ORIGINAL ARTICLE

Computational Fluid Dynamics (CFD) Simulation of Forage Chopper Discharge Tower

Simulación por dinámica de fluido computacional (CFD) de torre de descarga de picadora de forraje

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ABSTRACT: The work is part of an investigation project approved by the National Program of Food Animal. The objective of the work was to carry out the simulation by CFD of forage chopper discharge tower, using SOLIDWORKS tool to improve its design. The conditions of frontiers of speed, volumetric flow and atmospheric pressure to the inlet and outlet of the tower divided in four areas are established for the pattern in study. The speeds profile, pressure and the aerodynamic force, with and without particles of vegetable material, inside the tower were obtained. The results show similar speeds of 12,9 - 50,3 m/s, at the inlet and at the outlet of the tower with and without particles. A decrease of pressure of 1 466,33 - 2 508,22 Pa is manifested at the outlet of the tower with respect to the inlet pressure. The aerodynamic force average for the four studied areas, overcome the necessary haulage force of the particle of 0,0195 N, what facilitates their expulsion through the outlet of the discharge tower.

Keywords: design, speeds profile, pressure and aerodynamics force.

RESUMEN: El trabajo forma parte de un proyecto de investigación aprobado por el Programa Nacional de Alimento Animal. El objetivo del trabajo consistió en realizar la simulación por CFD de la torre de descarga de una maquina picadora de forraje, empleando la herramienta SOLIDWORKS, con vista al perfeccionamiento de su diseño. Se establecen las condiciones de fronteras para el modelo en estudio, de velocidad, flujo volumétrico y presión atmosférica a la entrada y salida de la torre dividida en cuatro zonas. Se obtienen el perfil de velocidades, de presión y la fuerza aerodinámica, con y sin partículas de material vegetal, en el interior de la torre. Los resultados muestran velocidades similares de 12,9 - 50,3 m/s, tanto a la entrada como a la salida de la torre con y sin partículas. En la presión se manifiesta a la salida de la torre, una disminución de 1 466,33 - 2 508,22 Pa con respecto a la presión de entrada. La fuerza aerodinámica promedio para las cuatro zonas estudiadas, superan la fuerza de arrastre 0,0195 N necesaria de la partícula, lo que posibilita su expulsión por la salida de la torre de descarga.

Palabras clave: diseño, perfil de velocidades, presión y fuerza aerodinámica.

INTRODUCTION

In the last 20 years, the Center for Research in Agricultural Mechanization (CEMA), has developed several investigations aimed firstly at the design and construction of forage chopping machines for the processing of thick stems and later at their improvement, carried out by different researchers like Martínez *et al.* (1998), in the case of choppers with a disc-type working organ, as well as by Valdés (2008); Valdés y Martínez (2009); Valdés *et al.* (2010. 2012), in the case of a cutting organ of the drum type, carrying out the elaboration of a theoretical physical-mathematical model of the technological process, which interrelates the physical-mechanical properties of the material to be processed, with the design and exploitation parameters. It was experimentally validated with the prototype of forage chopper of national production MF-IIMA model EM-01, during the shredding of sugarcane stalks variety C323-68, and the influence of the inertia moment and of different angles of constant and variable feeding was obtained, on the caliber of the particles, productivity and power consumed. Subsequently, in this chopper modified from the results obtained, the technological and exploitation indicators were evaluated and compared, with respect to the Brazilian chopper JF-50,

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in the production conditions of the livestock entities of the Institute of Animal Science (ICA), according to Valdés *et al.* (2015. 2017), obtaining positive results in favor of the chopper of national origin. However, despite having advanced in this direction, there are still reserves for the improvement of these chopping machines, due to the beating of the air generated by the rotor (chopping drum) during its rotational movement (in vacuum) and the interaction of the blades with the stems of the material to be processed and with the particles after cutting (under load), which creates fluctuations in the expulsion of these particles to the outside through the discharge tower. That can be simulated with the application of advanced computational tools, such as Computational Fluid Dynamics (CFD), for its possible improvement.

