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Applications of CFD Techniques in the Design of Fabric Filters

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Analyzing the gas flow inside a bag filter experimentally is a difficult challenge to overcome, since the complexity of the highly three-dimensional flow hinders any form of directly measuring the flow. In recent years, the increasing availability of computational resources together with the increasing accuracy of numerical methods built up techniques that describe the flow of fluids in industrial equipments through mathematical modelling and numerical simulations. Among these techniques, Computational Fluid Dynamics (CFD) is noteworthy regarding the design of new equipment, since it uses experimental data in their simulations. In this work, the CFD techniques are applied to investigate the best position for feeding the dirty gas in a filter bag, in order to support the search for a more efficient and durable equipment design. To evaluate the filter bag performance, two different inlet positions were simulated. The first, called "conventional", with gas jet reaching the bags in the centre and the second with concentric triple feed (called "triple"), in which the same gas flow rate is fed by in three regions roughly in the top, center, and bottom of the filter medium. The aim was to determine which design has improved uniformity of mass flow distribution between the bags and lower the equipment pressure drop, in order to increase the filter lifetime. For this purpose, it was used the isothermal and incompressible single phase flow model with turbulence being treated by realizable k-ε model. It was concluded that the "triple" showed a better gas distribution to be filtered among the bags system, thus representing a more advantageous layout option when compared to "conventional".

1. Introduction

Among the equipment used for dry particulate material separation, whether for air pollution control or for the recovery of raw materials with high added value, the fabric filter, in the industry, is the most used. The working principle of this device is simple: dirty gas is fed into the system and passes through the set of bags, in which the particles are adhered to bags by various filtering mechanisms and the clean gas flows through the bags and then released to the atmosphere.

When properly sized, bag filters have high collection efficiencies up to 99 % for a wide particle size range. The satisfactory device performance for a particular application depends on the proper material selection used in the bag construction, the cleaning mechanism and collector geometry design (Martins, 2001).

The overall pressure bag filter drop is one of the most important operating variables, since it is responsible for determining the moment that bags cleaning should occur. Therefore, the overall system pressure drop is directly related to the number of cleaning stops and, indirectly, the useful bags lifetime.

Rocha et al. (2010) studied, using numerical simulations, the effect of the gas intake position in the flowfield, within a two-dimensional filter box with 13 bags. The authors concluded that the inlet position interferes in overall pressure drop and at the mass flow distribution of the gas to be filtered among the bags. Damian (2003) showed through simulations using CFD techniques in the "conventional" feeding design the appearance of high speed regions and bags located in these areas exhibit premature wear when compared to other filter regions.

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In this context, the search for designs of bag filters which are more economical makes designers seek to build equipment that presents better distribution of the gas mass flow and lower pressure drops, to increase the bags lifetime.
Thus, in this work it was used the Computational Fluid Dynamics (CFD) techniques to evaluate the dynamics of a isothermal incompressible single-phase flow inside a bag filter for two different positions of the gas feed. For this purpose, it was simulated the “conventional” inlet design, with a single gas jet hitting the bags perpendicular and the “triple” feed, in which a triple gas jet also hits the bags perpendicularly, both with the same flow rate.

2. Methodology

The development of this work was based on four step methodology: geometry building and discretization, boundary conditions and physical properties definitions, solving and post processing the results. The geometry used was based on an industrial bag filter from PANAN (furniture maker) located at city of Linhares, Brazil. Its dimensions are: 5.3 m high; 1.8 m deep; 2.0 m wide. It was used a 49 bags set to promote a geometry simplification and thus a less element mesh. It is important to say that the same filtration area (75 m^2) was enforced. The bags dimensions were 0.3 m in diameter and 3.0 m high (Figure 1).

