ou inorgânica, métodos de adsorção de corantes, até síntese de materiais, como óxido de grafeno e zeólita sodalita, por questões ambientais e energéticas.

Com base nestes trabalhos, convidamos você a aprimorar seus conhecimentos na área da Engenharia Química. Os trabalhos selecionados oportunizam uma nova visão de materiais, métodos e técnicas, mostrando a produção de conhecimento na área bem como o impacto tecnológico no desenvolvimento da indústria e sua relação direta com a sociedade e meio ambiente.

Boa leitura.

Carmen Lúcia Voigt

SUMÁRIO

CAPÍTULO 5

PERFORMANCE OF A CYCLONE ADAPTED WITH WATER SPRAYERS

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ABSTRACT: Sugarcane bagasse is a lignocellulosic material used as fuel for energy cogeneration to supply the thermal and electric energy requirements of sugar mills. The combustion of this biomass releases pollutants including particulate material, which can have adverse effects in the environment and towards human health. One way to remove this type of pollutant from combustion emissions is to use modified cyclones fitted with water sprayers. The objective of this study was to achieve maximum efficiency of particle collection from waste gas streams in the sugar and alcohol industry. The variables gas velocity, mass flow, temperature, and collection time were optimized, and evaluation was made of the effect of water addition within the cyclone. In the absence of water, the highest collection efficiency achieved after optimization was 82%. The addition of water, using a liquid/gas ratio of 2.5 $L.m^{-3}$, resulted in increase of the collection efficiency from 82 to 97%, representing a 14% improvement. For particles with aerodynamic diameters of 10 and 2.5 μm, the collection efficiencies increased from 65 to 87% and from 20 to 46%, respectively. It could be concluded that optimization and the spraying of water within the cyclone resulted in improved treatment of the effluent gas, and that the technique represents an excellent option for use in the sugar and alcohol industry.

KEYWORDS: bagasse, cogeneration, collection, efficiency, particulate material.

1 I INTRODUCTION

The global significance of the Brazilian sugar and alcohol industry has increased over the years, due not only to the large scale of production, but also to the new technologies that have been developed. One example of the latter is energy cogeneration, involving the combustion of sugarcane straw or bagasse to generate steam and electric energy (HOFSETZ and SILVA, 2012).

Energy cogeneration must include treatment of the effluent gases, in order to prevent emission to the atmosphere of pollutants such as particulate material (PM), which is widely acknowledged to lead to harm to the environment and human health

(GUTTIKUNDA et al., 2013; HABIL and TANEJA, 2013; LI, XIA and NEL, 2008; PARK et al., 2013; PUNGLER and WEST, 2013; SUN et al., 2013).

Various systems are available for controlling PM emissions, including fabric filters, electrostatic precipitators, gravitational collectors, gas scrubbers, and cyclones (WANG, PEREIRA and HUNG, 2004). Selection of the best option needs to consider aspects including economic feasibility, the effectiveness of the technique, and the requirements of existing legislation.

The cyclone is a mechanical separator that uses centrifugal force to separate solid or liquid particles from a gas stream. The first cyclone patent was recorded in the United States in 1885. The patented separator was very different to the cyclones currently used, whose simple construction and low installation and operating costs have led to increased popularity and improvements in the design. The cyclones available in the 1920s already possessed many of the features of modern cyclones (HOFFMANN and STEIN, 2008). Today, cyclones are widely used in the chemical, food, pharmaceutical, cement, and mining sectors, among others. In catalytic cracking processes in oil refineries, cyclones are important for retaining the catalyst and ensuring continuous operation. In the cyclone, the gas enters tangentially at the top of the device, generating a peripheral descending helical flow towards the lower part of the cone, followed by a central ascending helical flow towards the top, where the clean gas exits the system in the outlet duct (MACINTYRE, 1990). The centrifugal force resulting from the spiral movement causes the solid particles to be transferred towards the walls and separated from the gas flow. Consequently, the PM deposits at the walls of the cyclone and descends by gravity to the base of the equipment, where it is collected (MESQUITA, ARAÚJO, and NEFUSSI, 1988).