The development of advanced CAD systems has allowed increasing the fields of application of Simulation Engineering and especially Computational Fluid Dynamics (CFD). This method constitutes one of the branches of fluid mechanics that uses numerical methods and algorithms to solve and analyze problems about fluid flow. The fact that CFDs were developed later than other DACs, such as those used for thermal stress analysis, it is due to the inherent difficulties that arise in the equations that describe the flow of fluids. Today, with the enormous possibilities of computers and the development of numerical methods, CFD is becoming a very practical and efficient tool for the analysis of situations in which fluids are involved and therefore, an invaluable tool for analysis and design, according to Fujun (2004).

At the national and international level, multiple investigations related to CFD have been developed, among which those carried out by Toneva *et al.* (2011); Chuanzhong *et al.* (2012); Lisowski *et al.* (2012). They carry out the development a hammer mill with sieving devices or screens; the characterization of the flow in a phase, during milling in an air sorting mill; the movement of the chopped material in the discharge nozzle of the forage harvester with flywheel cutting unit, for measurements with corn and numerical simulation, respectively. In addition, Coussirat *et al.* (2012), performs CFD study of the rotor-stator interaction in a centrifugal pump with diffuser, as well as Lisowski *et al.* (2012) who perform a theoretical and finite element analysis of load losses in a central pivot irrigation system; Salcedo *et al.* (2017), introduce computational fluid dynamics in the analysis of flows in porous medium and García & Rodríguez (2018) evaluate the sedimentation process of discrete particles in turbulent flow.

On the other hand, Herrera *et al.* (2006; 2012; 2013; 2014; 2015); Endalew *et al.* (2010), carry out research on modeling and simulation using the computational flow dynamics of the air stream of a sprayer, analyzing the effect of wind speed on the performance of agricultural fan sprayers. They also perform analysis of the aerodynamics of the fan in the ASS-800 sprayer used in fruit trees.

In the research mentioned, there are no studies related to the object of study. Therefore, the objective is to perform CFD simulation of the discharge tower of a forage chopping machine, using the SOLIDWORKS tool to perfect its design. It is associated with the research project entitled: Development of a module of machines for the production of animal feed from different crops, code: P131LH002 - 068, approved in the National Animal Feed Program.

MATERIALS AND METHODS

Figure 1 shows the three-dimensional model of the original forage chopper and an isometric view of its digitization, using the three-dimensional design program, in this case SOLIDWORKS 2017. Figure 1(a), shows a view of the original model of the fodder chopper, complete and figure 1 (b), shows the model of the discharge tower.

Figure 2 shows the geometric (Figure 2a) and physical (Figure 2b) characteristics of the particles that were incorporated into the three-dimensional model of the discharge tower. The minimum necessary force required by the particle for its drag is in the order of 0.0195 N, obtained from the mass known according to the program. Figure 3 shows the two three-dimensional models of the discharge tower, figure 3a), without particles and figure 3b), with particles. They were distributed through three different planes of irregular shape, along the interior of the discharge tower of the forage chopper, with the aim of making a simulation as close as possible to reality.

Figure 4 presents the four zones or regions for determining the average downforce exerted by the fluid on the particles (zone 1, 2, 3 and 4) in the YZ plane, starting at the bottom and along the cross-section of the discharge tower.

Figure 5 presents an isometric view of the computational domain and detail of the refinement of the meshing at the fluid-solid interface, of the three-dimensional model of the discharge tower. Two types of refinements were made 1: on the side and bottom of the tower and 2: on the back and front of the tower.

Figure 6 presents the boundary conditions imposed on the three-dimensional model for CFD analysis. The parameters introduced to the program were: a theoretically estimated speed of 30 m/s, according to Valdés (2008), at the outlet of the chopping organ, obtaining a volumetric flow at the inlet of the tower of 0.561 m^3/s; an atmospheric pressure of 103,325*10^3 Pa, introduced at the outlet of the discharge tower, and a surface roughness of the interior of the tower that was declared in 3 microns.

