Carbon Canister: technology, applications, development, validation

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ABSTRACT

Emissions laws are becoming more stringent aiming to protecting the environment and people, it leads to dictate the velocity of the development of technologies used in vehicles. In vehicles with internal combustion engines, the gases that are generated from the fuel tank must be properly treated so that they are not released directly into the atmosphere due to their toxic and polluting effect. The canister is then the component responsible for this filtering task through the adsorption of the volatile components of the fuel for their subsequent desorption for burning in the engine combustion chamber during the canister purging process. The objective of this work is to present carbon canister technologies and its applications. A detailing of the development process for this type of product, from the initial concept until the validation, as well as the modern technologies used in the development of carbon canister, such as structural computational modeling for evaluating mechanical strength, evaluation of the gas flow and the pressure losses through computational fluid mechanics and the experimental validation of the product.

INTRODUCTION

When it comes to vehicular pollution, the first system remembered is the engine and consequently the emissions through the exhaust of the vehicle. However, when it comes to vehicular pollution, it is possible to mention, in a simplified way, two main categories:

1- Gas emissions from the burning of fuel in the combustion chamber;

2- Evaporative emissions.

Evaporative emissions occurs during the operation of the vehicle, like gas emissions from fuel burning, but also and mainly it occurs during the period when the vehicle is with the engine off and/or during the filling of the fuel tank.

In the category of evaporative emissions there are several sources that contribute to the overall emission of the vehicle, either through the permeability of the components in contact with fuel (fuel tank, fuel lines, connectors, fuel filter and canister) or through openings that allow the evaporation of the fuel directly into the atmosphere as the vehicle's air intake system, fuel tank vent (canister) and fuel tank filling nozzle. In this work will be specifically addressed the evaporative emissions emitted through the canister vent both during the diurnal emissions cycle, with the vehicle off, and during the refueling of the vehicle's fuel tank.

In addition to the reduction of hydrocarbon emissions, the main function of the canister already mentioned above, the most recent legislations also require secondary functions such as the on-board diagnosis, which is a leak test of the system composed of the fuel tank, canister, purge valve and connections between these components.

This diagnosis is carried out through an electronic component that is usually attached to the canister. Because it is an electronic component that is relatively sensitive to impurities, it needs to be protected by an air filter, which in turn is also usually attached to the canister.

With new components attached to the canister, added to the greater volume of coal needed to meet the tighter levels of evaporative emissions, the canister is becoming an increasingly heavy component so that its mechanical strength, as well as the mechanical strength of its attachment interface to the vehicle become items of great importance during the development of a canister.

CARBON CANISTER DEVELOPMENT PROCESS

During product development in general, it is possible to separate product requirements into durability requirements and performance requirements. Initially addressing the performance question, there are 2 main factors that need to be analyzed and balanced carefully in the development of a canister:

1- Volume and type of coal used, as these influence the hydrocarbon retention capacity of the canister;

2- Loss of load, which is the restriction to the air flow offered by the canister, because it interferes with the regeneration capacity of the canister, which is the desorption of hydrocarbons during the purge process.

These 2 factors are concurrently related so that a large volume of coal brings the benefit of a greater capacity of the canister to retain hydrocarbons, but this greater volume of coal in turn causes an increase in the restriction of the flow of air through the canister resulting in a lower air flow during purging and consequently greater difficulty of the canister to eliminate the adsorbed hydrocarbons.

Since currently the different activated carbon alternatives available for application in canister are widely known and their capacities are well mapped, it is then possible to easily calculate the required volume of coal for a given project through its input data such as, useful volume and total volume of the fuel tank, geometry of the fuel tank, vapour pressure of the fuel used and/or rate of steam generation.

On the other hand, the pressure loss of the canister becomes a very difficult parameter to be calculated since it depends on numerous variables such as diameter and length of the canister connectors, hydraulic diameter and length of the canister coal chambers, properties/permeability of the fleeces and foams used in the retention of the coal, geometry of the internal passages of the canister, among others. Because of this, for the determination of the pressure loss of the canister during the product development phase, it is decided to perform computational analysis.

In the same way that on the side of the performance requirements there is the loss of load of the canister as a complex enough characteristic to require a computational modeling for its analysis, on the side of the durability requirements there is the mechanical resistance that also demands such analyzes after all these masses will be subject to stresses and accelerations throughout the life of the vehicle. As previously mentioned, canisters with large mass and with attached components become components where their own mechanical strength and the strength of the attachment points of the canister in the vehicle are factors of great importance in the definition of the project.

VALIDATION TESTS

After defining the canister and, in possession of physical samples, it is necessary to put the parts to the test, in order to validate all the characteristics calculated and simulated computationally during the development phase.

