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COMPUTATIONAL MODELING OF PRIMARY GAS CLEANING SYSTEM FOR BLAST FURNACE[1]

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Abstract

The blast furnace top gas contains high amount of dust, requiring pretreatment prior to use. The primary gas cleaning is usually performed in the gravity dust catcher, which has efficiency of 50 % to 60 %, generating dust as a byproduct of the blast furnace. Cyclones, according to the literature, are more efficient equipment to remove particulates than dust catcher. In this context, fluid dynamics models were developed through ANSYS-CFX® to simulate the gas and solid flows in dust catcher and cyclone, mainly evaluating the overall separation efficiency of these equipment. The results indicated that cyclones are more efficient than the gravity dust catcher. It is possible to obtain separation efficiency around 85 %, resulting in less generation of blast furnace sludge.

Key words: Blast furnace; Cyclone; Dust; Fluid dynamics modeling.

MODELAGEM COMPUTACIONAL DE EQUIPAMENTOS PARA A LIMPEZA PRIMÁRIA DE GÁS DE ALTO-FORNO

Resumo

O gás que sai no topo do alto-forno contém uma quantidade elevada de pó, exigindo tratamento prévio antes de sua utilização. A limpeza primária desse gás geralmente é realizada em balão de pó, que possui eficiência de 50 % a 60 %, gerando como subproduto o pó de alto-forno. Os ciclones, segundo a literatura, são mais eficientes para a remoção de particulados do que o balão de pó. Neste contexto, foram desenvolvidos modelos fluidodinâmicos, por meio de ANSYS-CFX®**,** para simular o escoamento de gases e sólidos em balão de pó e em ciclones, avaliando-se, principalmente, a eficiência total de separação destes equipamentos. Os resultados indicaram que os ciclones são mais eficientes do que o balão de pó. É possível obter uma eficiência de separação em torno de 85 %, o que resultaria em menor geração de lama de alto-forno.

Palavras-chave: Alto-forno; Ciclone; Pó de alto-forno; Modelagem fluidodinâmica.

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1 INTRODUCTION

The blast furnace top gas contains a high amount of dust requiring pretreatment prior to use. The cleaning of the gas generally includes a primary stage and a refining stage. In the Usiminas's blast furnaces, the primary cleaning is performed in dust catcher and the byproduct collected is dust. The separation of particles in this equipment is due to gravity and will be more efficient the higher the amount of dust to a given gas flow. The second cleaning can be done in electrostatic precipitators or venturi scrubber and the byproduct is blast furnace sludge(1). Currently, this sludge does not return to process because it contains harmful compounds for the operation of blast furnace. In relation to the dust, it is fully reused in the sintering process.

According to literature, cyclones by having more efficiency of gas-solid separation, reduce the amount of sludge generated in the next cleaning stage, besides contributing to the concentration of zinc in this byproduct. The collection of particles in this equipment is effected by the action of the centrifugal field resulting from its configuration. There are basically two types of cyclone for blast furnace: tangential and axial. The main difference between them is how the downcomer tube, that transports the blast furnace's gas to the primary cleaning, is connected to the cyclone.

It is worth noting that an inefficient cleaning gas can cause operational disturbances due to the accumulation of dust in the pipes that leading the gas to the gasholder. Therefore, it is necessary that the primary gas cleaning is efficient, especially, considering that the byproducts, dust and sludge, have a high iron content (35 % to 55 %) and carbon (20 % to 30 %). The reuse of dust become even more interesting in the current market, high price of iron ore and coal.

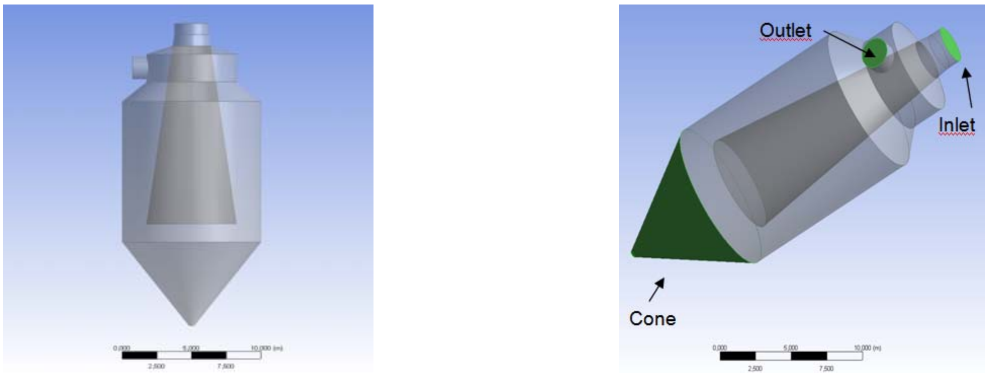
In this context, a fluid dynamic model was developed to simulate the flow of gases and solids in equipment used for primary gas cleaning, mainly evaluating the separation efficiency and pressure drop.

