Optimization of Air Distribution in a Baghouse Filter Using Computational Fluid Dynamics

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Abstract—**Baghouse filters are used to reduce the emission of pollutants in the atmosphere. With the stricter environmental regulations and the need to avoid the emission of pollutants into the atmosphere, the demand for better results in terms of collection efficiency and filtration rises. A good performance of a baghouse filter is closely linked to the correct flow distribution inside it, whether in the hopper or in the bags. Other important variables for good performance are internal speed, filtration rate (RAP), pressure drop, cleaning efficiency, etc. The upgrading of existing bag filters to current standards is a major challenge for the industry, generally due to, among other factors, emission regulations and common physical and dimensional constraints of the existing equipment. Computational Fluid Dynamics analysis (CFD) can help deal with this problem because it makes possible to perform several analyzes at a lower cost and with great result accuracy when compared with the traditional approaches. In this work, the analysis of an existing bag filter, which presents serious problems of premature discharging of components due to nonuniformity in the internal distribution of the flow, is performed. This analysis has several steps, among them, documentation survey, field survey, flow and pressure drop measurements (pressure differential between the clean side and the dirty side of the filter) with the aid of CFD, with the objective to raise pressure and velocity and to identify possible dimensional changes to improve flow uniformity.**

Keywords-baghouse filter; flow distribution; flow uniformization; computational fluid dynamics (CFD); internal flow

I. INTRODUCTION

Existing environmental standards have become increasingly restrictive because of growing concerns about climate change, employee and public health. Thus, the need emerged to control air quality, minimizing the amount of atmospheric pollutants released by the industrial sector. In this context, environmental protection systems have become increasingly important within industrial facilities, with the purpose of exhausting gases from the production process, containing particulate matter, providing separation and disposing of clean gases (particulate free) or containing particulate matter within the allowable limits. The baghouse filter is the most used in the industry because it has high collection efficiency (above 99%) for inhalable particles. Direct impaction is used as a particle capture mechanism. The gas mixture is exhausted by an exhaust system, which can be installed before or after the filter, passing through a pipeline network until it reaches the filter itself, forcing the mixture containing the particles through the filter material (bag filter). The mixture passes through its pores and most of the particles are retained on its surface. It is necessary to remove them from time to time to avoid the formation of a very thick layer that would make the passing of air difficult (increase of the loss of charge). In this work, a bag filter installed to exhaust and treat gases from the storage and transportation of raw materials (coke, iron ore and sinter) from a blast furnace is studied. The filter, since its installation, shows a premature wear of the bag filters, which causes a series of other problems such as constant need for interventions, high cost of replacement of bag filters, premature wear of the exhaust system, etc. In order to reduce the above mentioned factors, a case study of this filter will be carried out with the aid of fluid dynamics simulation (CFD), considering the great potential of this technique for the solution of engineering problems.

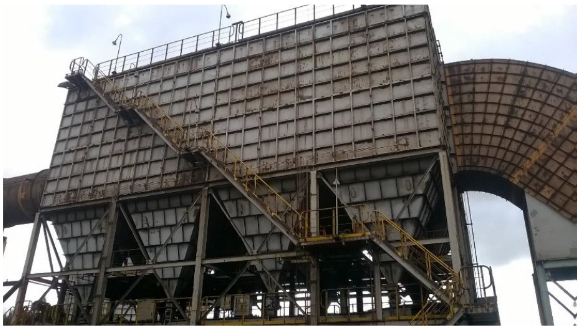

Fig. 1 Baghouse filter

II. LITERATURE REVIEW

The atmospheric pollutants are defined as any form of matter or energy with intensity and in quantity, concentration, time or characteristics not in accordance with the established levels, and which render or may render the air: improper, harmful or offensive to health, public or damaging to the material, the fauna and flora or harmful to the security, use, and enjoyment of the property and to the normal activities of the community [1]. Atmospheric pollutants can be classified initially according to their physical state: particulate matter,