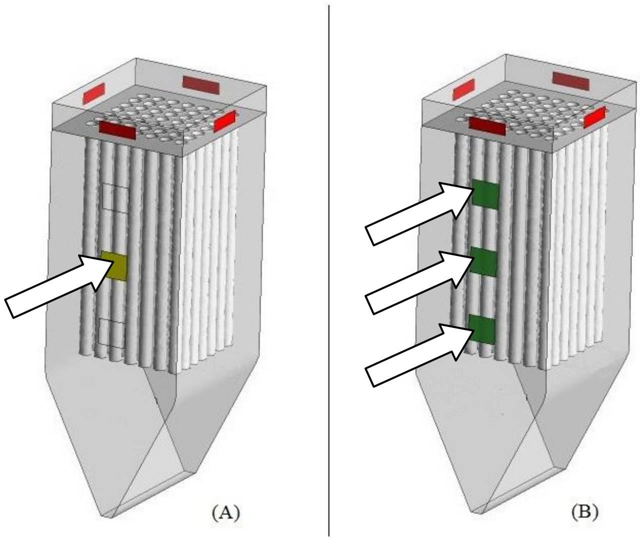

Figure 1: Filter bag geometry used in simulations

Figure 1 shows the details of filter internals. The arrows indicate gas feed (“A” indicate the “conventional design and “B” the triple inlet). The exits are arranged at slots on the filter top. The cylinders in the middle of the geometry are the bags which are represented in the simulation by porous thin walls, responsible for the pressure drop.
The volume of gas flow was discretized using an unstructured mesh approach. To secure mesh independent results a grid independence study was conducted using as monitored variables the mean velocity and pressure over the bags. The study conclusion reported a 527.609 elements for optimal discretization scheme.
The fluid used was the air with fixed density (1.225 kg/m^3) and dynamic viscosity (1.789×10^{-5} Pa s). At the inlet, a uniform velocity profile of 22.84 m/s was imposed for the “conventional” design. For the “triple inlet” design, this value was divided by three. The bags (porous jump) properties were the thickness of 0.0025 m and permeability of 5.87×10^{-10} m^2.
The commercial code ANSYS Fluent v13.0 was used in the simulations. It is based on the Finite Volume Method (Versteeg and Malalasekera, 2007) to discretize the governing equations (Navier-Stokes and Continuity equations). The fluid flow was modelled using the URANS (Unsteady Reynolds Averaged Navier-Stokes) approach. In this approach the equations are averaged over a period of time and then the terms concerning the fluctuation of flow (turbulence) are closed with a turbulence model (Wilcox, 1998). The turbulence model employed was the realizable k-ε which has been proving its robustness and accuracy in rotational flows (Rocha, 2010).

The use of unsteady version of RANS was due to convergence difficulties with steady state solution. The reason is probably concerned to high frequency fluctuations of the gas jet at inlet. The simulations were conducted through a suitable time to reach the flow steady state. In this case, 15 s suited for all simulations. The chosen time step was 0.002 s, being defined using a fraction of residence time and calibrated by iterative process stability.
Governing equations were solved using SIMPLE algorithm (Patankar and Spalding, 1972) to the pressure-velocity coupling. Second order advection schemes (Second Order Upwind) – (Barth and Jespersen, 1989) were used in all equations but the turbulence model due to equations nature of this model (Fluent, 2011).

3. Results and discussions

One of the main problems of the industrial filtering is the bags premature wear. The excessive wear usually forces maintenance stops. For this reason, researchers are compelled to investigate way to mitigate this problem. A recent alternative is the use of numerical simulations where it is possible to test new designs easily and reliably (Rocha et. al., 2009). Variables like velocity, pressure and mass flux are extremely important to check the performance of existing or new layout. These parameters are keys to understand the bags wear. In the search for better performance it is important that the mass flow distribution, velocity and pressure over the bags be as uniform as possible. In other words, to look for designs that presents low maximum values of these variables. Figure 2 shows the transient behaviour of the mean pressure and velocity over the bags.

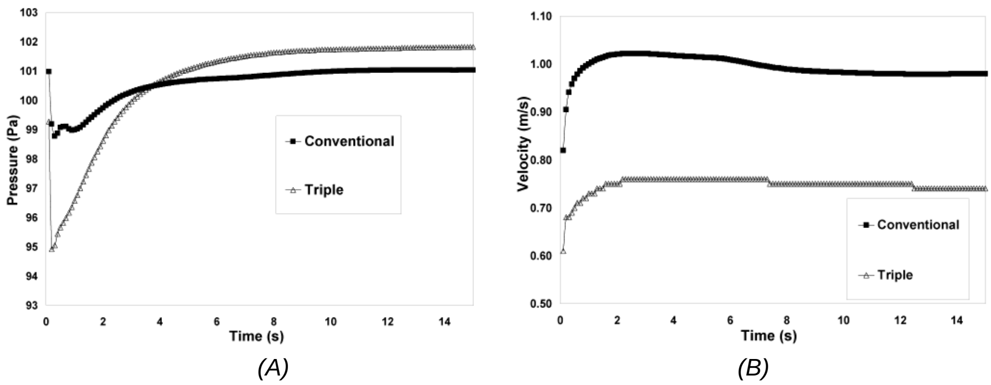

Figure 2: Averages pressure (A) and velocity (B) over the bags

3.1 Fluid dynamics of the gas

Figure 3 shows the gas flow streamlines after reaching steady state (15 s flow time) to the conventional (A) and triple inlet (B). The flow pattern in the conventional geometry showed a preferential scattering of trajectories in the vertical direction, which may have been caused by the strong impact of concentrated stream from the first row of bags. A better distribution of gas flow streamlines among the bags occurs at “triple inlet” as the initial impact of the gas flow is less intense.