2 METODOLOGY

2.1 Geometry

The first information to be introduced in the calculation to solve a problem of computational fluid dynamics is the field where it will seek the solution of the problem. In this study, the geometries were generated in the Design Modeler.

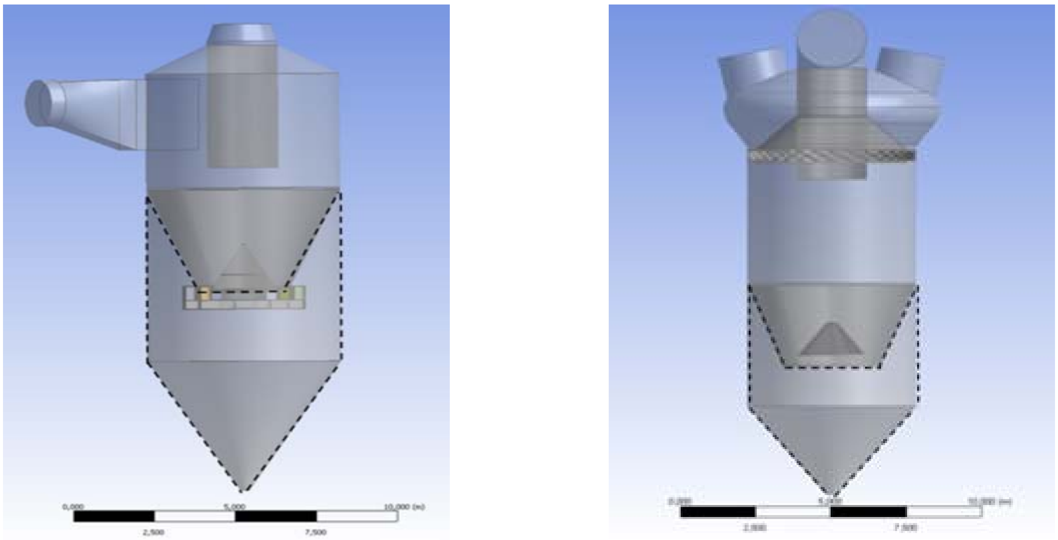
The dust catcher's geometry is shown in Figure 1.



(a) front view (b) boundary conditions

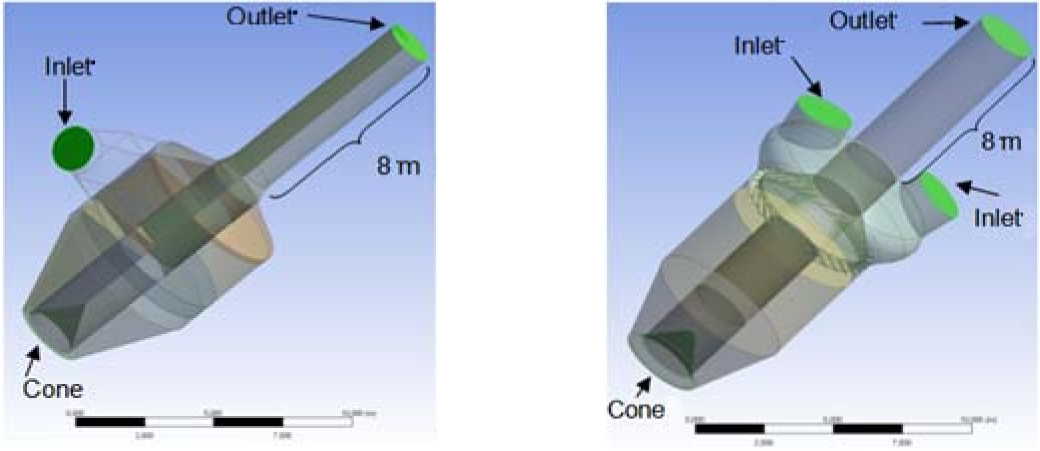
Figure 1. Dust catcher's geometry.

The boundary conditions corresponding to the inlet, the outlet and the cone are shown in figure 1 (b). The remainder was considered wall, including the diffuser. In the dust catcher's geometry was not require any modification for meshing or to stabilize the flow at the outlet.
Figure 2 shows the geometry of the cyclone tangential and axial.



(a) tangential cyclone geometry

(b) axial cyclone geometry – with 30 guides vanes with an inclination angle of 30 º



(c) boundary conditions of the tangential cyclone

(d) boundary conditions of the axial cyclone

Figure 2. Cyclones's geometry.

