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RESEARCH ARTICLE

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MAIN INDUSTRIAL AIR POLLUTION CONTROL EQUIPMENT: A REVIEW

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ABSTRACT

Current environmental concern has motivated the establishment of a legal protection policy which demands that industries minimize their activities' effects on the population and the environment. Therefore, requiring the integration of particulate air pollution control equipment has been seen as the best course of action. Among the high-performance pollution control devices cyclone, bag filter and electrostatic precipitator are the most commonly used. In this respect the present work presents pros and cons of these equipment, aiming to assist engineers in choosing the ideal control device taking into consideration the characteristics, yield and efficiency of each equipment.

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INTRODUCTION

Each year industries release tons of pollutants into the atmosphere as a result of their production process. These are very small particles in solid, liquid and/or gaseous form that can cause long-term environmental and health damage. Particulate matter is very small and light and, according to the World Health Organization (WORLD HEALTH ORGANIZATION, 2006), it is capable of causing health issues on exposed individuals. The inhalable particles are able to penetrate the body and affect organs such as the heart and lungs, causing potentially serious outcomes (ENVIRONMENTAL PROTECTION AGENCY, 2018). These particles can be classified as primary or secondary pollutants[1]. Primary pollutants come directly from a source into the atmosphere, such as carbon monoxide from combustion activities. Pollutants considered secondary are the result of chemical reactions within the atmosphere with participation of primary pollutants, some examples are: tropospheric ozone, hydrogen peroxide, sulfuric acid, nitric acid, sulfur trioxide and nitrates (VALLERO, 2007). Containment and pollutant treatment work is recommended by CONAMA - Conselho Nacional do Meio Ambiente (National Environmental Council) to be carried out at its production site, which function as a strategy to manage the amount of pollutants discharged into the atmosphere. CONAMA also guides air quality standards and presents criteria for the development of regional air pollution control plans (BRAZIL, 2018). These requirements drive many industries to adopt pollution control devices, for both particulate matter and gas or vapor treatment resultant from industrial processing. For review purposes, the present work sought to list the most used industrial air pollution control devices with their corresponding pros and cons. These equipment are divided into two groups: dry and wet systems. Only the most used high-performance dry systems were considered on this paper: cyclones, baghouse filters and electrostatic precipitators. Gravity settling chambers, although not considered a high-performance device, was also contemplated since it is widely used. All of these devices have the common characteristic of continuous treatment of the particulate matter, recovering most of the material that would be released into the atmosphere, thus minimizing losses as well as pollutant emissions.

AIR POLLUTION CONTROL DEVICE

Gravity settling chamber: Gravity settling chambers, also called settling chambers, gravity collectors, expansion chambers or outfall chambers, work by changing the air's velocity inside its compartment. According to Lisboa and Schirmer (LISBOA, 2007), the chamber's dimensions (see Fig. 1) should be sufficient to reduce the gaseous stream's velocity inside the chamber providing the suspended particles enough time to settle.

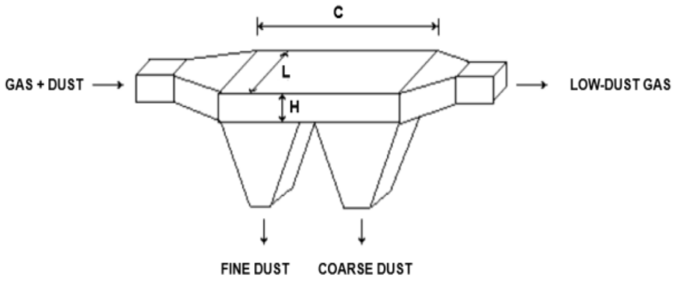

Fig. 1. Schematic of a gravity settling chamber (CHEREMISINOFF, 2002)

The presence of baffles and the gravity effect causes the particulate in the air to collide with the barriers and precipitate (7). This action scheme is shown in Figure 2.