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gases and vapors. Solid or liquid particles emitted by sources of air pollution or even those formed in the atmosphere, such as sulfate particles, are called particulate matter and, when suspended in the air, are called aerosols. Particulate matter particles can be classified by their size which is determined by the particle formation process and are directly associated with their health effects. Particles smaller than 10μm are called inhalable, while those with aerodynamic diameter less than 2.5μm are commonly called respirable. Both are of great interest because of their effects on human health [2]. They can also be classified in dusts (of cement, asbestos, cotton, street dust), fumes (of lead, aluminum, zinc, ammonium chloride), smoke (combustion particles of fossil fuels, asphalt materials or wood, containing soot, liquid particles and, in the case of wood and coal, a mineral fraction), and mists (liquid particles). According to [2] there is evidence of the association of particulate matter present in the air with effects on the respiratory and cardiovascular systems of the exposed population. Inhalable particles can penetrate the respiratory system, while the finer, respirable ones can also affect the heart and lungs causing serious health impacts.

A. *Treatment of Emissions*

Reduction in the amount of generated pollutants can be achieved by the following measures:

- Equipment use within its rated capacity.
- Good operation and proper maintenance of the equipment.
- Enclosures of sources, etc.

After exhausting all efforts with measures as mentioned above, without having achieved the necessary reduction in the generation of pollutants, it is necessary to use the equipment for treatment of the emissions (equipment of control of pollutants - filters). There are several types of equipment for this purpose, however, this work will be limited to the filter type of pulse jet baghouses.

B. *Baghouse Filter*

Baghouse filters are widely used for the control of emissions of particulate matter in industries and present high efficiency, generally above 99%, for fumes and dust above 0.1μm. They are a very complex installation and operation equipment. Some items that show the complexity of these devices are listed below:

- They treat abrasive gases at high temperatures and high speeds.
- They are closely related to the steelmaking process.
- Operational failures can lead to significant material losses and safety-critical situations.
- They are designed by adapting existing process conditions and are often not prepared for the future.
- They adapt to layout and available spaces.
- They consume a significant amount of water and/or energy.
- Their maintenance is difficult and time consuming.

C. *Filtering Process*

A brief description of the operating principle of the filter follows. The passage of the gaseous mixture containing the particles through a porous filter material, the gas passing through its pores and the particles, for the most part, are retained on its surface, which from time to time has to be withdrawn to avoid the formation of a very thick layer (cake), which would disturb the passing of gas (increase of the loss of charge). At the beginning of the filtration process, the collect begins with the collision of the particles against the fibers of the filter media and their subsequent adherence to them. As the process continues the layer of particles (cake) collected increases, becoming the collection medium and increasing the efficiency of the process. According to [4], as the particles are collected by the bags, the loss of charge (pressure drop) through the filter media increases until the moment it reaches a predetermined value or a fixed filtration time, where it is necessary, from the economic point of view, and operational to clean the bags. The bags need to be periodically cleaned to avoid excessive pressure drop on the baghouse filter. When the bags are cleaned, a layer of residual dust remains to act as a filter for the smaller particles. The baghouse filter is composed of a series of components, the main of them are:

- Captors
- Pipeline, dampers, orifice plates
- Entrance plenum
- Dirty tube
- Bags and cages
- Cleaning air chamber
- Cleaning air distribution system
- Cleaning system, manifold, blowpipe, valves
- Exhaust system, outlet duct, fan, casing and chimney

D. *Design of a Baghouse Filter*

Generally, the baghouse filter design is based on the manufacturer's experience with similar processes and applications. A configuration of inlet ducts and filter geometry is adopted, and it is assumed, for calculation purposes, that the flow at the inlet is uniform and that all the bags are subject to the same values of velocity and pressure, which in practice is not true. The author in [5] showed that the design of the filter directly influences the velocity distribution in the bags and that a filter with inhomogeneous distribution provides areas with filtration velocities higher or lower than the filtration rate by design. The existence of too high speed regions can cause premature wear of the baghouses. Poor flow distribution can promote non-uniformity in the cake, since higher filtration speeds are responsible for the formation of more compact and more difficult to remove cakes [6], as opposed to lower filtration rates. Therefore, the cleaning of the bags may be deficient, since the baghouse set and the surface of each baghouse are subject to filtration cakes of different characteristics.