The original geometry of the tangential and axial cyclones are shown in figures 2 (a) and (b), respectively. In order to simplify the problem, it was chosen to disregard the region bounded by the dashed line, resulting in the geometries shown in figures 2 (c) and (d). In these figures, which is not inlet, outlet and cone, it was considered wall. In addition, to the two cyclones, the outlet tube (overflow) was extended in 8 m in order to achieve stabilization of the flow in this region, and some cuts were made to obtain a appropriate mesh for this type of flow.

2.2 Mesh

The mesh generated for the dust catcher, approximately 555,900 elements, is shown in figure 3. The mesh was 100 % tetrahedral with 5 layers (*inflation)* to capture the effects of boundary layer.

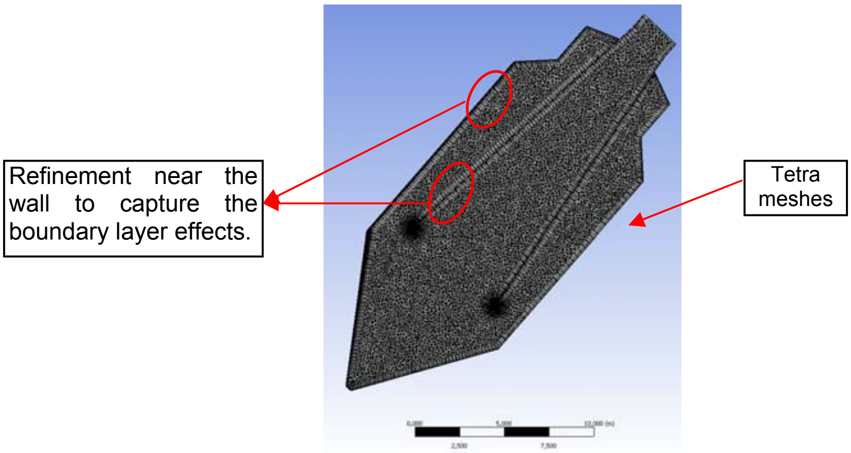
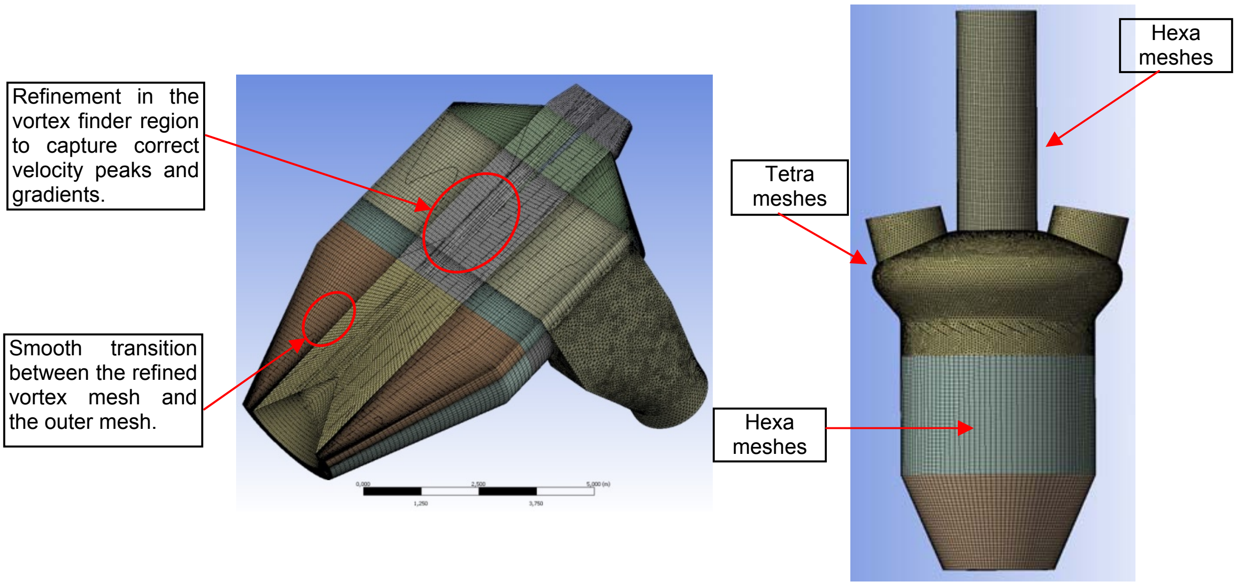


Figure 3. Characteristic of the generated mesh to dustcatcher.

The meshes generated for the simulation of the tangential and axial cyclones followed the characteristics shown in figures 4 (a) and (b), respectively. The mesh generated for the tangential cyclone obtained approximately 1,729,262 elements, while for the axial cyclone comprised 1,660,185 elements.