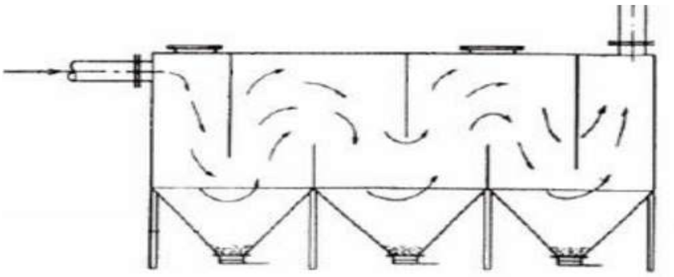

Fig. 2. Air flow behavior inside a settling chamber with baffles (Macintyre, 1990)

In Figure 2, it is possible to notice that the gas flow changes direction due to the baffles and the material is collected in the hoppers at the bottom. Thus, the equipment's efficiency is related to the particle's terminal velocity, which is directly proportional to its density and diameter (Capulli, 2019). Pros and cons of the gravity settling chamber usage are presented in Table 1:

Table 1. Pros and cons from the gravity settling chamber [5. LISBOA, 2007].

PROS	CONS
Low pressure drop (ranging from 10 to 25 mm w.c.).	Low efficiency for small particles (under 10 μm).
Dry collection results in easier recovery.	Recommended for large particulate (> 40 μm).
Operational temperature is limited only by the chosen construction material.	Air velocity inside the chamber is limited to 3 m/s.
Simplicity in design, construction and installation.	Large installation space required.
Long equipment life.	Special measures required if
Low cost installation and maintenance.	flammable or explosive substances are present.

Although the settling chamber is not considered a high-performance equipment (due to low efficiency in removing particles smaller than 40 μm) it is easily found in industries, being the predecessor of other treatments. It is a simple construction equipment of dry collection and low pressure drop (Lisboa, 2007). It is clear that the use of pre-collector devices, in general, improves process performance and increases lifespan of following collection equipment such as baghouse filters, electrostatic precipitators and scrubbers, which have more complex and expensive parts than mechanical collectors.

Cyclone: Cyclones consists of a conical-cylindrical chamber where the gaseous stream enters from a tangential direction at high speed, forming an external downward spiral and an internal upward spiral (see Fig. 3).

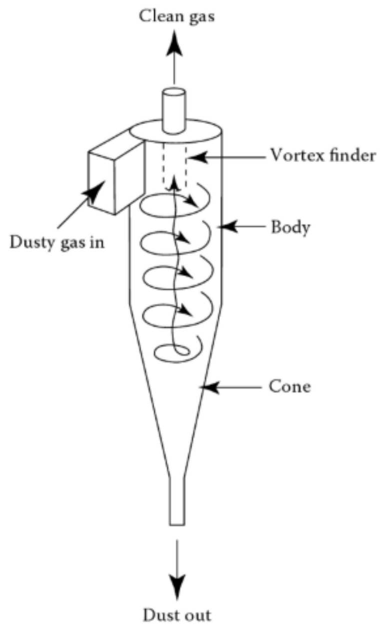

Fig. 3. Schematics of gas flow inside a cyclone [Schenelle, 2016].

Centripetal force pushes the particles against the wall, so that gravity can channel the particles towards the chamber's bottom (Chaves, 2013). Thus, the air (loaded with particles) enters the equipment through an upper-side opening and is "forced" into a downward spiral. It hits the cyclone's inner wall leaving the particulate impregnated and the large particles fall through the bottom opening. As explained by Massarani (Massarani, 1992):

> A drag force, caused by the radial movement of the stream flow towards the cyclone's central axis, acts along with the gas' turbulence in opposition to the centrifugal force and their combined effect is the particulate flowing towards the bottom outlet hopper (10, our translation)[1].

