EXPERIMENTAL STUDY OF SO_2 ABSORPTION IN A CYCLONE SCRUBBER

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Abstract*. Atmospheric pollutants originated from sources of industrial combustion (NO_X, SO_2 and particles) are responsible for several environmental and health problems. Concerning particles, special care is taken for that with diameter dimensions varying from 0,1 to 10μm. One of the most traditional equipments for particulate collection are the cyclones that operate by reverse flow, however its efficiency for particles with dimensions below 5 μm is very low. The addition of pulverized water at cyclone inlet results in a higher collection efficiency of these particles. The SO_2 emission in the combustion gases is usually realized in absorbers, and the most used equipments are: the packet tower, the nebulization tower and the cyclone tower. The combination of particulate separation process with the SO_2 absorption can be obtained if an absorbing solution is pulverized in the reverse flow cyclone inlet. The possibility to achieve SO_2 absorption inside equipment designed originally for particulate matter collection turns possible the realization of two processes inside of just one equipment. This can represent a reduction in operation and installation costs, besides allowing the implantation of these equipments for emissions control in a larger number of industrial units, particularly the small ones. The present work intends to study the performance of a wet cyclone as SO_2 absorption (cyclone scrubber) and comparison with removal efficiencies obtained in a nebulization tower. The liquid utilized as absorber was sodium hydroxide suspension with pH upper or equal to 9. An experimental system was built for this purpose and tested for different values of pollutant gas flow rate; liquid solution and SO_2 concentration at the inlet of the equipment.*

Keywords*: Cyclone scrubber, SO_2 absorption, nebulization tower, desulfurization*

1. Introduction

Release of sulphurous gases in the atmosphere is responsible for the phenomenon of acid rain that contributes for the environment degradation.

Concern with the quality of atmospheric air demands that industrial processes, as the combustion of coal or solid residues containing sulphur, have a system for SO_2 and SO_3 absorption in its process line.

There are several techniques for SO_x absorption from a gaseous flow. These techniques can be classified as wet, dry or half dry. Considering the wet process, the contaminated gas contacts a liquid absorber and mass transfer occurs between the phases. At this process, SO_x is transferred from gas to liquid, producing a less harmful solution for environment. Nebulization towers and wet cyclones are equipment that can be used with this purpose.

The current reverse flow cyclones are used for particulate collection in units that burn solids fuels, highlighting soot, ashes, solid unburned fuels etc. They are not efficient for particles with diameters smaller than 5 μm. For an efficient separation it is necessary an implantation of equipments that can do this collection, among these equipments are: electrostatic precipitators, bag filters, cyclonic towers, Venturi washers etc. According to Pacheco (2002) electrostatic precipitators presents high efficiency, up to 98% for particles larger than 0,001 μm and bag filters presents efficiency up to 99,99% for particles larger than 1 μm. Still in agreement with Pacheco (2002) reverse flow cyclones have efficiency between 70% and 90% for particles larger than 10 μm. These numbers show that cyclones are not so efficient as electrostatic precipitator and bag filters in the collection of particulates.

The use of the cyclones is justified because its constructive and operational simplicity, providing low initial investment cost for implantation and also for subsequent technical maintenance. In such a way it is necessary improving cyclone efficiency, once comparing with others separation equipments, it is simplest and cheapest.

At this work it was studied experimentally the performance of a cyclone scrubber and a nebulization tower, concerning SO_2 absorption in an alkaline aqueous solution of sodium hydroxide. Parameters tested were: polluted gases flow rate, liquid absorber flow rate and SO_2 inlet concentration.