According to Aguirre and Damian,(2) in case of cyclones and hydrocyclones, the use of hexa meshes reduces the number of nodes using the same grid size and, due to higher quality, helps in stability and simulation speed. Additionally, this type of mesh is used to better align the mesh with the flow, thereby minimizing the phenomena of false diffusion. In the case of figure 4, the only part that has not been generated hexa meshes, but tetrahedral was the region of entry. For the two cyclones, the mesh was refined in the central region, where there may be a change in flow direction.



(a) tangential cyclone (b) axial cyclone

Figure 4. Characteristics of the generated mesh to cyclones.

2.3 Pre-processing

This step consist in modeling the physical problem of flow with the structuring of this information so that the solver can use them. The input parameters such as gas velocity, mass flow of gas and blast furnace dust, pressure and others were raised on the Blast Furnace #1 of Ipatinga Plant – Usiminas.

2.3.1 Initial conditions

Physical properties of blast furnace gas (BFG) and blast furnace dust are shown in table 1. Obtaining the mass flow of dust was based on the premise that the amount of dust contained in the blast furnace gas, before the primary cleaning stage is 20 g/Nm^3.(1) Table 2 shows a typical size distribution of dust in BFG(3).

Table 1. Physical properties of the gas and solid

	Property	Unity	Value
BFG	Density	kg/m^3	1.38
	Viscosity	Pa/s	2.04×10^{-5}
	Mass flow	kg/s	46.04
Dust	Density	g/cm^3	2.90
	Mass flow	Kg/s	0.67

Table 2. Typical size distribution of dust in BFG(3)

Particle size (μm)	Mean Size (μm)	Distribution (%)
0 - 10	5	9.5
10 - 20	15	7.5
20 - 40	30	13.0
40 - 80	60	18.0
80 - 120	100	15.0
120 - 200	160	17.0
200 - 300	250	10.0
300 - 600	450	10.0

2.3.2 Boundary conditions

The boundary conditions of input to the gas and particulate phase are defined as uniform velocity distribution. As for the outlet tube was set to continuous flow to all variables except to the pressure, which it was prescribed. To the dust catcher, the output condition used was outlet type, i.e., the flow is directed out of domain. In the cyclones, the output condition was the opening type, i.e., the flow can be both inside and outside of the domain, being characteristic of flow within a cyclone.

In the region of the walls, to the gas phase, it was defined that the velocity is zero, by the principle of phase adhesion to the wall surface. It was adopted the condition of zero slip without friction for the particulate phase. For the region of the cone, in the three equipment, the coefficient of restitution of the particles was zero. For these particles do not continue to be accounted for in the solver, it was enabled Mass Flow Absorption and configured the Absorption Coefficient equal to 1. Thus, all particles that have touched the surface of the cone were collected and removed from the simulation.

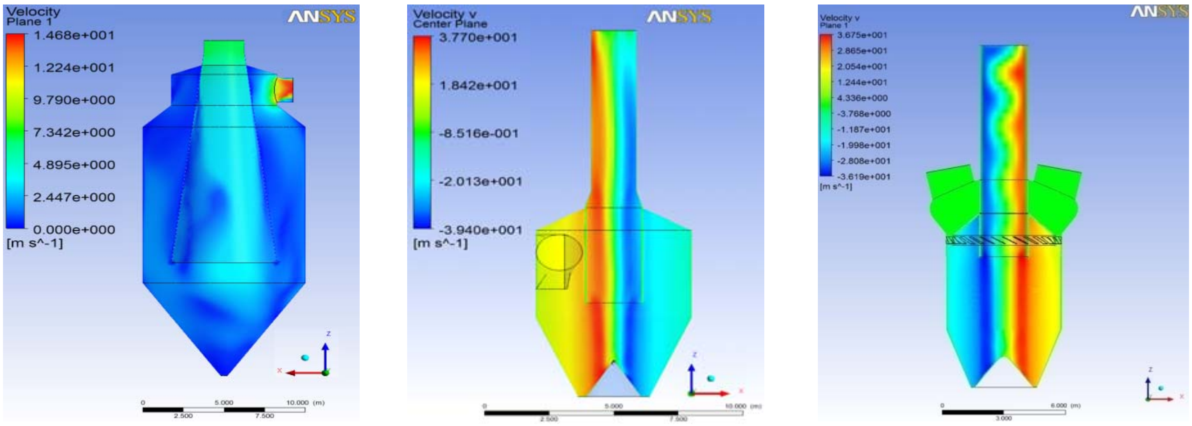
The drag force was modeled by the relation of Schiller Naumann. In addition to the forces due to gravity were considered as the turbulent dispersion forces for the transport of particles by the BFG. The thermal effect was not considered in the simulations.

The turbulence model used for the simulations was the anisotropic model SSG.