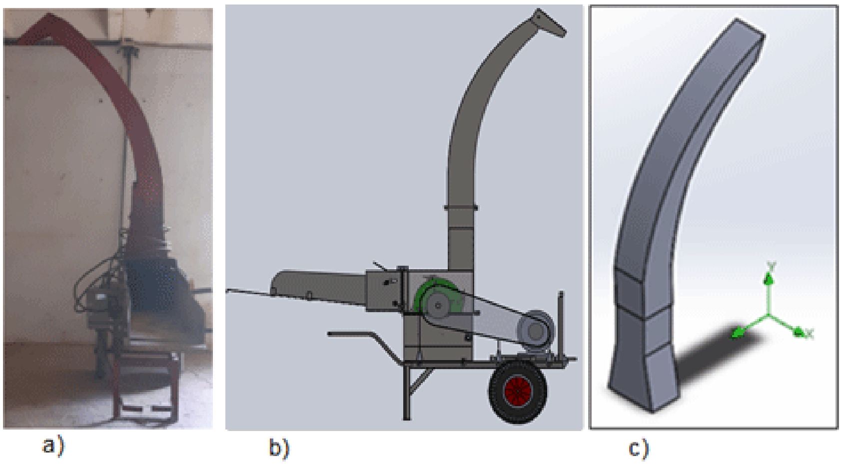

Figure 1. Three-dimensional model of the forage chopper. (a) Original chopper; b) Digitized chopper and c) Discharge tower.

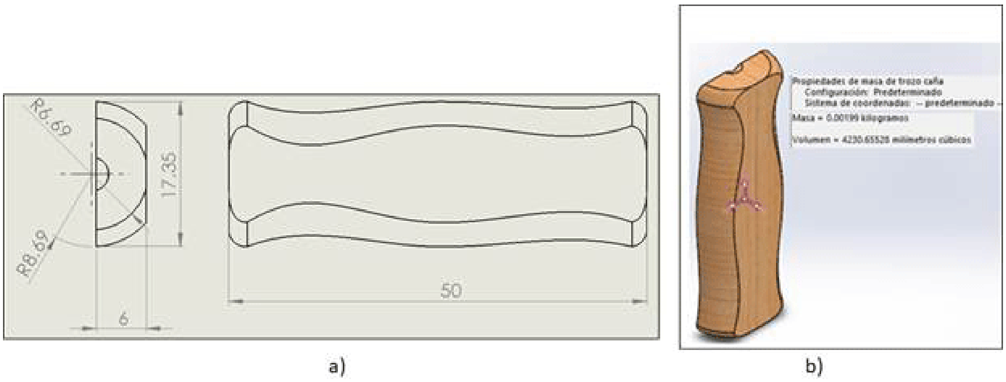

Figure 2. Three-dimensional model of the particle used in the simulation, a) geometric characteristics; (b) physical characteristics.

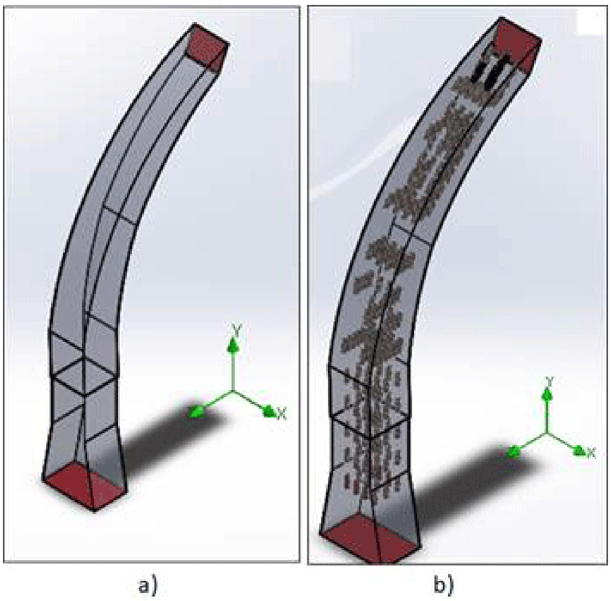

Figure 3. Translucent view of the discharge tower for CFD analysis, a) without the presence of particles and b) with particles.