Hence, the air flows downward forming an outer vortex in which the gas' tangential velocity increase with the decrease of the radial position to a maximum value. This maximum value happens in an intermediate region between the outer and the inner vortex which defines the cyclone's central axis. In the inner vortex the air flows in an upward spiral, where the gas' tangential velocity decreases with the decrease of the radial position. The gaseous stream's path inside the cyclone until the clean gas leaves via the top opening is represented in Figure 3. The cyclone's shape favors the device's separation efficiency. According to Junior (Junior, 2014) in dry operations the cyclone has shown an average efficiency of 76,7% and the best efficiency obtained when operating with moist particulate was 85,3%. The larger the particle's diameter, the stronger is the centrifugal and gravity forces' action and consequently more efficient is the collection (Cooper, 2011). The cyclone's comparative performance regarding other air pollution control equipment is presented in Table 2. When compared to other equipment with the same function, cyclones have a lower cleaning capacity, which makes this equipment not recommended for situations where air pollution control requirements are rigorous. In these cases, cyclones can act as precleaners, complementing more effective machinery, since, according to Cooper and Alley (Cooper, 2011), cyclones reduce the particulate concentration sent to the following equipment, which can generate savings. Thus, it is noticeable that cyclone equipment displays advantageous points towards its acquisition and operation, but also some functional disadvantages that can result in losses if they are neglected in during process design.

[1] Original quote: Em oposição à força centrífuga, está o arrasto desta força causada pelo movimento radial do fluxo de gás em direção ao eixo central do ciclone, e a turbulência da corrente gasosa, cujo efeito combinado é que as partículas coletadas vão à conduta de saída (9).

Baghouse filter: The baghouse filter, also known as bag filter or fabric filter, is a widely used air pollution control device whose main characteristic is safety. It consists of an external metallic structure and filter bags, which can be of porous fabric or some type of felt. Its main function is solid-gas separation for product recovery and purification of gases via pollutant collection (Pacheco, 2013). The bags act as filters retaining heavy particles in the fabric and fragmenting them with the assistance of gravity (OLIVEIRA, 2014). Schematic of a baghouse filter operation is shown in Fig. 4, the gas flow enters the equipment loaded with contaminants (A), it is conducted internally leaving the heavy particulate when it moves across the fabric and coming out at the other side (B). Then, the particles precipitates by means of gravity, reverse flow or pulses.

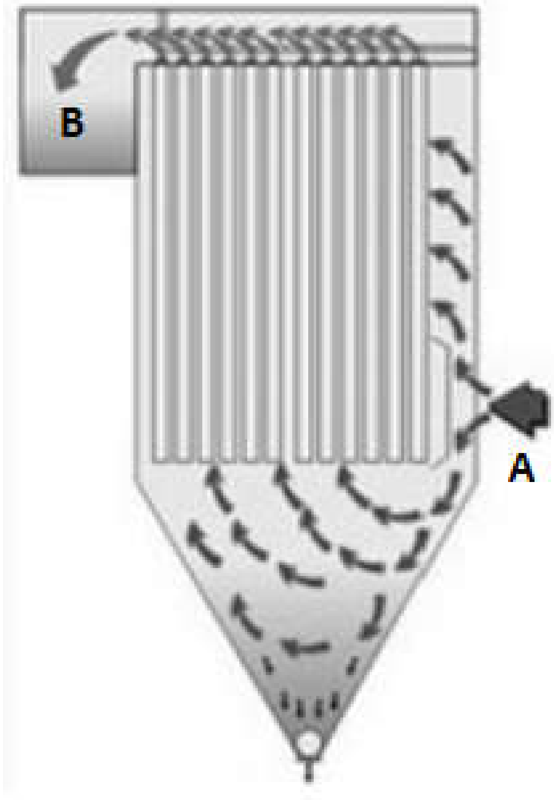

Fig. 4. Air flow inside the baghouse filter [5]