3. RESULTS AND DISCUSSION

3.1 Map of Velocity Field

The maps of velocity field in the three equipment are shown in figure 5.

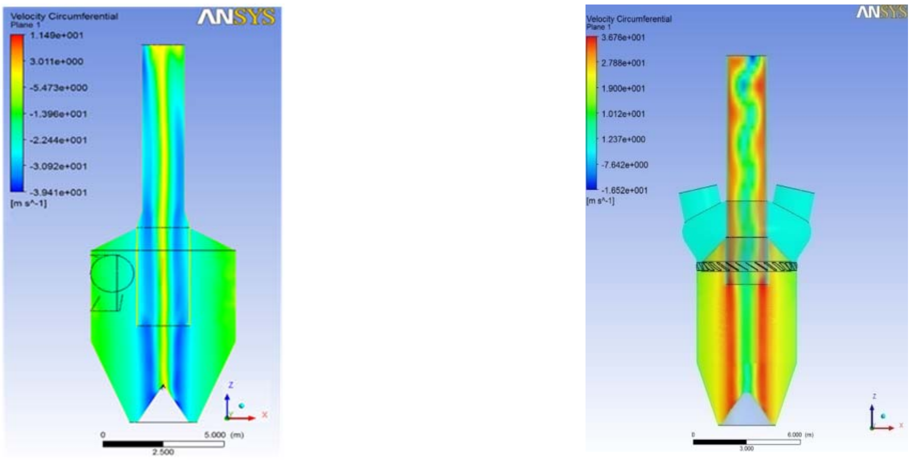


(a) dust catcher (b) tangential cyclone (c) axial cyclone

Figure 5. Maps of velocity field.

The gas enters at velocity of approximately 6.8 m/s and comes out of the dust catcher to 11.1 m/s, figure 5 (a). By inspection of figures 5 (b) and (c), due to the entry position of the cyclone in a plane (XZ), the velocity is positive on one side and the other is negative, with a maximum velocity closer to the center and a more stable core. This behavior is consistent with the velocity field of cyclones. Preservation of high velocity rotation is observed throughout the cyclone for the two cases. In tangential cyclone, the gas velocity at outlet (18.6 m/s) was almost twice that the velocity at inlet (10.7 m/s), while for axial, gas enters at a velocity of approximately 5.0 m/s and comes out to 30.0 m/s. The velocities in the interior and at the outlet of cyclones are much larger than the velocities in the interior of the dust catcher, due to high rotation velocity in cyclonic flow.

The maps of tangential velocity field for the tangential and axial cyclone are shown in figure 6.



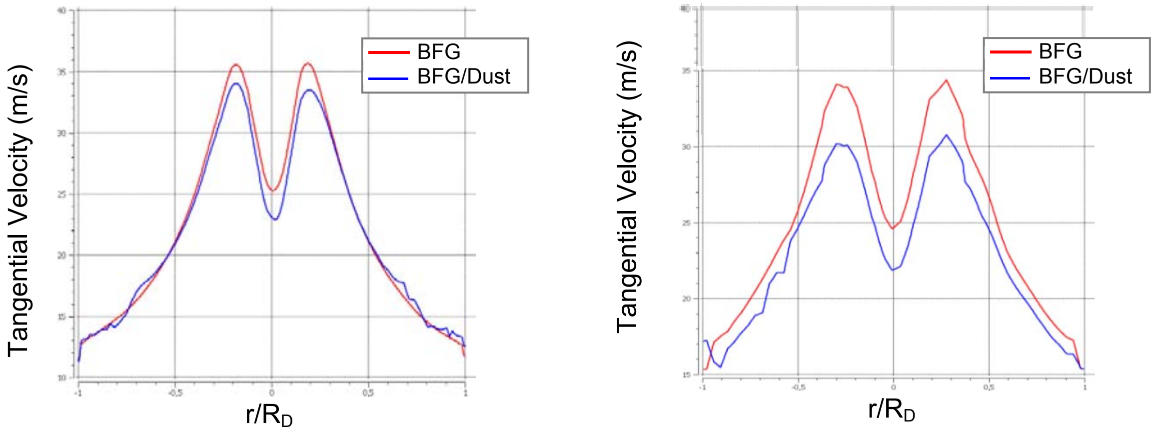
(a) tangential cyclone (b) axial cyclone

Figure 6. Maps of tangential velocity field.

It is observed in both cases that the tangential velocity gradually increases from the wall of the cyclones towards the center up to a maximum and then declines rapidly, figure 6 (a) and (b).

The profiles of tangential velocity of gas, with or without the presence of particles to the two cyclones in cylindrical region (12 m) are shown in figure 7. Note the influence of the particulate phase in the tangential velocity of the gas phase.