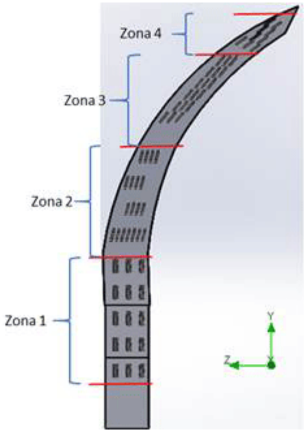

Figure 4. Regions to determine the average downforce of the fluid on the particles, along the cross-section of the discharge tower, YZ plane.

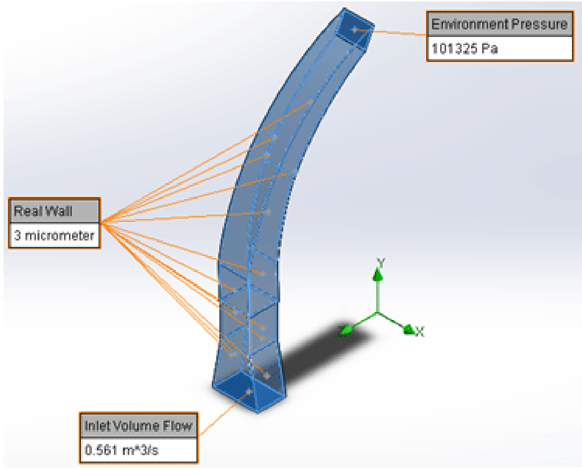

Figure 6. Boundary conditions imposed on the three-dimensional model for analysis.

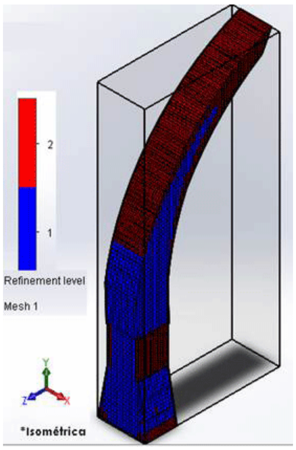

Figure 5. Computational mastery and detail of the refinement of the meshing in the interface of the fluid-solid of the discharge tower.

Figure 7 presents the convergence of the project goals and number of iterations achieved during the CFD analysis, with the presence of particles in the fluid, observing that with the number of iterations performed, the appropriate convergence of the project goals is presented, which allows guaranteeing a reliability in the results obtained.

RESULTS AND DISCUSSION

Figure 8 presents the results of the distribution of the air pressure profile in three planes inside the discharge tower, a) without the presence of particles and b) with particles. Similar pressure values are obtained for both models analyzed, ranging between 101,325 and 103,811*10^3 Pa, for a difference of 2,486.21 Pa, with respect to the inlet and outlet of the discharge tower, respectively.

Figure 9 presents the results of the distribution of the air velocity profile in three planes inside the discharge tower, a) without the presence of particles and b) with particles. Similar speed values are obtained for both models analyzed, ranging from 9.5 to 50 m/s, for a difference of 40.5 m/s, with respect to the input and output of the discharge tower, respectively.