2. SO_2 absorption process by alkaline aqueous solution

Fossil fuels burned at combustors installed in thermo electrical units and industrial ovens can produce a great quantity of gases containing sulfur, particularly SO_2 and SO_3. A liquid substance, usually an alkaline aqueous solution, is frequently used as SO_x absorber from combustion gases. Important parameters for the desulfurization process are: interfacial area between the two phases, solute solubility and gas residence time inside the equipment, which depends directly on the gas velocity and equipment geometry. The mass transfer process is by diffusion and it is associated to SO_2 concentrations in the two phases. During this process three stages can be identified: diffusion through the gaseous phase until the interface gas-liquid, solute transference through the interface and, finally, diffusion through the liquid phase. By modeling these processes, the second stage (transference in the interface) can be discarded because it happens extremely fast in comparison to the other ones. When the gaseous diffusion velocity component in the liquid is high, which is strongly dependent on its solubility, the absorption is controlled only by the diffusion through the gaseous phase until the interface gas-liquid. Inversely, when the solubility of the gaseous component in the liquid is small, the liquid film controls the absorption. Considering SO_2 absorption, the addition of an alkaline reagent in the water increases the absorption efficiency, therefore, when reacting with the alkaline reagent another substance is produced, that helps to keep the gas concentration below of the liquid phase solubility level (Mycock et all, 1995). To prevent the absorption that is controlled by the liquid film, the pH of the liquid absorber must be maintained above nine. According Pinilla et all (1984) a highly alkaline solution must be remained.

Aspersion of an alkaline water solution that generates drops with bubble diameters and concentration controlled permits the collection of solid particles with diameters below 5 μm. The mechanism that explains how this collection is done is called inertial impactation, which is the shock between particles and liquid drops that causes the shunting of these fine particles from the gas flow and posterior collection in the liquid phase.

According Krames and Buttner (1994) atomizers are generally pneumatic and they can produce drops with average diameter around 50 μm, or either, with dimension ten times bigger than the smallest solid particles collected by a conventional reverse flow cyclone. Liquid drops contain higher kinetic energy than fine solid particles, independently of its density, so, they are capable to modify solid particle trajectory. Still in accordance with Krames and Buttner (1994) by collecting solid particles, liquid drops have an increase in theirs dimensions and this phenomenon contributes to their separation inside cyclones. Although drops with big diameters guarantee that particles will be captured, it is expected that drops size be the smaller as possible and be in a great quantity, to increase the impact probability with a solid particle, besides the increment on the interfacial area between gas and liquid.

3. Experimental system

It was constructed an experimental bench composed by a cyclone scrubber and a nebulization tower, both in acrylic, with the dimensions showed in Fig.1. The equipments were transparent in order to facilitate the hydrodynamics visualization inside the equipments. The objective was to compare SO_2 absorption efficiency presented by the two equipments as a function of the gas flow rate, liquid absorber flow rate and SO_2 inlet concentration.