E. Computational Fluid Dynamics

Numerical simulation in fluid mechanics and heat transfer, known as CFD (Computational Fluid Dynamics), has an impressive development over the last 20 years [7]. Initially used as a tool for analyzing physical problems at the level of scientific research, it is currently recognized as a powerful tool for solving important engineering problems. Improving the flow behavior of the fluid inside a bag filter is an engineering problem. There are three ways to develop a project or analyze a problem: analytical methods, numerical methods (numerical experimentation) and laboratory experimentation [7]. Out of these, the numerical simulation has been notable for its ability to solve complex problems, with complex geometries and general contour conditions, presenting results quickly.

III. RESEARCH METHODOLOGY

A. Characterization of the Problem

Since the baghouse filter's operational start, it has been showing a marked wear of the filtering units (bags) shown in Figure 2. The cost of maintenance and procurement of spare is high, due to the need for constant interventions for the exchange of damaged bags.

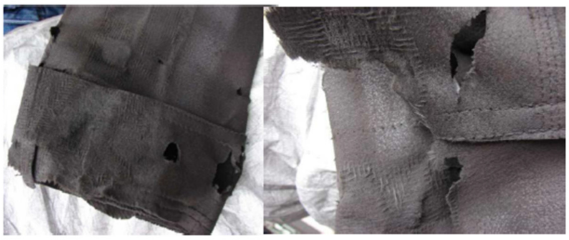


Fig. 2 Worn baghouses

B. Field Survey

The data acquisition step was performed in the plant's premises where the baghouse filter is installed and operating. The obtained data were used as input parameters in the numerical model, for its calibration. Numerical simulation and modeling steps were performed using the ANSYS SpaceClaim and CFX software, respectively, available and licensed in this plant. The filter to be studied is a pulsed jet type, and its data are listed in Table I. Drawings were drawn up, the equipment available history was studied and photographic records were made. Data were collected in order to obtain enough information to validate the model, the boundary conditions adopted and the simulations to be performed. A data collection chamber was chosen considering the ease of access and the positioning of the measuring points.

C. Mathematical Modeling

In this section a brief description will be developed of how the modeling and the numerical simulation were done using FVM (finite volume methods) to obtain the response variables of interest. For the modeling step the Ansys SpaceClaim 19.2 (2018) software was used. Figure 3 shows the model of the original chamber of the baghouse filter. For the mesh generation, ANSYS meshing software was used (Figure 4). Figure 5 shows the generated mesh data.