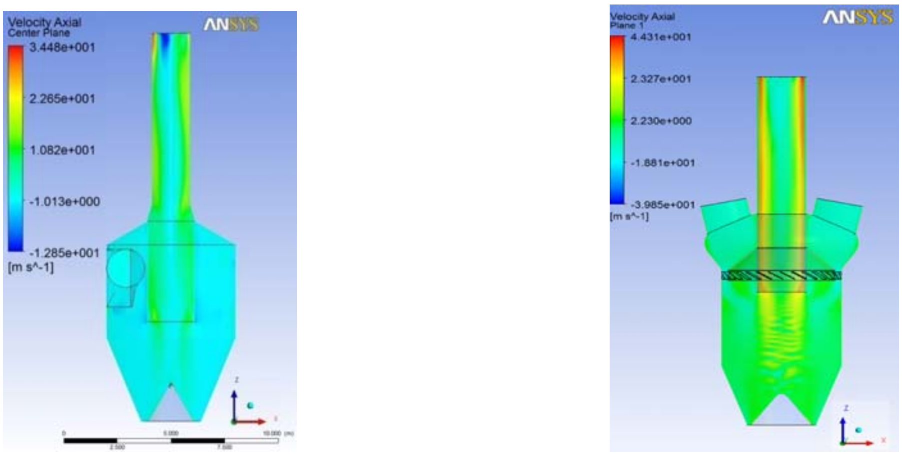
The maximum value of the tangential velocity of gas was 35.5 m/s to tangential cyclone and 34.0 m/s for the axial cyclone, which indicates a condition of high rotation within the cyclones. With the introduction of the particles to flow, there was a decrease of the maximum velocity at about 1.5 m/s for the tangential, while the axial cyclone this decrease was 4.0 m/s. This behavior was expected, since once initiated the feeding of particles occurs a larger transfer of momentum of the gas to solid, producing the drag and resulting in a lower gas velocity, as may be seen in figures.



(a) tangential cyclone (b) axial cyclone

Figure 7. Tangential velocity profiles of cyclones.

The maps of axial velocity fields for both cyclones are shown in figure 8.



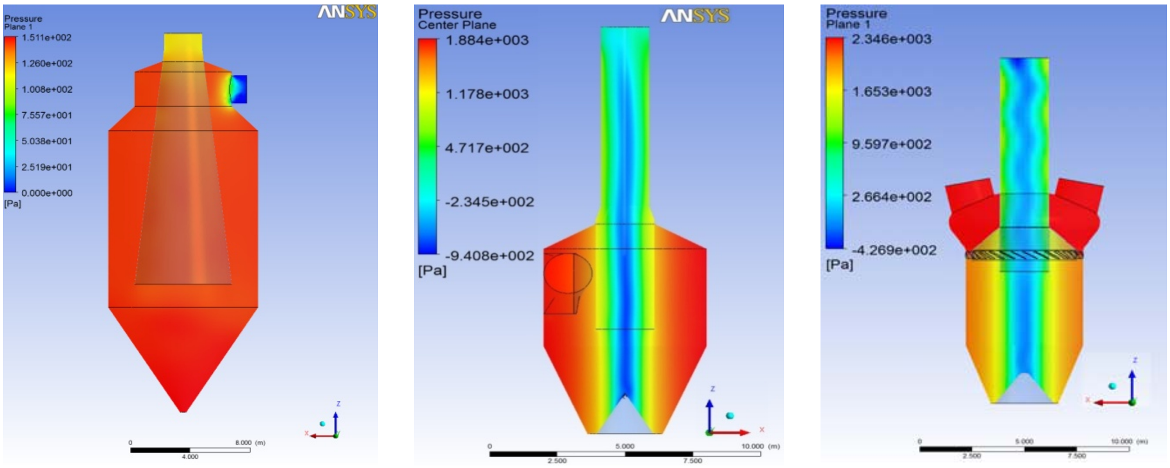
(a) tangential cyclone (b) axial cyclone

Figure 8. Maps of axial velocity field.

The maps of axial velocity fields shown in figures 8 (a) and (b) indicates that the reversal of gas flow extending over practically the whole equipment, justified by the fact of having high preservation of rotation velocity. The axial velocity is high near the walls of the outlet pipe and in the central region near to the inlet of outlet pipe.

3.2 Map of Pressure Field

The mappings of the pressure field in the three equipment are shown in figure 9.