The collection efficiency of cyclones for particles with aerodynamic diameter (D_a) of around 25 µm is around 90%, although the efficiency decreases considerably in the case of particles with D_a smaller than 10 µm (LEE, JUNG and PARK, 2008). Given that these smaller particles are in the size range most harmful to health, it is therefore necessary to modify cyclones in order to improve collection efficiencies. A modification that has attracted increasing attention is the injection of water into the interior of the cyclone, in the form of a spray that enhances the PM collection efficiency. The solid particles separated from the gas are transferred in the water to the base of the cyclone, where they are collected in the form of sludge (MACINTYRE, 1990). The water injected into the system leads to agglomeration of the particles, resulting in better separation of the fine particulate material ($PM_{2.5}$) and consequently higher collection efficiency for particles smaller than 10 µm. In addition, the water spray creates a film on the inner walls of the cyclone, hence preventing the particle bounce that occurs in simple cyclones and causes decreased collection efficiency (MACINTYRE, 1990).

This technique emerged in the 1990s and has subsequently led to advances in research and industrial applications involving the treatment of gaseous effluents

(KRAMES, BÜTNER and EBERT, 1993; YANG and YOSHIDA, 2004; LEE, JUNG AND PARK, 2008 and MOMENZADEH and MOGHIMAN, 2010).

There have been no previous studies concerning the efficiency of collection of particulates from biomass burning, using cyclones fitted with water sprays, especially considering inhalable particles (those with aerodynamic diameter smaller than 2.5 µm). Therefore, the aim of the present work was to achieve the maximum possible efficiency of collection of this type of particle present in emissions from sugar cane bagasse combustion in the sugar and alcohol industry. An experimental design approach was used for optimization, considering the influence of the variables gas velocity ($m.s^{-1}$), mass flow ($g.min^{-}1$), temperature (°C), and collection time (min) on the efficiency of collection of $PM_{2.5}$ by a cyclone operating without water sprayers. After establishing the optimum conditions, evaluation was made of the effect on the $PM_{2.5}$ collection efficiency of introducing a water spray.

2 I METHODOLOGY

2.1 Experimental system

The collection efficiency tests were performed using an experimental gaseous effluent treatment system installed in the Environmental Control Laboratory of the Chemical Engineering Department of the Federal University of São Carlos, (Figure 1).

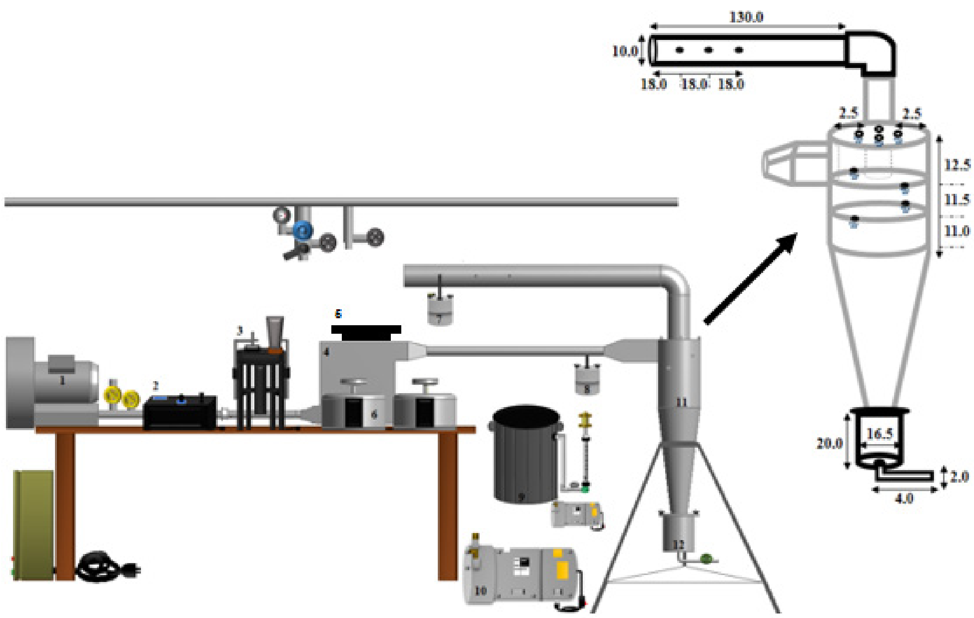

Figure 1. Experimental system used to perform the experiments and the dimensions of the cyclone in centimeters

The system consisted of the following components: blower (1); rotating plate speed controller (2); rotating plate (3); heater (4); electrical resistances (5); voltage regulators (6); outlet and inlet sampling probes (7 and 8, respectively); water reservoir with pump and flow control rotameter (9); air pump (10); cyclone (11) and cyclone collecting box (12).