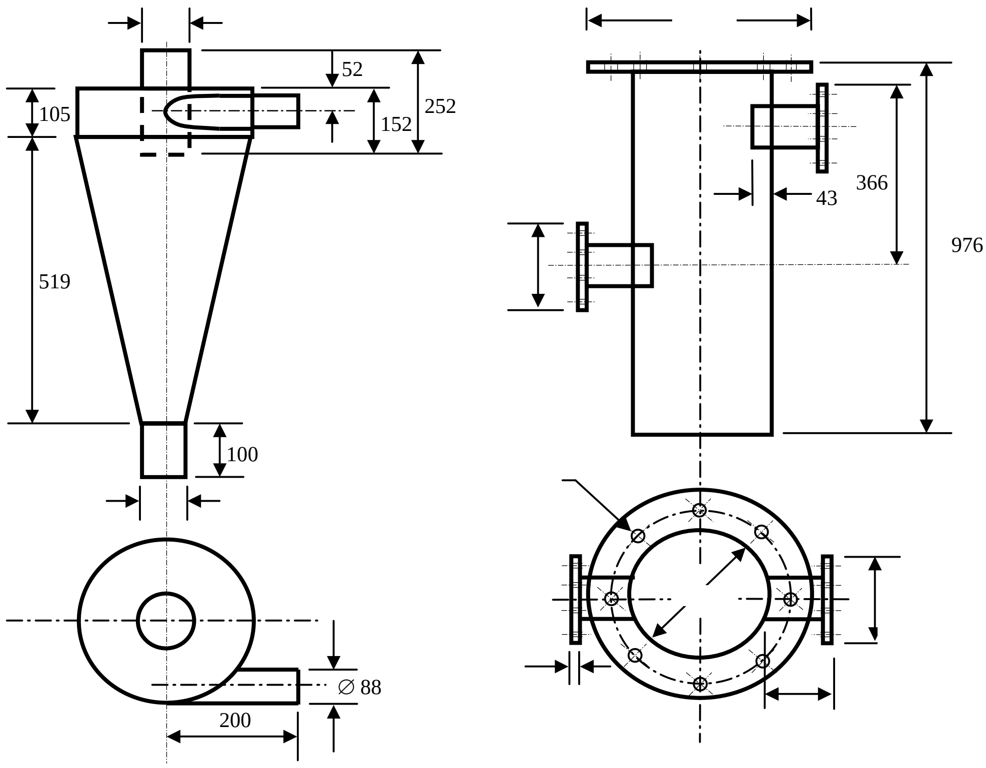

Figure 1. Layout of the cyclone scrubber and nebulization tower

For combustion simulation like that found in an industrial plant, a certain quantity of air atmospheric was contaminated with a determined quantity of pure SO_2 coming from a pressurized bottle. After contamination, these gases had been absorbed inside the two equipments by an alkaline sodium hydroxide water solution. SO_2 concentration measurements were measured at the outlet of the equipments in order to obtain the absorption efficiency.

Solution pH was kept upper to nine and was controlled by a diaphragm bomb coupled to a pHmeter. This bomb introduced an alkaline liquid (concentrated solution of NaOH) in the solution each time that pH decreased below 9, as recommendation of Pinilla et all (1984).

Contaminated gases used in the tests for cyclone scrubber and nebulization tower are free from solid particles; therefore, particle efficiency was not analyzed at the present study, being delayed for a posterior phase of the research.

Absorbent liquid was sprayed in the superior part of the nebulization tower by five pressurized nozzles, one central with exit angle of 30^o and other four distributed around the central nozzle with exit angle of 10^o. The liquid was sprayed directly in the tangential inlet by a pneumatic atomizer.

As defined by Eq. (1), absorption collection (η) was obtained measuring gases concentration at inlet and outlet of the equipments.

$$\eta = 1 - \frac{C_{SO_2,S}}{C_{SO_2,e}} \quad (1)$$

where: $C_{SO_2,S}$ and $C_{SO_2,e}$ represent SO_2 outlet and inlet concentration in the gas flow in the gas flow, respectively.

Another parameter analyzed in the experimental tests was the ratio between liquid absorber and contaminated gas flow rates (ℓ / g).

$$\frac{\ell}{g} = \frac{Q_l}{Q_g} \quad (2)$$

A total of 23 experimental tests had been carried out, among them 7 were taken at nebulization tower and 16 at cyclone scrubber. The factors analyzed were liquid absorber (Q_l), contaminated gas flow rate (Q_g) and SO_2 concentration at the gas inlet $(C_{SO_2,e})$.

The inlet SO_2 concentration at the gas flow was gotten from insufflated air and SO_2 injected mass flow rate data. A HORIBA (model ENDA-1400) gases analyzer was utilized for SO_2 outlet concentration measurements.

Gas residence time was obtained from washers volume (V) and contaminated gas flow rate as:

$$t_R = \frac{V}{Q_g} \quad (3)$$

Equations concerning t_R for cyclones, considering the gas trajectory inside the equipment are available in the literature (Leith and Licht, 1972) but had not been used due to the controversial influence of the liquid presence on gas residence time.

4. Results and discussion

Tables (1) and (2) present results consolidation for the experimental tests in the nebulization tower and in the cyclone scrubber, respectively.