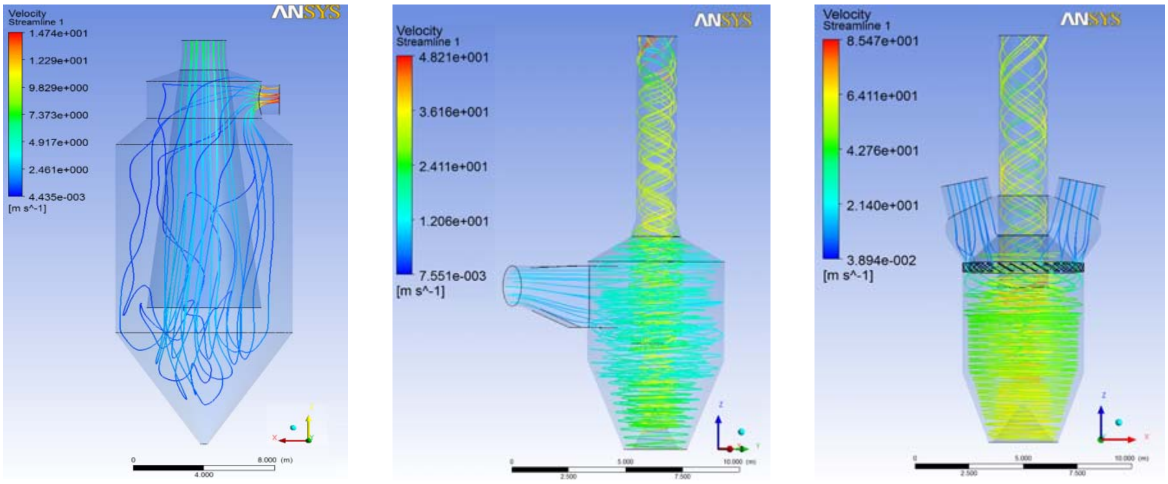


(a) dust catcher (b) tangential cyclone (c) axial cyclone

Figure 9. Maps of pressure field.

It can be seen in figure 9 (a) a uniform distribution of pressure within the dust catcher. The mapping of the pressure field to the cyclones corroborates the relationship between the low pressure region and reversal of the gas flow, figures 9 (b) and (c).

The trajectories of gas in the three equipment are shown in figure 10.



(a) dust catcher (b) tangential cyclone (c) axial cyclone

Figure 10. Trajectory of the gas inside the equipment.

The trajectory of gas inside the dust catcher is due to gravity, figure 10 (a). The preservation of high velocity rotation is observed in practically all the cyclones, figures 10 (b) and (c). The gas that enters axially passes through the guide vanes and so starts the rotary movement, figure 10 (c). It is observed that after passing through the guide vanes, the gas is accelerated.

3.3 Separation Efficiency

The separation efficiency of any equipment is highly dependent on the particle size distribution, the geometry of the equipment and operating conditions. Table 3 presents the overall separation efficiency for the three equipment.

Table 3. Overall separation efficiency

Equipment	Efficiency (%)
Dust catcher	65
Tangential Cyclone	87
Axial Cyclone	84

The dust catcher is the less efficient (65 %) of the three equipment. The separation efficiency of the dust catcher of Blast Furnace #1 is about 60 %. This difference may be due to distribution of particle size used in the simulation, since this parameter varies with the metallic burden and operating conditions of the blast furnace. Regarding the cyclones, the separation efficiency values were very similar, being 87 % to tangential cyclone and 84 % to axial cyclone.

In figure 9 is shown a graph of the separation efficiency as a function of particle size.

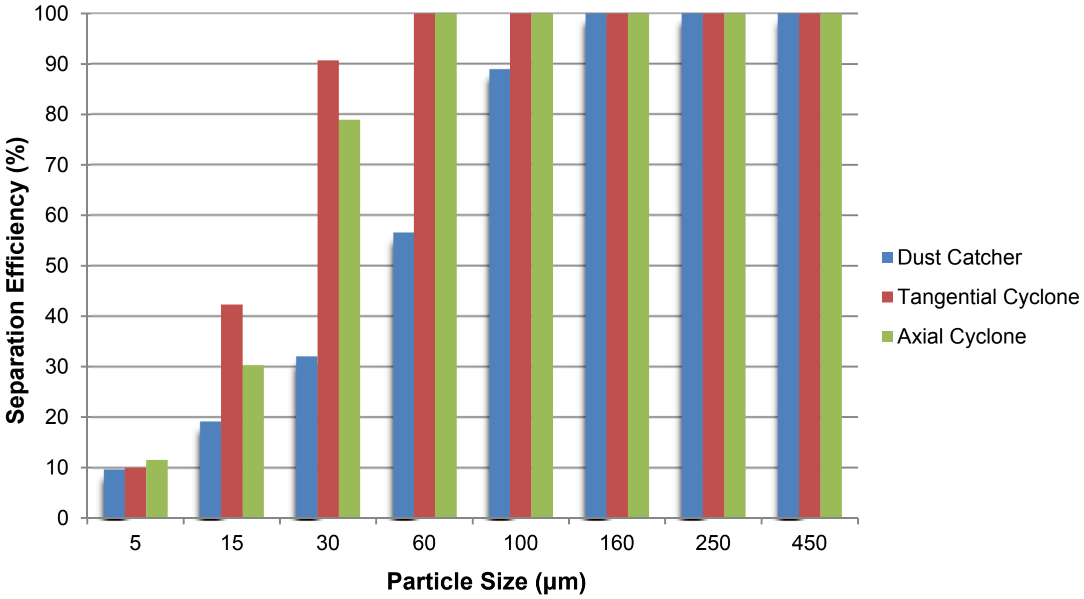


Figure 9. Separation efficiency of the equipment as a function of particle size.