According to the American Conference of Governmental Industrial Hygienists – Committee on Industrial Ventilation (American Conference of Governmental Industrial Hygienists, 2017), the fabric filters used in this kind of equipment, showed in tests 99% of collection efficiency for particulate matter, which is a satisfactory result considering the increasing demands from environmental agencies. This efficiency yield is obtained even with variations in air speed, dust load and granulometry, which indicates that most dry particles, regardless of size, can be removed (http://www.sinto.com.br. Accessed March 26, 2018.). Some limitations presented by this device are: possible high-temperature gas emission; excessive humidity absorption; emission of condensable and sticky particles; and large space occupied by this system in industries. Detailed characteristics in comparison with other equipment are shown in Table 3.

Filter bags: The filter bags are pieces made of needled punched nonwoven materials specially manufactured to remove particulate from gaseous streams (see Fig. 5). When the gas is passing through the filtration element, it leaves the heavy particulate impregnated on the device's walls. Over time and use the bags become overloaded with dust requiring cleaning, which can be done by means of: compressed air jets; manual or mechanical vibration; or washing. The effects of cleaning via compressed air jets on the bags are shown in Figure 6.

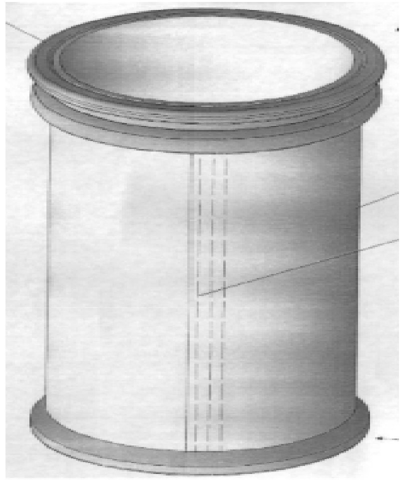

Fig. 5. Filter bag [19]

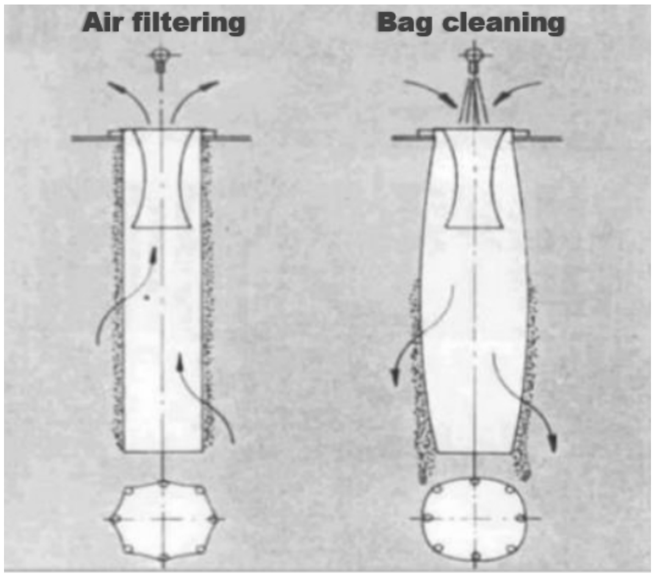

Fig. 6. Bag filter cleaning via compressed air jets [20]

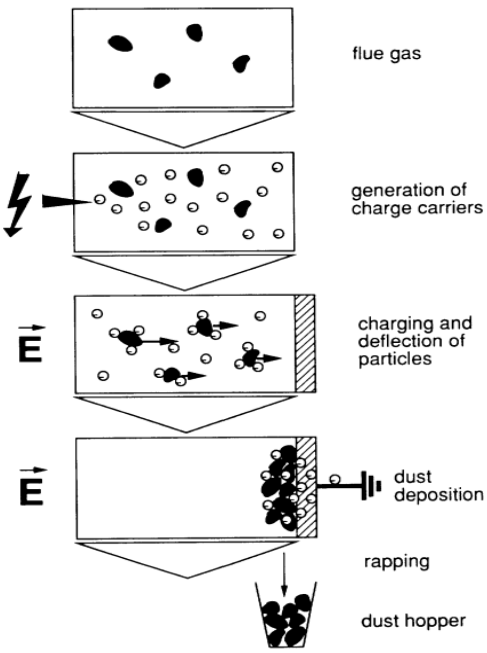

Fig. 7. Schematic illustration of the separation process in electrostatic precipitators [22]