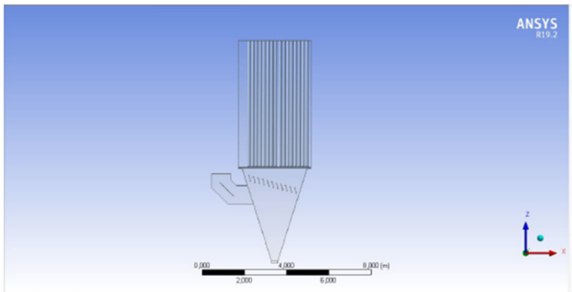


Fig. 3 Model of the filter chamber

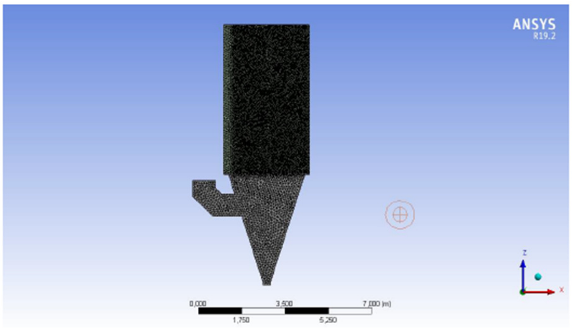
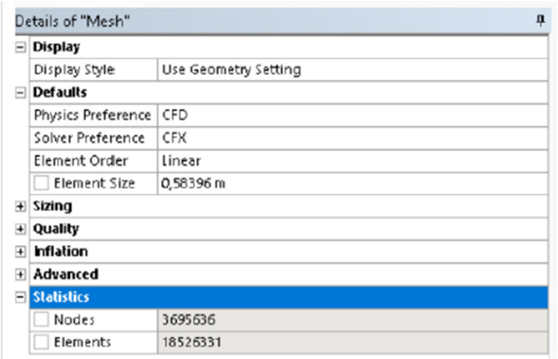


Fig. 4 Computational mesh generated



Details of "Mesh"	
Display	
Display Style	Use Geometry Setting
Defaults	
Physics Preference	CFD
Solver Preference	CFX
Element Order	Linear
Element Size	0,58396 m
Sizing	
Quality	
Inflation	
Advanced	
Statistics	
Nodes	3695636
Elements	18526331

Fig. 5 Generated mesh data

For this case, the domain was determined to be fluid with air at 25°C and no particulates. The simplifying assumptions regarding flow conditions are listed below with their respective justifications:

- Permanent flow: the properties of the fluid can be considered constant in time.
- Incompressible fluid: the fluid can be considered incompressible since the Mach number is less than 0.3, the flow is permanent and isothermal.
- Isothermal conditions: the studied baghouse filter exhausts conveying belts and silos in an open place. The air was considered to have temperature of 25°C and therefore the effects of thermal exchange can be neglected.
- The filter is divided into 8 chambers with medium inlet. For this work, air was considered uniformly divided between

the 8 chambers. A symmetry hypothesis was used to facilitate the work.

- Hypothesis of the fluid as continuous: a fluid can be treated as a continuous distribution of matter.
- The bags were not simulated due to the complexity of geometry, meshes and computational resource.

The objective of this work is to find a better distribution of the pressure profile and velocity within the dirty air chamber of the bag filter, so the variables to be evaluated will be the velocity in the three directions $ui=(u1, u2, u3)$ and pressure p, because there is no heat transfer or chemical reactions. To do so, the following laws will be considered:

- Mass conservation principle: The mass of a fluid in the system is preserved.
- Newton's second law: the rate of change of momentum is equal to the sum of the forces in a fluid particle.

IV. Results

A. Analytical Results

Table I shows the results obtained by analytical calculations for the original geometry.

TABLE I. BAGHOUSE FILTER DATA AND ANALYTICAL RESULTS

Parameter	Value	Unit
Volumetric gas flow rate	600,000.00	m³/h
Bag diameter	130.00	mm
Bag length	6,000.00	mm
Filtering area per bag	2.45	m²
Number of compartments	12	un
Number of bags per row	32	un
Number of compartments	8	un
Total number of bags	3,072.00	un
Total filter area	7,527.76	m²
Filtering velocity	1.33	m/min
Filtering velocity in cleaning	1.52	m/min
Maximum can velocity	Bags + cages	
Distance between centers - direction of flutes	180	mm
Internal dimension of filtration region - direction of flutes	5.94	m
Distance between centers - direction of the air manifold	180	mm
Internal dimension of the filtration region - direction of the air manifold	2.34	m
Transversal area of filtration region	111.20	m²
Sum of the areas of the bottoms of the bags or pulse pleats	40.78	m²
Transversal area of the filtration region available for gas rise	70.42	m²
Can velocity	2.37	m/s
Can velocity in cleaning	2.95	m/s

B. Original Geometry

In Figure 6, the streamlines are shown reaching the opposite side of the hopper inlet. It is observed that the velocity collides with the wall with values close to 20m/s, which for a typical application are about 10 times higher than the recommended one. Strong recirculation in the bottom of the hopper is also observed, which causes undesirable effects for the efficiency of the filter.