Table 1 – Consolidation of the results – Nebulization tower

Test	Q_l [L/h]	Q_g [m^3/h]	ℓ / g [L/m^3]	$C_{SO2,e}$ [ppm]	$C_{SO2,s}$ [ppm]	t_R [s]	η
1		29.62	12.83	700	36	2.127	0.949
2		41.53	9.15	730	59	1.517	0.919
3		50.67	7.50	718	183	1.243	0.745
4	380	58.37	6.51	709	129	1.079	0.818
5		73.08	5.20	690	170	0.862	0.754
6		83.70	4.54	677	125	0.753	0.815
7		98.96	3.84	645	268	0.637	0.740

Table 2 – Consolidation of the results – Cyclone scrubber

Test	Q_l [L/h]	Q_g [m^3/h]	ℓ / g [L/m^3]	$C_{SO2, e}$ [ppm]	$C_{SO2, s}$ [ppm]	t_R [s]	η
8	160	29.63	5.40	514.84	27	2.126	0.948
9		41.56	3.85	544.59	37	1.516	0.932
10		50.63	3.16	565.66	55	1.244	0.903
11		60.61	2.64	583.38	129	1.039	0.779
12		67.23	2.38	581.19	194	0.937	0.666
13		75.12	2.13	601.13	246	0.839	0.591
14		53.04	1.91	587.11	273	1.188	0.535
15		61.24	1.78	538.34	287	1.029	0.467
16	100	29.59	3.38	486.80	19	2.129	0.961
17		41.49	2.41	499.25	24	1.518	0.952
18		50.76	1.97	545.20	28	1.241	0.949
19		60.61	1.65	550.88	36	1.039	0.935
20		67.11	1.49	587.37	49	0.939	0.917
21		75.19	1.33	571.78	81	0.838	0.858
22		84.03	1.19	554.24	94	0.750	0.830
23		90.09	1.11	548.69	110	0.699	0.800

Contaminated gas flow rate and inlet SO_2 gas concentration was tried to keep constant. However, operational difficulties in the SO_2 line distribution provoked variations in the SO_2 inlet concentration, as verified at Tabs. (1) and (2). This operational problem did not harm comparisons between the two equipments, once the operational conditions were far from SO_2 equilibrium concentration at gas and liquid. It was admitted that SO_2 absorbed by the liquid was quickly transformed into sodium sulfate, since solution pH was kept upper to 9, as argued by Mycock et all (1995) and Pinilla et all (1984).

It was observed that the average inlet SO_2 gas concentration at cyclone scrubber was about 20% less than the obtained at nebulization tower and the average absorber liquid consumption at cyclone was 65% lesser than at the nebulization tower, for equal contaminated gas flow rate. These values prove that cyclone scrubber consumes less alkaline solution, producing less liquid effluent in the process, showing a SO_2 efficiency collection similar to that obtained at nebulization tower.

The cyclone scrubber tested presented high air consumption at the pneumatic atomizer, due to its constructive characteristics. This fact becomes impracticable extrapolation of laboratorial results for industrial scale, otherwise air consumption would be very high. This fact reveals that even so cyclone scrubber consumes less quantity of absorbent alkaline solution; it presents high levels of air consumption. This equipment deficiency can be solved with substitution of pneumatic atomizer by pressure nozzles, similar to that used at nebulization tower.

At the experiments it was taken care to remain absorbent pH solution above nine, in order to prevent that absorption process be controlled by the liquid film.

Residence time as defined in Eq. (3) must be analyzed with caution for comparison between the two equipment efficiencies, once its value was obtained dividing the washer volume by the gases flow rate, neglecting the presence of the liquid flow and the difference between the fluid dynamics behavior inside the cyclone and the tower. Residence time for liquid in a wet cyclone is probably very different of the gas residence time. The drops, as observed visually, are not distributed along the cyclone volume, remaining as liquids particles just at the inlet region, after the atomization point. Visually it was observed that liquid seems to reach the equipment wall in a rectilinear trajectory from the atomizer, forming, a spiral descending current.

Concerning the liquid consumption at the process, expressed by the ratio ℓ / g , it was observed that, besides the values obtained in the cyclone were smaller than the values for the nebulization tower, they were very above of that obtained by Krames and Buttner (1994) whose values had varied between 0.05 and 0.5 L/m^3. This fact reveals that the equipment needs some adjustments to become prompt to carry through the SO_2 absorption with higher efficiency and less consumption of liquid absorbent.