Table 2. Pros and cons of cyclones [13-14]

PROS	CONS
High efficiency in medium and large particulate removal.	Low efficiency for particles smaller than 10 µm.
Low average pressure drop (from 50 to 150 mm w.c.)	Cannot be used when adhering particles are present.
One-step or multi-stage systems are available.	Possibility of clogging (due to smaller, hygroscopic and/or adhering particles).
Simple construction and it requires relatively small space to install.	Excessive abrasion wear
Contains no moving parts, except when rotary airlock valves are used in dust collection	Requires serial equipment setting to increase efficiency (which leads to higher pressure drop).
Resistant to temperature and corrosion.	
Low capital and maintenance costs.	

Table 3. Pros and Cons of Baghouse filters [13-14]

PROS	CONS
High removal (up to 99.9%) of both large and small particulate (down to submicron).	Uncapable of working with humid streams.
Efficiency and pressure drop are little affected by variations in ash loading on filters that are cleaned periodically.	Differential pressure required is, on average, within 100 to 250 mm w.c.
Selected fibers usage and precoating of granular filters allows for high efficiency collection of particulate matter with micrometer dimensions and gaseous contaminants.	Some kinds of powders treatment may require specific bag manipulation to reduce dust infiltration, or to help removing collected dust.
Ability to operate with a great variety of powders.	Possibility of clogging.
Relatively insensitive to gas flow fluctuations.	Bag replacement requires usage of adequate respiratory protection equipment.
The collected material can be dried for further processing or disposal.	Bag's lifespan can be shortened due to high temperatures, presence of acids and bases or some particular gas constituents.
There are no disposal problems of liquid waste, water pollution or freezing liquids (as it happens in scrubbers).	Special additive addition is required when working with hydroscopic materials, mixture condensation, or tar components which may cause fouling and/or clogging.
No high voltage risk, simplifying operation and maintenance.	Small dust accumulation inside the collection device may pose a risk of fire or explosion, and fabric bags may burn if collecting oxidizable dust.
Relatively simple operation.	Large space required.
Several possible configurations that result in different inlet-outlet flange dimensions and positions, easily adjusting to the process' layout.	Frequent cleaning is necessary demanding a parallel system in order to maintain continuous operation.
Corrosion and rusting are not, in general, problematic.	For stream treatment in temperatures above 300°C, it is required special refractory mineral or metal bags, which are still in development and very expensive.
Possibility of air recirculation back to the industrial plant resulting in energy savings.	Relatively high maintenance and operating costs (due to periodic bag changes, for example).

Table 4. Properties of different filter bag materials [18]

Bag material	Resistence to					Maximum Operation Temperature ºC	
	Traction	Abrasion	Acids	Alkalis	Combustion	Continous	Peaks
Cotton	Good	Good	Poor	Good	Yes	80	90
Polypropylene	Excellent	Excellent	Excellent	Excellent	Yes	90	90
Nylon	Excellent	Excellent	Poor	Excellent	Yes	90	120
Homopolymer Acrylic	Good	Good	Very Good	Poor	Yes	130	140
Copolymer Acrylic	Fair	Poor	Good	Poor	Yes	110	120
Polyester	Excellent	Excellent	Poor	Poor	Yes	135	150
Aramide (Nomex)	Very Good	Excellent	Poor	Good	No	190	220
PTFE (Teflon)	Fair	Poor	Good	Poor	No	230	260
Fiberglass	Excellent	Poor	Good	Poor	No	260	290
PPS (Ryton)	Very Good	Excellent	Excellent	Very Good	No	190	220
P-84	Very Good	Excellent	Very Good	Poor	No	260	290

Table 5. Characteristics of different filter bag materials [18].