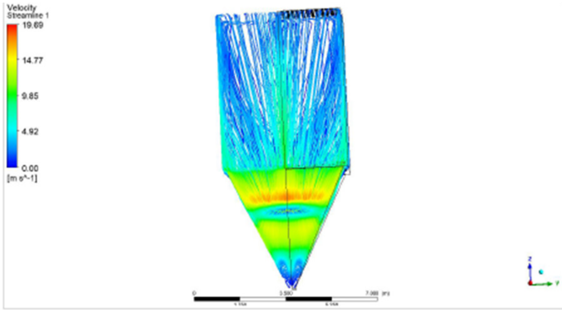


Fig. 6 Current lines on the opposite side of the hopper inlet

In Figure 7 we can see the velocity profile in a plane just before the baghouses. It is observed that the highest velocity values are on the opposite side of the hopper inlet, it is where there is greater wear and consequent change of baghouses, which agrees with the data collected in the field. It is also observed that the flow is not evenly distributed.

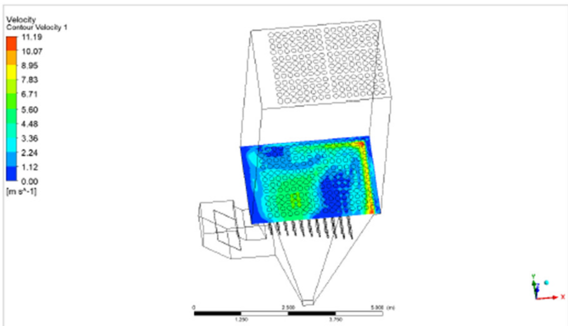


Fig. 7 Profile of velocities in the plane just before the baghouses

The ascent velocity (can velocity) has average values of 2.3m/s and can reach 2.9m/s when the chamber is cleaned. The simulation showed values in the order of 11.19m/s on the opposite side to the entrance in the hopper and values close to zero in the distant regions of the entrance. Recirculation is also observed in the lower part of the hopper. This recirculation is very damaging to the system, because in addition to recirculating the powder that is already fallen in the hopper, it also causes loss of energy by the turbulent dissipation. Studies show that the formation of the cake in the bags is not uniform, just as the pressure drop is not uniform either. The high-speed value inside the filter, besides causing an overload of a part of the filter, still cause the entrance of particulate material in the interstice of the baghouse. This material is not removed by the cleaning system and causes increase in pressure drop, which leads to premature wear of the filter's baghouses.

C. Proposed Geometry

Changes in the hopper inlet plenum in the baffle frame will be carried out, as shown in Figure 8. The angle of entry of the lower part of the plenum was changed and a baffle was added in the curve of the plenum. The number of baffles was decreased, and the angle increased from 15° to 20°, as shown in Figure 8. This was necessary because of the high velocity values in the plenum curve before entering the hopper.

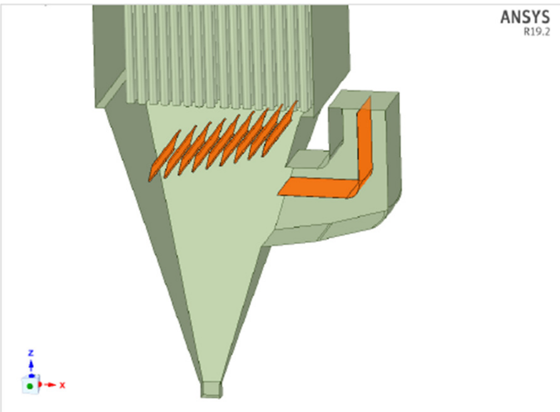


Fig. 8 Proposed geometry

The velocity profile of the proposed geometry is shown in Figure 9. It is observed that there is a significant reduction in the speed values within the baghouse filter. The input speed, which was close to 20m/s, is now close to the recommended value which is approximately 7m/s. Figure 10 shows a uniform distribution of the pressure field in the selected study regions.