The blower transferred the gas without particles, with the flow being controlled using valves, an orifice plate, and a manometer gauge. The flow passed through a rectangular section, where it was heated by the electric resistances, according to the power supplied by the voltage regulators. The PM was fed by the rotating plate, controlled by the speed regulator, and the gaseous fluid containing the solid particles was transferred to the cyclone inlet and the sampling probe (at the same velocities). During passage through the cyclone, a large portion of the particles was deposited in the collecting box, while the treated gas exited through the upper duct and the outlet sampling probe (at the same velocities).

The cyclone was constructed according to the geometric relations described by Stairmand (1951), with modifications to increase the collection efficiency. The upper part and the cylindrical structure of the cyclone were fitted with eight fan-type water spray nozzles with 1.8 mm aperture diameters. Subsequently, the upper duct was extended in order to reduce the turbulence induced by the cyclonic movement of the gaseous fluid. A collecting box was also added, for collection of the sludge at the outlet. The cylindrical and conical sections of the cyclone were fabricated from sheet steel. The steel inlet and outlet ducts (5.1 and 10.2 cm, respectively) were attached to steel elbows (5.1 cm) with angles of 90°.

The ash particulate material used to feed the cyclone was obtained from the boiler outlet of a sugar and alcohol production facility. The size distribution of the particles was determined using a Mastersizer MicroPlus particle analyzer (Model MAF 5001, Malvern Instruments). The particles presented a mean volumetric diameter of 9.0 µm and density of 2 $g.cm^{-3}$.

Morphological and elemental chemical characterization of the PM was performed by scanning electron microscopy (SEM) coupled with energy dispersive X-ray detection (EDS), using a Philips Model XL-30 FEG instrument, at the Structural Characterization Laboratory (LCE) of the Materials Engineering Department (DEMa) of UFSCar. The elemental analysis showed the presence of carbon (C, 31.2%), oxygen (O, 9.1%), silicon (Si, 51.5%), potassium (K, 1.1%), calcium (Ca, 1.0%), iron (Fe, 3.2%), and magnesium (Mg, 2.9%).

2.2 Isokinetic sampling

Isokinetic sampling was used in order to obtain material representative of the total particle flow in the system. This procedure employed a pump (Model 5KH35HNA522X, GE Motors), two standard air rotameters (AppliTech), a set of interconnection hoses, and inlet and outlet sampling probes (with nozzle diameters of 0.003 and 0.004 m, respectively) connected to a support for membrane filters.

The input and output probes were positioned within the ducts, at the points at which the mean velocities were determined. The sampling gas flow rates were calculated based on the mean velocity values and the nozzle areas of the probes, and were adjusted using the rotameters. The membrane supports were sealed using plastic seals and screws, so that there was no possibility of escape of the gaseous fluid and particles. This ensured that isokinetic conditions were maintained, with the velocity of the gaseous fluid within the ducts being the same as that within the sampling probes.

2.3 Isokinetic sampling collection efficiency

The isokinetic sampling collection efficiency was determined by calculation of the mass collected (m_c), using the equation:

$$m_c = m_f - m_i \qquad (1)$$

Where (m_f) is the final mass of the membrane and particles, and (m_i) is the initial mass of the membrane.

The concentrations of PM in the inlet and outlet of the cyclone ($C_{i,o}$) were determined using the equation:

$$C_{i,o} = \frac{m_c}{T_C.Q_S} \qquad (2)$$

Where (Tc) is the collection time and (Qs) is the volumetric flow rate in the sampling probe.

Finally, the isokinetic sampling collection efficiency of the cyclone (η) was calculated as follows:

$$\eta = \frac{C_e - C_s}{C_e} \qquad (3)$$

Where (C_i) and (C_o) are the PM mass concentrations in the inlet and outlet, respectively.

2.4 Experimental fractional collection efficiency

The experimental fractional collection efficiency was determined by transferring the membranes used for the collection to beakers containing water and fifteen drops of sodium polyacrylate ((C3H3NaO2)n, available commercially as Disperlam L).