Material	Fibers characteristics
Polypropylene	Resistant fibers, low moisture absorption and excellent chemical resistance
Nylon	Strong fibers with excellent resistance to abrasion and alkalis.
Acrylic	Good in acid conditions. Excellent dimensional stability and hydrolysis resistance.
Polyester	High tensile strength, good dimensional stability, heat resistance up to 135ºC.
Aramide (Nomex)	Excellent heat resistance (190ºC) and excellent abrasion resistance.
PTFE (Teflon)	It can be used in temperatures above 230ºC and has excellent chemical resistance.
Fiberglass	It can be used at high temperatures and has high tensile strength.
PPS (Ryton)	Excellent chemical and abrasion resistance. Excellent heat resistance at 190ºC.

Table 6. Pros and cons of electrostatic precipitators [13-14]

PROS	CONS
High collection efficiency of particulate matter (fine and coarse).	Difficult removal of some particles due to extreme resistive properties (high or low).
Low pressure drop (less than 13 mm w.c.).	No control of gaseous pollutant emissions, only particulate matter.
Capable of operating at both high pressures (up to 10 atm) and under vacuum conditions.	Highly sensible to fluctuating gas stream conditions (in particular, flow rates, temperatures, gas composition and particulate matter).
Dry collection and disposal of waste.	Incapable of treating streams with a wide range of particles.
Wide range of operation temperature (up to 700°C).	Risk of explosion when treating combustible gases or particles.
Able to effectively treat high flow rates.	Special precautions needed to protect workers from high voltage risks.
Minimum maintenance requirement allows for continuous operation.	Ozone production at the negative electrode during gas ionization.
Low cost of operation and maintenance in comparison to the cyclone and baghouse filters.	Complex and personalized maintenance required.
	Relatively large space required for installation.
	High capital cost (design, engineering and installation).

Table 7. Particulate matter collection efficiency as a function of particle size distribution (in percentages) [28]

Pollution Control Equipment	Diameter (µm)				
	0 → 5	5 → 10	10 → 20	20 → 44	> 44
Gravity settling chamber (with baffles)	7,5	22	43	80	90
Low presure cyclone	12	33	57	82	91
High presure cyclone	40	79	92	95	97
Multicyclone	25	54	74	95	98
Baghouse filter	99	100	100	100	100
Electrostatic precipitator	97	99	99,5	100	100

Filter bags' materials: Commercially, it is possible to find a variety of filter bags with specific materials to meet chemical processes' needs. The bag's material choice may vary according to the equipment's operating conditions, it should take into consideration fibers properties and the outlet gas temperature. In order to help identify the most appropriate material, performance characteristics from commonly used materials to manufacture bags are described on Tables 4 and 5.

Electrostatic precipitator: Electrostatic precipitators, also called electrostatic air cleaners, are equipment used for pollution control in industries that produce large amounts of harmful gases. Its operation principle consists of electrically charging the particulate matter that enters the equipment through the so-called corona discharge. The electrical discharge occurs between two electrodes when they are submitted to a high potential difference. Generation of a high intensity electric field is necessary for the production of ions in large quantities in a gaseous stream. Then, the charged particles are attracted to a grounded electrode that "collects" them in a plate (Lisboa, 2020). Dullien (DULLIEN, 1989) adds that the migration rate of charged particles to the collecting electrodes is a function of their size, electric field intensity, gas flow and the magnitude of the particle's electrical charge. Figure 7 shows the stages of operation of an electrostatic precipitator that include charging (when the chamber is charged by the flow of air and particles), adhesion – in which the particles adhered to the chamber's walls due to electromagnetic attraction, and rapping, where the trapped particles are separated from the walls through impulse or vibration and collected by gravity.