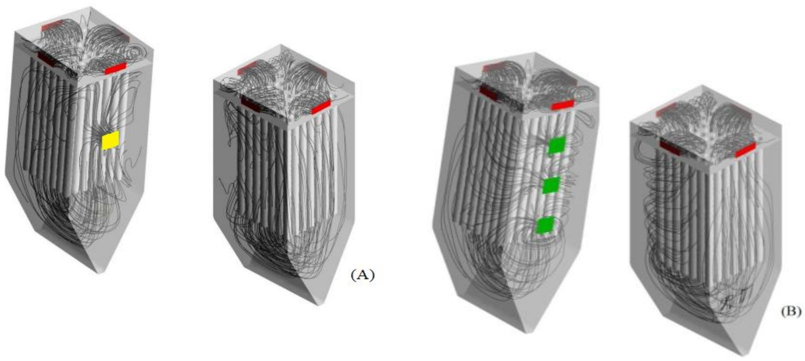

Figure 3: Streamlines of the flow in steady state: (A) Conventional and (B) Triple inlet

3.2 Velocity

Tanabe (2008) has investigated the relationship between the filtration velocity profile and the filter cake (the thickness of particles settled over the bag surface), he, concluded that for higher filtration velocities there is an increase: at the filter cake, at the diameter and the collected particles inside the filter medium. Decreasing the filtration time in subsequent cycles and increasing the pressure drop, the filtration system would reach the pre-established overall pressure drop more quickly, increasing the number of cleaning shutdowns (Rodrigues, 2004). However, the velocity influence on the filtration time only occurs until the filter media clogging Martins (2001). Considering the previous issues, it was possible to evaluate among the two studied layouts, which one has a better performance related to the filtration velocities profile Figure 4 outstands that the triple inlet (4b) has greater velocity dispersion over the bags; it is noticed that the filtration area achieved with velocities greater than 4.6 m/s is lower when compared to conventional inlet (4a).

High values in the filtration velocity result in small filtration time, but increase the particles penetration in the filter tissue, difficult the filter cake removal during the cleaning process. Other aspect is the pressure drop increase, which reduces the real-time the filtration cycle, elevating the number of cleanings that the bag is subjected; and consequently influences the bag lifetime. This lifetime may be lower due to the structural stress applied to the bags during cleaning process, regardless the mechanism.

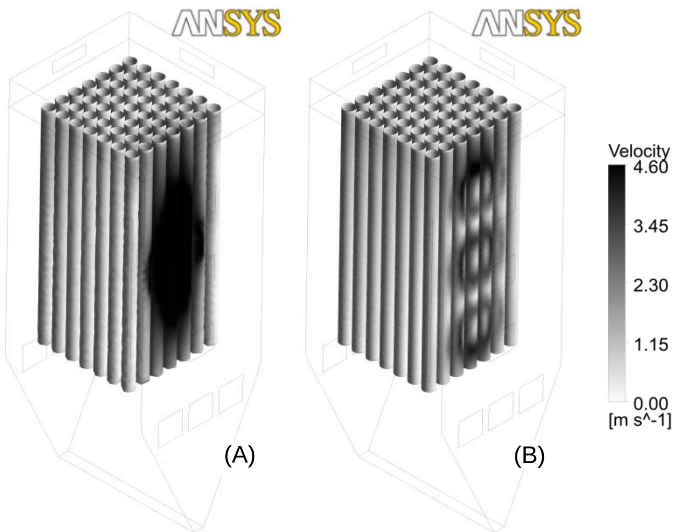

Figure 4: Velocities over the bags surface: conventional (A) and triple inlet (B) layout

Therefore, the velocity at the conventional inlet can provide a greater difficulty in the filter cake removal and even could cause the bag rip due to the high speed, resulting in a shortened filter media lifetime. In triple inlet layout, the gas velocity inside the bag filter is much smaller than the conventional inlet lowering the particle penetration in the filter media, which will provide greater ease of removal of the filter cake during cleaning process can extend the bags lifetime.

3.3 Pressure

The Figure 5 shows the bags pressure distribution in different inlets. The largest scatter in the static pressure distribution and lower pressure drop at triple inlet is an indication that the filtration time will be higher resulting in reduced number of stops, since the conventional input generates a highly localized gas flow, which may lead to misinterpretations, causing premature stoppage for cleaning of the filtration system.