The beakers were placed in an ultrasonic bath to assist dispersion of the particles, followed by removal of the membranes from the solution. The suspensions of PM were then analyzed using the Malvern Instruments Mastersizer MicroPlus analyzer. The particle size distribution curves were then used to construct the experimental fractional collection efficiency curves, given by the equation:

$$\eta_{(dp)} = 1 - \frac{(1-\eta) \cdot f_{s\,(dp)}}{f_{e\,(dp)}} \tag{4}$$

Where ($\eta_{(dp)}$) is the experimental fractional collection efficiency for a particle of diameter (dp), ($f_{s(dp)}$) is the fraction of particles of diameter in the top outlet of the cyclone, and ($f_{e(dp)}$) is the fraction of particles of diameter(dp) in the cyclone feed.

2.5 Theoretical fractional collection efficiency

For the purpose of comparison, after determination of the experimental fractional collection efficiency, the theoretical fractional collection efficiency (η_{ft}) was determined, as follows (LOZIA and LEITH, 1990):

$$\eta_{ft} = \frac{1}{1+\left(\frac{D_{50}}{d_p}\right)^{\beta}} \tag{5}$$

Where (D_{50}) is the 50% particle collection efficiency cut diameter and (β) is an exponent that depends on the (D_{50}) cut diameter.

2.6 Experiments

An experimental design was performed using the calibrated experimental system in tests without operation of the water sprayers. The first step was selection of the main variables to be analyzed, considering feasible operational criteria, with the setting of values that enabled evaluation of the maximum, mean, and minimum conditions of the equipment. The variables and their values are shown in Table 1.

Variables	Levels		
	Maximum (1)	Medium(0)	Minimum (-1)
V1 = gas velocity ($m.s^{-1}$)	30	20	10
V2 = Mass flow ($g.min^{-1}$)	0,5	0,3	0,1
V3 = Temperature (°C)	95,5	75,5	55,5
V4 = Collection time (min)	60	40	20

Table 1. Planning variables and their values

A Box-Behnken factorial design was adopted, based on the fact that it is suitable for experiments performed under conditions representing maximum, mean, and minimum levels. Furthermore, accurate results can be obtained without the need to employ extreme conditions. Considering the four variables (k = 4), with three replicates at the central point (nr = 3) and three levels (n = 3), the experimental design required a total of 27 different assays.

The assays were performed similarly for sampling at the inlet and the outlet, using Schleicher & Schuell mixed ester membranes with pore size of 0.8 µm and diameter of 47 mm. Any moisture present in the membranes was previously removed by heating for 24 h at 60 °C in an oven (Model LTR 583/05, Nova Ética).

The membranes were then placed for 24 h in an electrostatic charge eliminator (Model PRX U, Haug), in order to reduce the influence of static electricity on the membrane surface. Finally, the initial masses of the membranes (prior to particle collection) were obtained by weighing on an analytical balance (S/N 1128191483, Mettler Toledo). The membranes were placed onto the supports, with care being taken to avoid any bypass leakages. The supports together with the sampling probes were only installed in the system after it had been fully adjusted according to the conditions established for each experiment (ALVES, 2017). In order to avoid possible carryover between experiments, the gas alone was first allowed to recirculate within the equipment for a period of 10 min. After these procedures, the supports with the probes were installed in the inlet and outlet ducts and the collection start time was recorded at the moment that the suction pump was switched on. After the collection period, the membranes were placed in an oven for 24 h at 60 °C, followed by weighing to obtain the final masses (after particle collection).

The isokinetic sampling collection efficiency results were submitted to statistical evaluation, using Statgraphics v. XVII software, in order to determine the significance of the variables and to identify the optimal condition.

The experimental design used 24 representative combinations of equipment parameters, considering different spray nozzle arrangements and water flow rates (ALVES, 2017). The 24 experiments were performed under the optimum condition obtained in the experiments without the water sprayers, with a triplicate of the best result.

2.7 Particle diameter conversion

In this work, the size distributions of the particulate material were determined using a Mastersizer MicroPlus particle analyzer (Model MAF 5001, Malvern Instruments), which provided values in terms of volumetric diameter.