There are two models of electrostatic precipitators, the single-stage one - where the charging and migration of the particles to the collector plate occur in a single step - and the two-stage precipitator - where the particles are charged in the first section and removed in the second. In simple stage electrostatic precipitators, the re-suspension of particles already collected is minimized (MIZUNO, 2020), while in the double stage equipment there is a longer loading (charging) time of particles and less tendency for occurrence of the phenomenon called reverse corona (FALAGUASTA, 2005). Electrostatic precipitators are used in small scale applications, such as cleanroom technology (PARKER, 1997), pros and cons of this equipment are presented in Table 7:

USAGE AND WORKABILITY RANGE: Each of the presented equipment's usage varies according to the industry and processed material[2]. The gravity settling chamber is widely used as a pre-collector for particles larger than 40 µm decreasing the final collector's loading in metallurgical installations and metal refining processes – in which the gas streams are very dirty - or in food industries, in processes that generate ash such as boilers fueled by coal (26-27). The dry centrifugal collectors called cyclones are generally used as pre-collectors of medium and large particles (above 10 µm) in chemical processes, oil refineries and food processing industries. It is very useful in processes involving cement furnaces, steel mills and foundries (DE MELO LISBOA, 2008; SILVA, 2007). Baghouse filters, according to De Melo Lisboa (DE MELO LISBOA, 2008) and Silva (SILVA, 2007) are used as final collectors of particles of all sizes, and it can be implemented to recover powders from carpentry works; weighing and sieving of granular chemicals; rock and cement crushing; cereal, clay and minerals processing; as well as tanning, fertilizers and paper production. Lastly, electrostatic precipitators are commonly used as final collectors of particles of all sizes, or when treating a large flow rate. They are found in industries acting as a mechanism to control ash emission from boilers, incinerators, and manufacturing processes involving lime, cement and paper (Lisboa, 2020). CETESB (CETESB, 1987), Sao Paulo State Environmental Company, compared the presented air pollution control devices' collection efficiency by particulate diameter and their general performance is presented in Table 8.

[2] The website consultoria ambiental.com.br (24) presents several articles related to the environment and pollution control equipment, mentioned in the text.

CONCLUSION

Growing environmental concern, motivated by the aggravation of respiratory diseases, has motivated policy enforcement to control and reduce pollutant agent's concentration in the atmosphere. In this respect, chemical industries have sought to adopt measures such as control systems for the emission of gases and particulate matter which, although indispensable, also offer additional benefits such as recovering materials used in operations generating savings by reducing operational costs. Deeper understanding of each equipment's usage and workability allow us to understand their role in industrial processing and their efficiency when dealing with each particulate matter produced, such as dust, ashes, soot and various vapors. Pros and cons of each air pollution device presented here enables, therefore, a more precise analysis of the required and expected performance and results of the pollution control devices. Funding: This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

REFERENCES

American Conference of Governmental Industrial Hygienists – Committee on Industrial Ventilation: "Industrial Ventilation: a manual of recommended practice" 24ª Ed. Cincinnati: Ohio, 2001.

BRAZIL. Ministério do Meio Ambiente. Resolução CONAMA nº 3, de 28 de junho de 1990. Dispõe sobre padrões de qualidade do ar. http://www.ibram.df.gov.br/images/resol_03.pdf. Accessed March 17, 2018.

CAPULLI, D.; ALLEVATO, M. Poluição atmosfera industrial – perfis tecnológicos de equipamentos de controle. http://www.capmetal.com.br/novo/_artigos/gamapar.pdf. Accessed June 18, 2016.

CETESB. Companhia de Tecnologia de Saneamento Ambiental - Apostila do curso de seleção de equipamentos de controle da poluição do ar. São Paulo, 1987.