The collection efficiency for the three equipment is very dependent on the particle size distribution. In case of dust catcher, it is found that particles below 30 µm are removed very little due to their small mass. Particles of 60 µm are partially removed (about 56 %) and particles larger than 160 µm are completely removed, figure 9. It appears that no significant difference in collection efficiency among the three equipment for the removal of particles of 5 µm. Due to their small mass, these particles are not effectively captured by the equipment. However, to particles from 15 µm, cyclones are definitely more effective than dust catcher. Although tangential cyclone be more efficient for removing particles between 15 µm to 30 µm than the axial cyclone, the overall collection efficiency for the two cyclones was very similar.

According to Ogawa(4), the residence time of the gas flow in the cyclone with tangential inlet is greater than that for the axial inlet. This means that it is possible to collect smaller particles which corresponding to the lower sedimentation velocity in the flow with tangential inlet.

The tangential velocity in the type with tangential inlet (34.0 m/s) is faster than the type with axial inlet (30.0 m/s). Another detail is that the outlet velocity in axial cyclone (30.0 m/s) is greater than the outlet velocity in tangential cyclone (18.6 m/s). This means that an unnecessary generation of turbulence is being promoted by the guide vanes. This turbulence not only reduces the tangential velocity of the gas also increases the turbulence diffusion of smaller particles, resulting is a reduction in collection efficiency of the type with axial inlet(4). However, this problem can be solved by adjusting the inclination of angle of the guide vanes.

3.4 Pressure Drop

Knowledge of the pressure drop in a gas-solid separation equipment is one of the items needed for the calculation of energy consumption and parameters optimization of this equipment.
The results of pressure drop are shown in table 4.

Table 4. Pressure drop for the equipment

Equipment	**Pressure Drop (Pa)**		
	Simulation	Actual	Literature
Dust catcher	115	608	-
Tangential cyclone	1,774	-	300 a 1,200
Axial cyclone	1,600	-	

According to table 4, there is almost no pressure drop inside the dust catcher. The separation in this equipment is performed only by gravity. In the case of dust catcher of Blast Furnace #1, the pressure on the top of the reactor is around 5775 Pa. Considering that the gas travels the length of the downcomer to enter in the dust catcher, it can expect a decrease of pressure in this route. Therefore, it is believe that the input pressure on the dust catcher is less than 5775 Pa. The pressure measured at outlet of the dust catcher is approximately 5167 Pa. Thus, the pressure drop to the dust catcher is about 608 Pa. The value of pressure drop obtained in the simulation was 115 Pa lower than the actual value (608 Pa). One possible reason is that considering the inlet pressure of the dust catcher as the pressure measured at the top of the blast furnace.
Regarding the cyclones, the tangential presented pressure drop larger than the axial cyclone, however, the values found for the two cases are of the same order of magnitude. It was not found data available in literature for pressure drop of a cyclone for primary cleaning of a blast furnace. It was compared with cyclones used for industrial gas-solids. In general, the pressure drop obtained in industrial cyclone varies from 300 Pa to 1200 Pa, with inlet gas velocity from 9 m/s to 13 m/s. However, these cyclones are much smaller when compared to a cyclone for blast furnace. The average height is about 1 m in the first case, while the second exceeds 10 m. It would expect a greater pressure drop in a cyclone for blast furnace.

4 CONCLUSIONS

Models were developed for the dynamic flow in the inner of dust catcher, tangential cyclone and axial cyclone. By means of the models were evaluated mappings of the velocity field, mappings of the pressure field, separation efficiency and pressure drop.
Evaluating the velocity fields inside the equipment, it was found that the velocities are greater in the inner and outlet of cyclones than the dust catcher.
Regarding the pressure fields, the dust catcher presented a uniform distribution of pressure. For both types of cyclone, it was observed the existence of a low pressure region in the center along the equipment.

Of the three equipment in this study, the dust catcher is the less efficient. The separation efficiency of the cyclones was very similar. Therefore, it is possible to obtain a more separation efficiency using cyclones, resulting in less generation of blast furnace sludge.

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