Therefore, for conversion to aerodynamic diameter (D_a), which is the parameter considered in current environmental legislation, the following equation was used was performed:

$$\sqrt{C_a . D_a = \sqrt{\frac{C_v . \rho_p}{\chi . \rho_0}} . D_v} \qquad (6)$$

where (C_α) and (C_v) are aerodynamic diameter and volumetric diameter correction factors, respectively, (p_p) is the PM density, (p_0) is the unit density, and (χ) is the approximate shape factor of the PM (equal to 1.95 for charcoal ash).

3 I RESULTS AND DISCUSSIONS

The isokinetic sampling collection efficiencies (η) obtained in the 27 experiments performed without the water sprayers are shown in Figure 2.

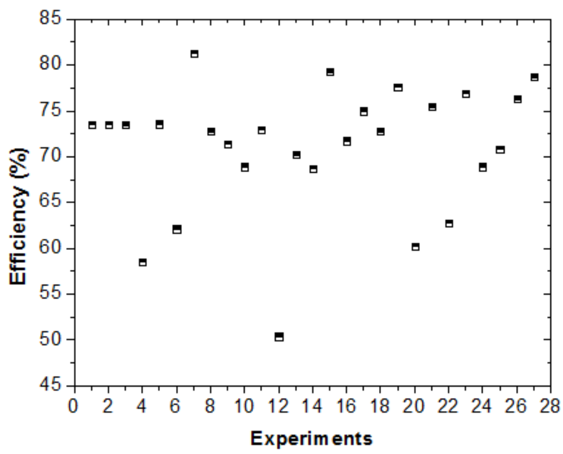

Figure 2. Results of sampling efficiencies of isokinetic sampling (without water sprays)

The highest value of η was 81.3%, which was achieved using a gas velocity of 30 $m.s^{-1}$, mass flow rate of 0.5 $g.min^{-1}$, temperature of 75.5 °C, and collection time of 40 min.

The lowest value of η was 50.4%, obtained with a gas velocity of 10 $m.s^{-1}$, mass flow rate of 0.3 $g.min^{-1}$, temperature of 75.5 °C, and collection time of 20 min. It can also be seen that for most of the conditions employed, the values of η were in the range from 70 to 80%.

The Pareto diagram was used as a basis for further optimization of the separation process, using only the significant variables. The data were treated using response surface methodology. It should be noted that the isokinetic sampling collection efficiency was higher in the gas velocity range from 25 to 35 $m.s^{-1}$, with collection time from 50 to 60 min, as shown in Figures 3a and b.

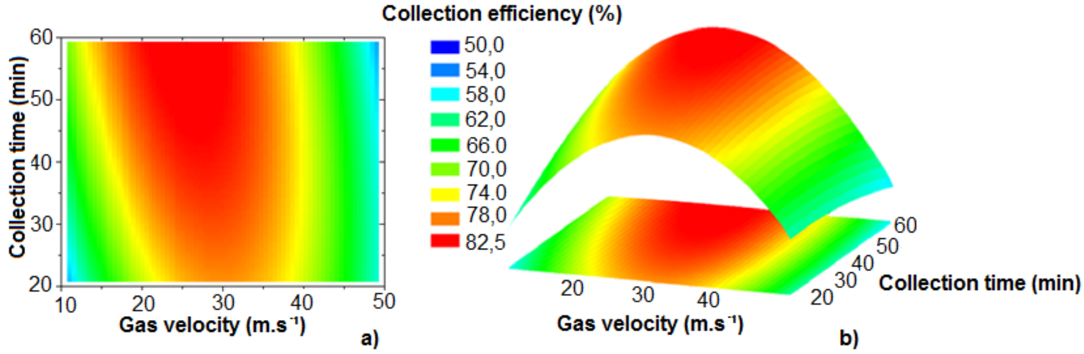

Figure 3. Contour Surface (a) and Response Surface (b)

The results obtained in determination of the significant and insignificant variables were in agreement with the findings of Koch and Licht (1977) and Massarani (2002), who reported that the collection efficiency increased with increase of the gas velocity up to 30 $m.s^{-1}$. In the present work, the mass flow rate variable was insignificant, since the feeding of particulate material into the system was independent of the plate rotation rate. On the other hand, the collection time variable was significant, since a longer collection period provided particle collection that was more representative, compared to shorter times. Finally, the temperature variable was found to be insignificant, because a higher temperature led to a proportional increase of the viscosity of the gas, resulting in lower isokinetic sampling collection efficiency, as observed previously by Koch and Licht (1977).