CHAVES, Enrico Lara. Gestão Ambiental do gás do alto forno e avaliação dos sistemas de controle atmosféricos de siderúrgica, viabilizando um sistema de geração de energia elétrica. M.S. Thesis, Florianópolis: UFSC, 2013.

CHEREMISINOFF, Nicholas P. Handbook of Air Pollution Prevention and Control. Woburn: Butterworth Heinemann, 2002.

Controle de poluição de ar. Disponível em: https://www.consultoriaambiental.com.br/pdf/pdf-15.pdf. Accessed June 19, 2020.

COOPER, C. D.; ALLEY, F. C. Air Pollution Control: A design approach. 3° Ed. Waveland: Long Grove, Illinois, 2011.

DAVIS, W. T; BOUNICORE; A.J. LOUIS, T. Air Pollution Engineering Manual. New York: John Wiley, 2000.

DE MELO LISBOA, H. (2008) Controle da Poluição Atmosférica. http://www.ufsc.br. Accessed March 20, 2018.

DULLIEN, F. A. L., Introduction to Industrial Gas Cleaning, Academic Press: Inc. San Diego, 1989. 285 p.

Eco Tech System. http://www.ecotechsystem.com.br. Accessed March 26, 2018.

ENVIRONMENTAL PROTECTION AGENCY (US-EPA). Particulate Matter (PM). 2013. www.epa.gov/ttn/scram/modelingappsinde/.Accessed March 13, 2018.

FALAGUASTA, M. C. R., Estudo do Desempenho de um Precipitador Eletrostático Operando na Captura de Partículas Submicrométricas e Nanométricas, *PhD Thesis*, São Carlos: UFSCar, 2005.

JUNIOR, C. J., Avaliação do Desempenho de um Ciclone *Stairmand* Adaptado com Bicos Injetores de Água. M. S, Thesis, São Carlos: UFSCar, 2014.

LISBOA, Henrique de Melo; SCHIRMER, Waldir Nagel. Controle da Poluição Atmosférica: Metodologia de Controle da Poluição Atmosférica, 2007. https://pt.scribd.com/doc/313542774/71589130-metodologia-decontrole-a-poluicao-capitulo-7-pdf. Accessed May 25, 2020.

MACINTYRE, Archibald J. Ventilação industrial e controle da poluição. 2 Ed. Rio de Janeiro: Livros Técnicos e Científicos Editora S.A. 1990.

MASSARANI, G. Desempenho de Ciclones e Hidrociclones. CETEM, 1992.

MIZUNO, A., Electrostatic Precipitators, IEEE Transactions on Dieletrics and Electrical Insulation. V. 7 nº 5, 2000, p. 615-624.

OLIVEIRA, A. A. B. de. Inventário das emissões atmosféricas na indústria siderúrgica. *Term paper*, Rio de Janeiro: UFRJ, 2014.

PACHECO, T. de A. Tecnologia de filtro manga combate poluição atmosférica. Revista Meio Filtrante. Ed. 63, jul./ago. 2013. Interview granted to Bruna Lavrini. http://www.vortexindustrial.com.br/media//DIR_25601/1fc0282151a9e37fffff8660ffaf2815.pdf. Accessed June 19, 2020.

PARKER, K. R. Applied Electrostatic Precipitation: Champman & Hall, 1997.

Patentes Online. http://www.patentesonline.com.br. Accessed March 26, 2018.

SCHENELLE, K. B.; BROWN, C.A. Air Pollution Control Technology Handbook. 2º ed. Ed: CRC Press LLC. Nova York, 2016.

SILVA, F. R. Guia de tecnologias ambientais: Ar e Poluição do Ar: Via Sapia, 2007.

Sinto. http://www.sinto.com.br. Accessed March 26, 2018.

VALLERO, D. Fundamentals of air pollution. 4 ed: Academic Press, 2007.

WORLD HEALTH ORGANIZATION (WHO). Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide: Global update 2005. WHO, 2006.

****