Figures (2) and (4) show the behavior of the SO_2 absorption efficiency as a function of the ratio between absorbent liquid and contaminated gas flow rate (ℓ / g), residence time of the gas and gas flow rate, respectively.

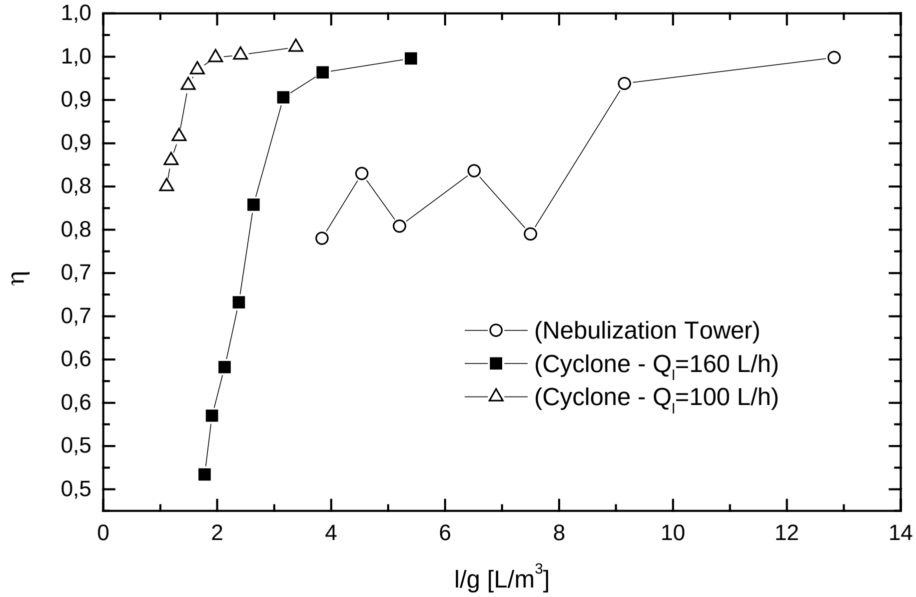

Figure 2. SO_2 absorption efficiency as a function of the ratio ℓ / g

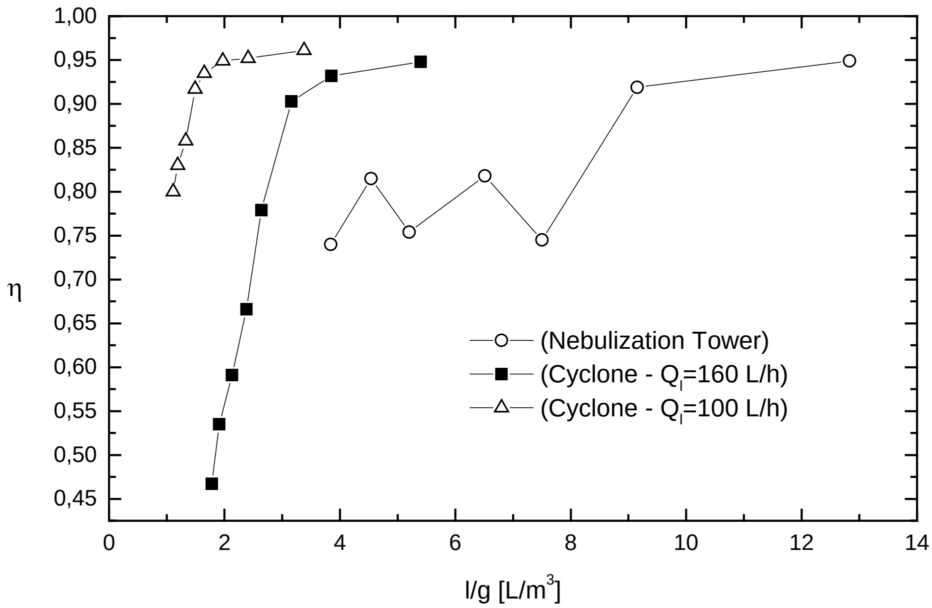

Figure 3. SO_2 absorption efficiency as a function of gas residence time

Analyzing Tabs. (1) and (2) and Figs. (2) and (3) it was verified that SO_2 absorption efficiencies at cyclone presented the same order of magnitude of that obtained in the nebulization tower, with lower consumption of absorbent solution. It is still observed that SO_2 absorption efficiency increases with the increment on the gas residence time. This fact is explained by the increment of interface area between gas and liquid as the ratio ℓ / g is increased and consequently, it is obtained an increase in the mass transfer between the phases.

Figure (4) shows that increasing contaminated gas flow rate, the SO_2 absorption efficiency in the cyclone and nebulization tower decrease. This effect can be attributed to the gas residence time reduction inside the absorbers, which is more accentuated in the nebulization tower because of the fluid dynamics inside the equipment, where there is no centrifugal forces, as occur at cyclones. Comparing the two curves relative to the