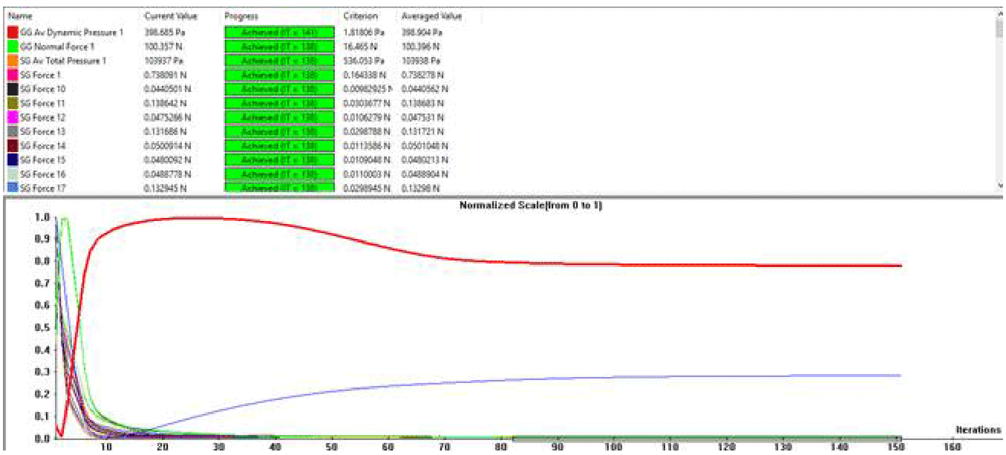

Figure 7. Convergence of project goals and number of iterations achieved during CFD analysis, with the presence of particles in the fluid.

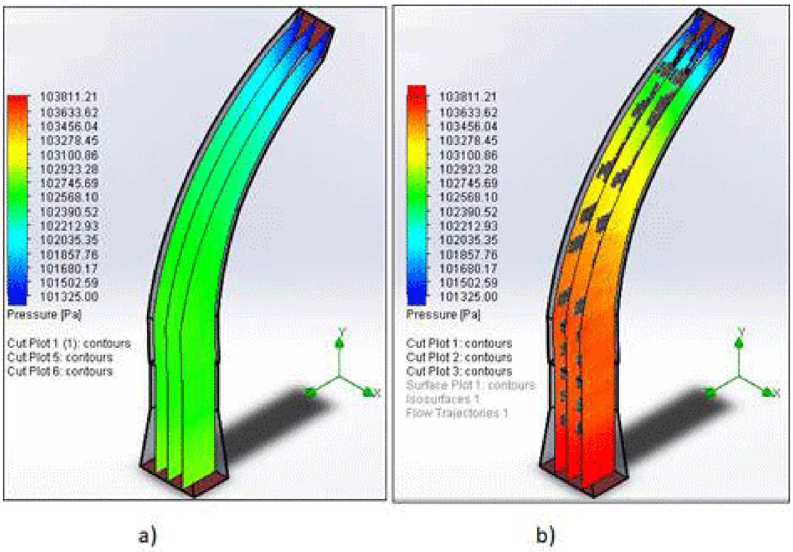

Figure 8. Distribution of the air pressure profile in three planes inside the discharge tower, a) without the presence of particles and b) with particles.

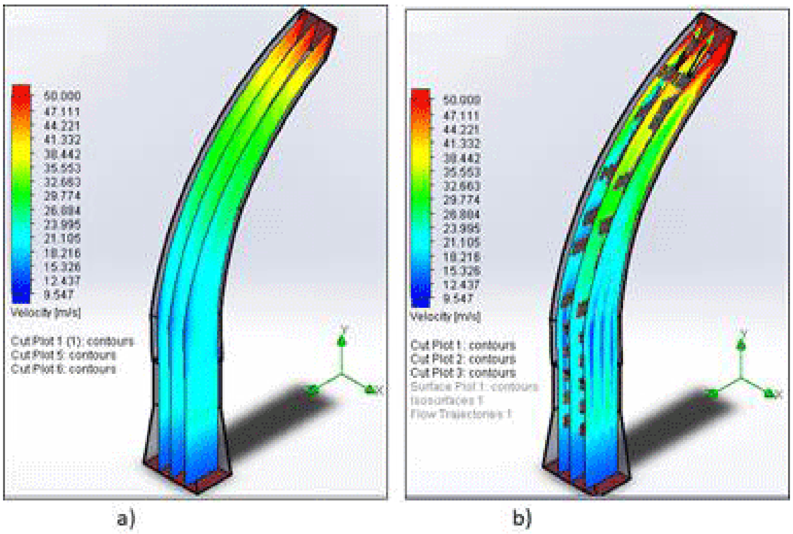

Figure 9. Distribution of the air velocity field in three planes inside the discharge tower, a) without the presence of particles and b) with particles.