Two of the most important validation tests for carbon canister are pressure loss test and vibration test, that are detailed in the next two sub-topics. Tests like fixation resistance and natural frequency evaluation are presented in only in the computational modeling. As the focus of the work is the computational analyses, the tests that represent the two analyses carried out in the development of the canister are:

1- Pressure Loss test:

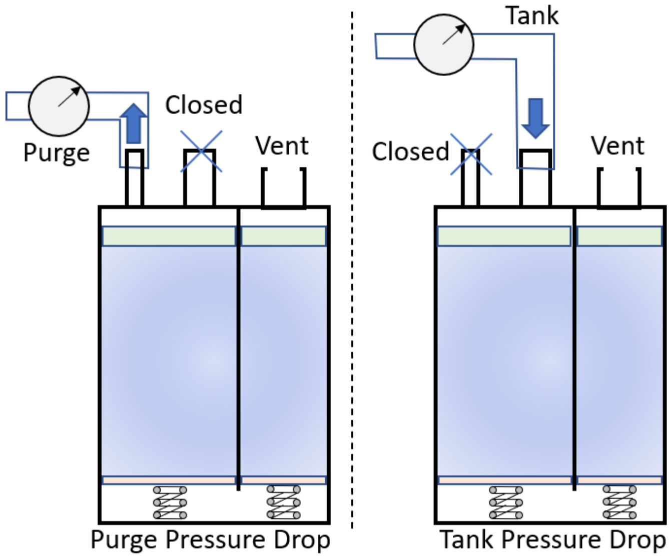

Figure 1. Schematic description of pressure loss test

The a test that is carried out on the cleaning (purging) and loading (tank) connectors in two steps.

During the pressure loss test shown in the figure 1 above, the canister vent is opened to the atmosphere, depending on the flow to be analyzed, one connector is capped and the other connector is connected to the test bench that promotes a known flow of dry atmospheric air at different defined flows, and a manometer displays the difference between the atmospheric pressure and the pressure at the inlet of the analyzed connector. The result presented by the manometer represents the sum of the restriction caused by all permeable components and caused by the geometry of the canister

2- Vibration test

It is a test that aims to simulate the most extreme conditions with the greatest accelerations that the component can be subjected to during its life installed in the vehicle.

The canister, along with all the components that are assembled attached to it, is installed on a vibrating table. Vibration cycles are performed with varying frequencies and accelerations in each of the 3 axes, as illustrated in the scheme in the Figure 2 below.

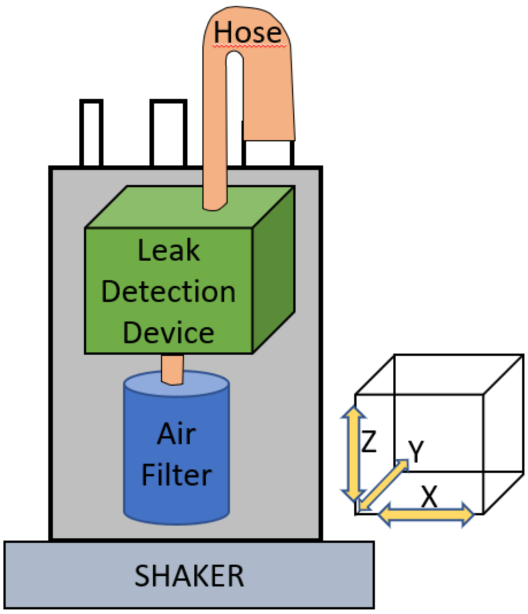

Figure 2. Schematic description of vibration Test

After the 3 vibration cycles are completed, the physical integrity of the canister and the attached components is analyzed, looking for possible mechanical failures, especially in the points that were previously indicated in the computer simulation as being points of greater stress in the part.

In addition to the mechanical resistance, the performance of the part after the vibration test is evaluated, but it is not the focus of this work.

MODELAGEM COMPUTACIONAL

Computational modeling is a powerful numerical tool that can be used to increase the quality, reliability and optimization of components in general, as well as canister. The reduction of product development time also makes the use of numerical simulation indispensable for achieving time-to-market demands. [BATHE-2008].

Numerical simulation is adopted in several stages of development such as: manufacturing process analysis (injection of fiber-reinforced polymer), static structural evaluation (load limit and fatigue tests), dynamic structural analysis (modal and transient) and fluid dynamic analysis (flow evaluation and load losses).

The flowchart in figure 3 below shows the sequence of simulations of a carbon canister made of polymer reinforced with glass fiber, a standard canister design. From the solid three-dimensional model defined in the design stage (CAD model) the simulations of plastic injection, structural simulation and fluid simulation are performed. The pairs of arrows with opposite directions indicate the possibility of altering the initial solid model based on corrections and optimizations of the product based on the results of the models performed. It is important to note that structural simulation can be performed directly based on the initial solid model (modeling with isotropic material) and/or taking into account the results of the injection model such as warping, fiber orientation (modeling with anisotropic constitutive model).