cyclone it was observed that tests with higher liquid flow rate (Q_L= 160 L/h), presented smaller values of absorption efficiency. This indicate that an increase on the liquid flow rate provokes the formation of big drops which are quickly separated from the gas current in the cyclone, so the interface area between the gas and liquid is reduced.

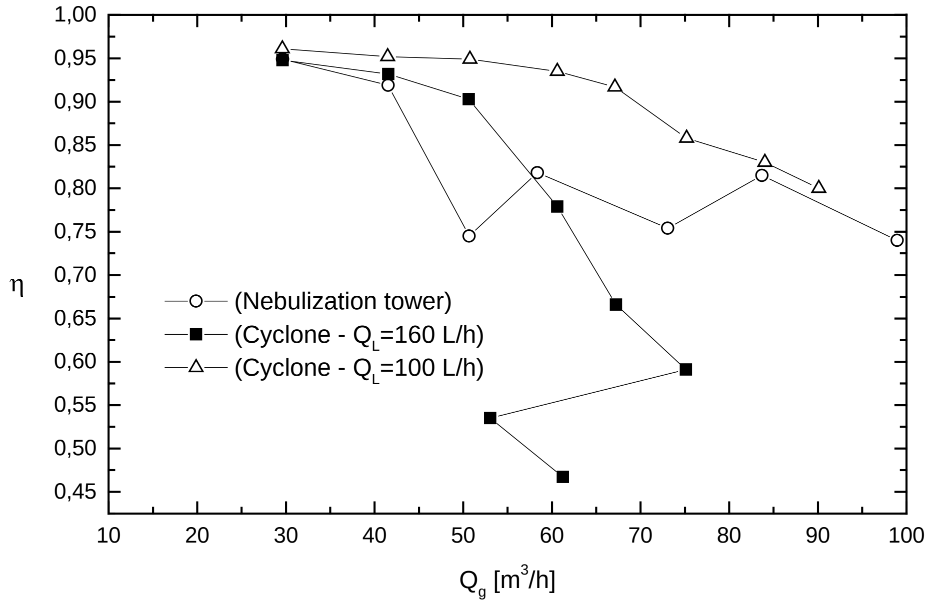

Figure 4. SO_2 absorption efficiency as a function of contaminated gas flow rate

5. Conclusions

Results showed that cyclone scrubber is equipment with great potential to substitute other equipments concerning SO_2 absorption process from exhausted gases. Cyclone scrubber has the advantage to carry through particulate collection simultaneously with gas absorption. Experimental results showed that cyclone scrubber is efficient in SO_2 absorption, but it is not possible to affirm that it is more efficient than nebulization tower because it was not possible to keep the same inlet conditions at the two equipments. For the next phase of this research it is intended to substitute the pneumatic atomizer by pressure nozzles in order to verify absorption efficiency without so high air consumption. It is also intended to verify particle collection efficiency considering particles diameters smaller than 5μm, using contaminated gases with soot from a solid combustion process.

6. References

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