After establishing the response surface methodology, statistical treatment provided the optimum values of the variables required to optimize the separation process and maximize the isokinetic sampling collection efficiency (η), which was estimated at 82.5%. Although the significances obtained for the mass flow and temperature variables were below 0.05%, these variables were also considered in the optimization, since the process studied was one in which all the variables were interconnected. Table 3 shows the values obtained using the model.It is worth noting that even though the variables mass flow and temperature did not reach significance above 0.05%, as it is a process in which all variables are interconnected, they were also considered in the optimization. Table 2 shows the values proposed by the model.

Variables	Optimal value	Goal
Gas velocity ($m.s^{-1}$)	26.0	82.5 %
Mass flow ($g.min^{-1}$)	0.1	
Temperature (ºC)	55.5	
Collection time (min)	55.5	

Table 2. Values to obtain the optimization of separation processes

Experiments were then carried out in triplicate, using the optimum values obtained with the model, in order to validate the experimental design procedure employed (Table 3).

Experiment	Collection efficiency (%)	Mean (%)
1	82.5	
2	82.4	82.4
3	82.4	

Table 3. Model validation results

The results obtained are shown in Table 3. The deviation of the mean, relative to the target value, was 0.03%, demonstrating that the model performed satisfactorily for the case studied, and that the cyclone separation process was successfully optimized.

In comparison with the theoretical fractional collection efficiency curve, the experimental curve showed higher values in the volumetric diameter (D_v) range from 0.2 to 2.0 µm, which could be explained by the effect of filtration of gas by the membrane. The results were in agreement for the other ranges of D_v, confirming that the methodology was effective (Figure 4).

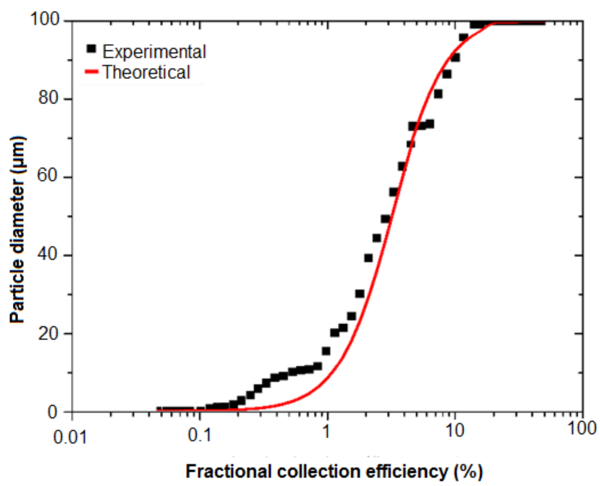

Figure 4. Results for experimental and theoretical fractional collection efficiencies for experiments performed without water sprays

When the water sprayers were used, higher water flow rates led to proportional increases in the isokinetic sampling collection efficiency (η), as shown in Figures 5a and b. A maximum value of η of 97% was achieved in the experiment with all the sprayers operational, with a liquid/gas (L/G) ratio of 2.5 $L.m^{-3}$.The increase in the isokinetic sampling collection efficiency was due to two mechanisms. The most important was associated with the addition of water inside the cyclone, with the droplets providing media for the collection of particles that could not be collected using the cyclone under dry operational conditions. The second mechanism was the prevention of particle bounce at the walls of the cyclone, since the addition of water provided a film of moisture that reduced the impact energy of the individual particle at the wall, hence retaining the particle and preventing it from being transported in the gas stream towards the top outlet of the cyclone.

The lowest isokinetic sampling collection efficiency was 84%, using L/G of 0.7 $L.m^{-3}$ and only one water sprayer nozzle operational. However, despite being the lowest value in these tests, the efficiency was nonetheless 2% higher than found for the cyclone operated under dry conditions (Figures 5a and b).