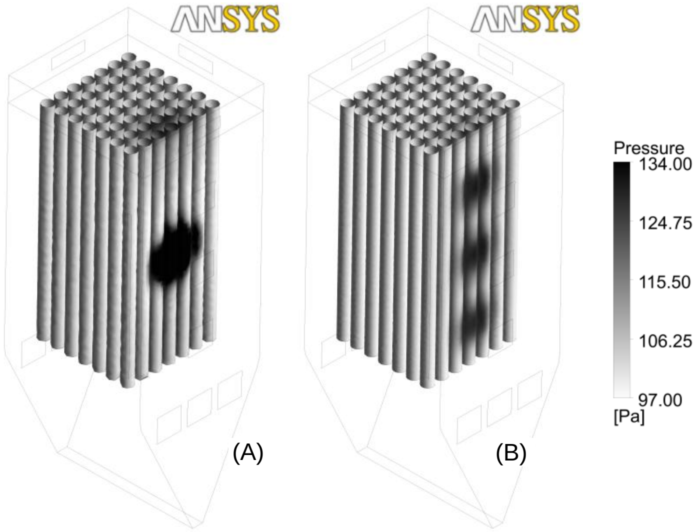

Figure 5: Static pressure in the bags: (A) conventional and (B) triple inlet

3.4 Mass flow

In order to compare the performance of conventional and triple inlet, the Figure 6 show the mass flow distribution across the filter media. This information is directly related to the filtration efficiency. The best mass flow distribution, a lower pressure drop and a lower filtration velocity indicate that the “triple inlet” may perform better, a longer service life for the bags and reducing the number of stops for cleaning, because, due to repetitive movement of the cleaning mechanisms applied, is a decrease in the elasticity of cloth, may cause disruptions in the bags. Therefore, this layout “triple inlet” leads a longer service life for the bags, which are the most expensive elements of filtration systems (Figure 6).

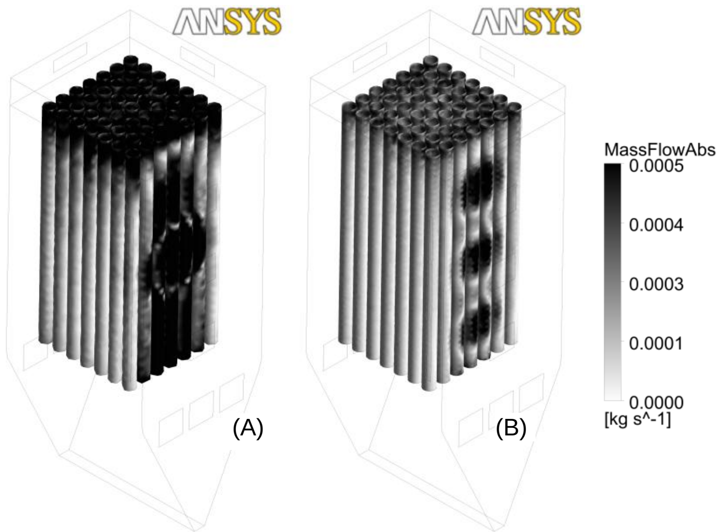

Figure 6: Mass Flow distribution over the bags: conventional (A) and triple inlet (B)

In the following Table 1, presents data filtration efficiency. The filtration efficiency is calculated as the ratio between the area of the filter medium where the filtration is effective (greater than zero flow mass) over the entire area of the filter medium.

The triple inlet geometry outstand a higher efficiency. Confirming the results of the qualitative analysis showed that a better distribution of gas load over the filter medium. This is indicative suggests that the abrasion, as discussed, is lower in that geometry.

Table 1: Comparison of results for area and filtration efficiency

Inlet Geometry	Filtration Area [m²]	Filtration Efficiency [%]
“Conventional”	58.9	78.5
“Triple inlet”	65.6	87.4

4. Conclusions

The results obtained by CFD technique provided a qualitative and quantitative analysis of the influence of the gas inlet on the fabric filter performance. The suggested layout of triple gas inlet showed more uniform distribution of mass flow, velocity and pressure over the filtration area when compared to the conventional configuration at the same operating conditions. Also the suggested layout presented lower filtration velocity and reduced pressure drop in the system. Thus, the results indicated that, under the point of view analysed, the “triple inlet” could provide a longer service life for the bags, resulting in fewer stoppages for cleaning, providing savings for the industry, since the bags replacement are the higher cost of the installed equipment.

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