On the other hand, in Figure 10, the behavior of the turbulence intensity is presented in three planes inside the discharge tower, a) without the presence of particles and b) with particles. The values obtained show a similar turbulence for both models analyzed, but a greater number of regions with turbulence in this tower are appreciated, for the model with particles.

Finally, in Table 1, the results of the calculation of the average aerodynamic force of the fluid on each of the particles in each zone are presented. The average values of this force, in the four areas studied, exceed the minimum necessary force required by the particle for its dragging (0,0195 N), with a difference of 0,8635 N for the case of the value of the lowest force obtained in zone 1, which makes it possible to expel it by the outlet of the discharge tower.

CONCLUSIONS

- The results show that similar average speed values are obtained both at the inlet and at the outlet in the order of 9,54 - 50 m/s for the case of without and with particles, so it is possible to perform the simulation of the fluid by CFD, the same without particles as with particles.
- In the generated pressure values, a slight difference of 1 041,16 Pa can be seen at the tower inlet, which is not manifested at the tower outlet, but a decrease of 1 466,33 - 2 508, 22 Pa with respect to the inlet pressure, comparing both cases without and with the presence of particles respectively, mainly due to the decrease in its cross section, which generates an increase in the velocity of the fluid at the outlet of

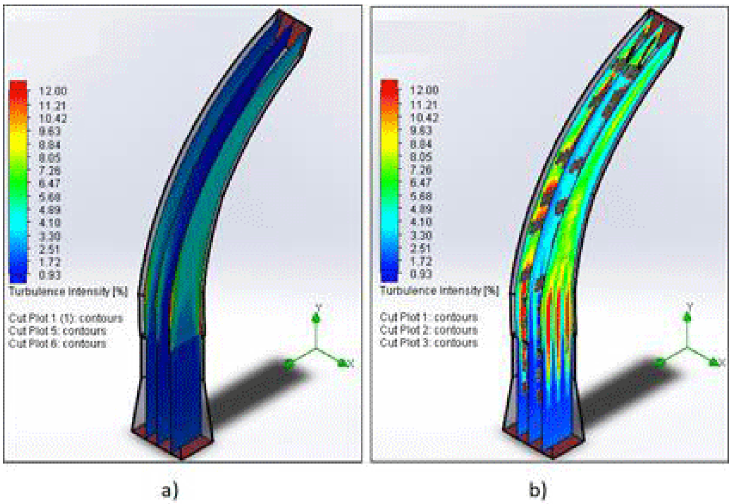

Figure 10. Behavior of the turbulence intensity in three planes inside the discharge tower, a) without the presence of particles; (b) with particles.

Table 1. Results of the calculation of the average aerodynamic force of the fluid on each of the particles in each zone.

	Average force, N			
Zone	**Resultant**	**Component X**	**Component Y**	**Component Z**
Zone 1	0,883	0,018	0,883	- 0,007
Zone 2	1,792	- 0,009	1,284	- 1,250
Zone 3	2,779	0,019	0,940	- 2,615
Zone 4	3,759	0,112	0,228	- 3,750

the tower, in correspondence with the principle of conservation of energy.

- The average values of the aerodynamic force, in the four areas studied, exceed the minimum necessary force required by the particle for its dragging (0,0195 N), with a difference of 0,8635 N for the case of the value of the lowest force obtained in zone 1, which makes it possible to expel it by the outlet of the discharge tower;
- With the CFD simulation carried out of the discharge tower of the forage chopper, object of study, the necessary parameters are obtained for the improvement of its design.

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