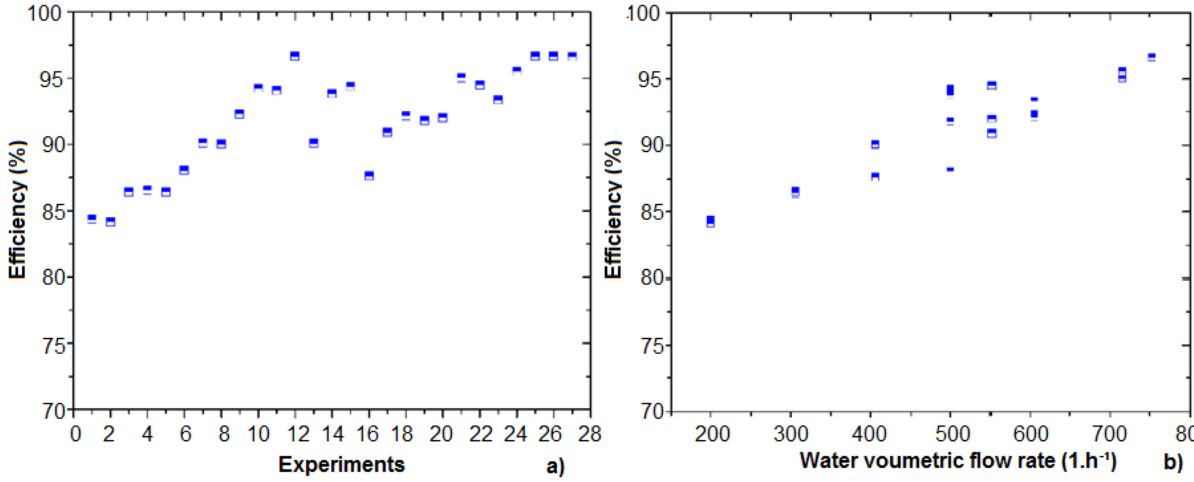

Figure 5. Results of isokinetic sampling efficiencies (with water sprayers) (a) and results of isokinetic sampling efficiencies in relation to water flows (b)

Comparison of the fractional collection efficiencies (η_{ft}) for the cyclone operated with and without the spray system showed that use of the sprayers resulted in higher values of η_{ft} for particles in the entire diameter range considered (0.01-10 μm). Importantly, for respirable particles (with aerodynamic diameter of 10 μm) and inhalable particles (with aerodynamic diameter of 2.5 μm), the η_{ft} values increased from 65 to 87% and from 20 to 46%, respectively, with a conversion factor of approximately 1.5 (Figure 6).

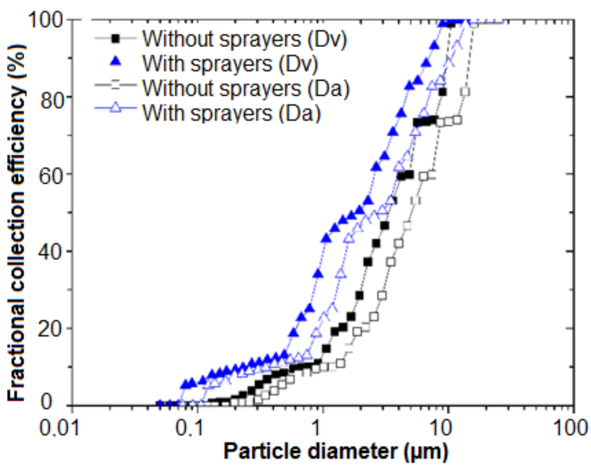

Figure 6. Fractional collection efficiency results for volumetric (Dv) and aerodynamic (Da) diameters

These results are significant, given that the respiration of PM_{10} and the inhalation of $PM_{2.5}$ can lead to a range of detrimental effects on human health. The results demonstrated that the injection of liquid into the cyclone effectively increased the removal of particles in the diameter size range of greatest interest.

4 I CONCLUSION

Optimization of the variables gas velocity, mass flow rate, temperature, and collection time resulted in an isokinetic sampling collection efficiency of 82% for the cyclone operated under dry conditions, while the efficiency increased to 97% when water was sprayed into the system at a liquid/gas ratio of 2.5 $L.m^{-3}$.The fractional collection efficiency increased from 65 to 87% for particles with aerodynamic diameter of 10 µm, and from 20 to 46% for particles with aerodynamic diameter of 2.5 µm. Therefore, comparing the performance of the cyclone with other types of equipment employed to treat gaseous effluents, it represents an excellent option for use in the sugar and alcohol industry. However, considering the public health aspects, subsequent filtration of inhalable particles would be recommended.