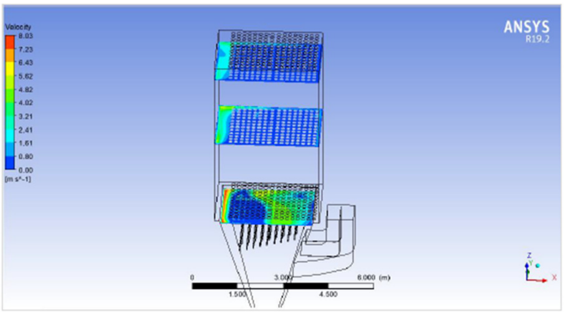


Fig. 9 Velocity profile for the proposed alternative geometry

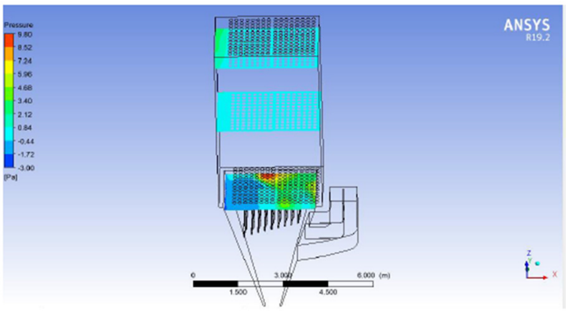


Fig. 10 Pressure profile for the presented alternative

V. Conclusion

CFD technique was used to investigate the reduction of the consequences generated by the non-uniform distribution of the flow inside the baghouse filter, and thus to find the best solution with optimized time and cost. During the design of the filter, we assumed the averages of the calculated variables are constant, but in practice, this was not verified. A simulation of the baghouse filter model was carried out according to the original design and the results were as suspected: high gas inlet velocity in the hopper, very high-rise velocity and uneven flow distribution, causing overflow on the back side of the hopper inlet, and non-uniform velocity and pressure profile. Several tests were carried out by altering the dimensions of the existing baffle frame in order to improve the flow inside the filter with a lower pressure drop to obtain the best speed field, especially in the region just before the start of the baghouses. It was found that in this case, due to the high inflow velocity in the hopper, changes in the baffle frame were not causing significant effects. There was an improvement in the distribution of the gases, but not enough to solve the problem. Simulations were carried out through CFD analysis, and it was concluded that it was necessary to increase the angle and the area where the flow enters the hopper, and to change the angle of the baffle frame. After analysis of the alternatives, it was concluded that the alternative which represents the most significant gain in the velocity field is shown in Figure 8. In Table II the main parameters studied in this work for the tested models are listed.

TABLE II. COMPARISON BETWEEN THE STUDIED PARAMETERS

	Model	
Parameters	**Original**	**Proposed**
Entering velocity [m/s]	17.78	9.85
Velocity on the opposite side [m/s]	17.67	9.59
Velocity in the lower plane [m/s]	11.74	0.03
Velocity in the central plane [m/s]	7.14	5.32
Velocity in the upper plane [m/s]	5.19	4.04
Velocity in the symmetry plane	17.74	10.93

In Table II we can see that there is a reduction of approximately 45% in the main monitored parameters, and in the others an average reduction of 30% was found. This change did not cause a significant change in the recirculation of the flow in the region of deposition of particulate material in the hopper, which can generate the resuspension of the powder. This was presented as the best alternative due to the gains in the uniformity of the pressure and velocity fields at the entrance of the hopper and in the region immediately below the baghouses, where the rate of gas rise is characterized.

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