REFERÊNCIAS

ALVES, A. C. M. **Optimization of the separation processes of a cyclone adapted with water sprayers**. 2017. 134 f. Dissertation (Maters Chemical Engineering) - Department of Chemical Engineering, Federal University of São Carlos - São Paulo, 2017.

GUTTIKUNDA, S. K. et al. **Particulate pollution in Ulaanbaatar**, Mongolia. Air Quality, Atmosphere & Health, v. 6, n. 3, p. 589-601, 2013.

HABIL, M.; MASSEY, D. D.; TANEJA, A. **Exposure of children study**ing in schools of India to PM levels and metal contamination: sources and their identification. Air Quality, Atmosphere & Health, v. 6, n. 3, p. 575-587, 2013.

HOFFMANN, A. C.; STEIN, L. E.; BRADSHAW, P. **Gas cyclones and swirl tubes: principles, design and operation**. Applied Mechanics Reviews, v. 56, n. 2, p. b28-b29, 2003.

HOFSETZ, K.; SILVA, M. A. **Brazilian sugarcane bagasse: Energy and non-energy consumption**. Biomass and bioenergy, v. 46, p. 564-573, 2012.

KOCH, W. H.; LICHT, W. **New design approach boosts cyclone efficiency**. Chemical engineering, v. 84, n. 24, p. 80-88, 1977.

KRAMES, J.; BÜTTNER, H.; EBERT, F. **Particle separation in a wet operated cyclone**. Journal of Aerosol Science, v. 24, p. S591-S592, 1993.

LEE, B.; JUNG, K.; PARK, S. **Development and application of a novel swirl cyclone scrubber**. Experimental. Journal of Aerosol Science, v. 39, n. 12, p. 1079-1088, 2008.

LI, N.; XIA, T.; NEL, A. E. **The role of oxidative stress in ambient particulate matter-induced lung diseases and its implications in the toxicity of engineered nanoparticles**. Free radical biology and medicine, v. 44, n. 9, p. 1689-1699, 2008.

LOZIA, D. L.; LEITH, D. **The logistic function and cyclone fractional efficiency**. Aerosol Science and Technology, v. 12, n. 3, p. 598-606, 1990.

MACINTYRE, A. J. **Ventilação Industrial e Controle Da Poluição**. 2. Ed. São Paulo; LTC, 1990.

MASSARANI, G. **Fluidodinâmica em sistemas particul**ados. 2.ed. Rio de Janeiro: E-Papers, p.1-152, 2002.

MESQUITA, A. L. S.; GUIMARÃES, F. A.; NEFUSSI, N. **Engenharia de Ventilação Industrial**. São Paulo: Editora CETESB, 1988.

MOMENZADEH, A.; MOGHIMAN, M**. Effect of droplet injection on particle separation efficiency of cyclone separators**. In: 13th Annual & 2nd International Fluid Dynamics conference, 2010.

PARK, M. et al. **Effects of air pollution on asthma hospitalization rates in different age groups in metropolitan cities of Korea**. Air Quality, Atmosphere & Health, v. 6, n. 3, p. 543-551, 2013.

PUNGER, E. M.; WEST, J. J. **The effect of grid resolution on estimates of the burden of ozone and fine particulate matter on premature mortality in the** USA. Air Quality, Atmosphere & Health, v. 6, n. 3, p. 563-573, 2013.

STAIRMAND, C. J. **The design and performance of cyclone separators**. Transactions of the Institution of Chemical Engineers, v. 29, p. 356-383, 1951.

SUN, G. et al. **Characterizing $PM_{2.5}$ pollution of a subtropical metropolitan area in China**. Atmospheric and Climate Sciences, v. 3, n. 1, p. 100, 2013.

WANG, L. K. et al. **Air pollution control engineering**. Totowa, New Jersey: Humana Press, 2004.

YANG, K.; YOSHIDA, H. **Effect of mist injection position on particle separation performance of cyclone scrubber**. Separation and purification technology, v. 37, n. 3, p. 221-230, 2004.

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