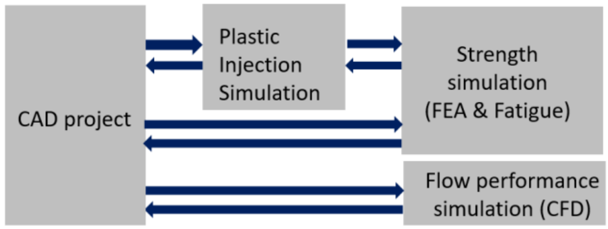

Figure 3. Computational modeling flowchart

The simulation of plastic injection is fundamental to evaluate the complete filling of the mold in an adequate time respecting the real manufacturing conditions as well as minimization of warping, contraction, dispersed voids, cold welds, shear stress, thickness verification, fiber orientation, visual aspects among others. An injection simulation is performed for each mold, as shown in Figure 4 where is possible to observe 2 covers that are injected simultaneously and the housing injection system beside it.

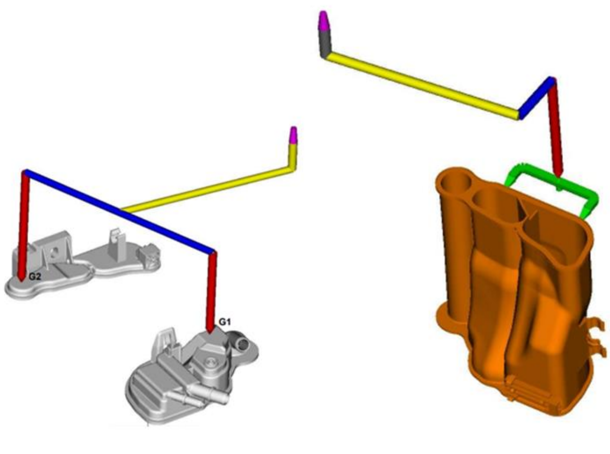

Figure 4. Carbon canister plastic injection system of housing and covers.

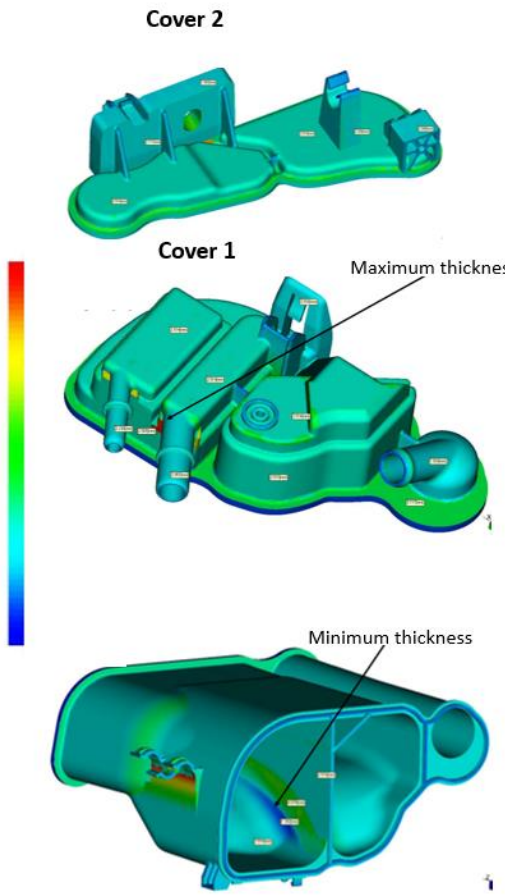

Figure 5. Wall thickness results – plastic injection modeling.

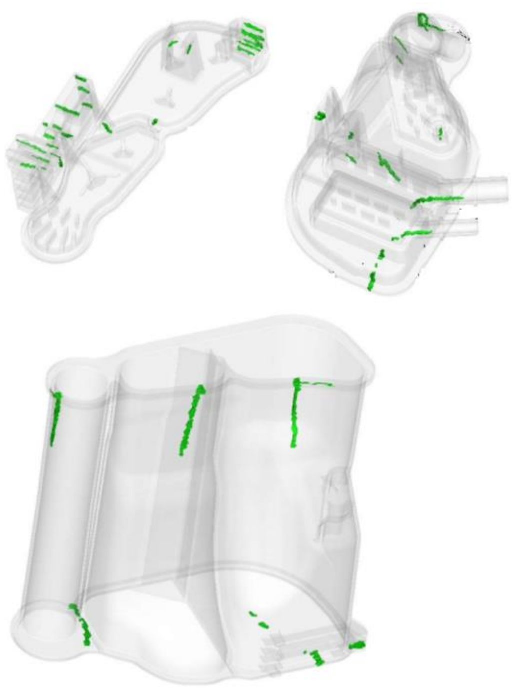

Figure 6. Weld line results–plastic injection modeling.

In Figure 5 are presented the final wall thickness and weld regions in Figure 6, both results are example of important results from injection modeling analysis. Several manufacturing parameters can be optimized aiming to improve the final injected parts such as fiber orientation, warpage and shrinkage for example, which can have relevant effect on component structural performance

It is essential to make structural evaluation of mechanical strength the most severe tests of the validation process of the canister. Usually, the evaluation of resistance of the fixation of the canister when subjected to high deceleration in the 3 directions is one of the most severe tests of structural validation. It is shown in Figure 7 an example of a finite element model evaluating a resistance limit test subjected to maximum acceleration in the 3 directions, in both directions (Figure 8).

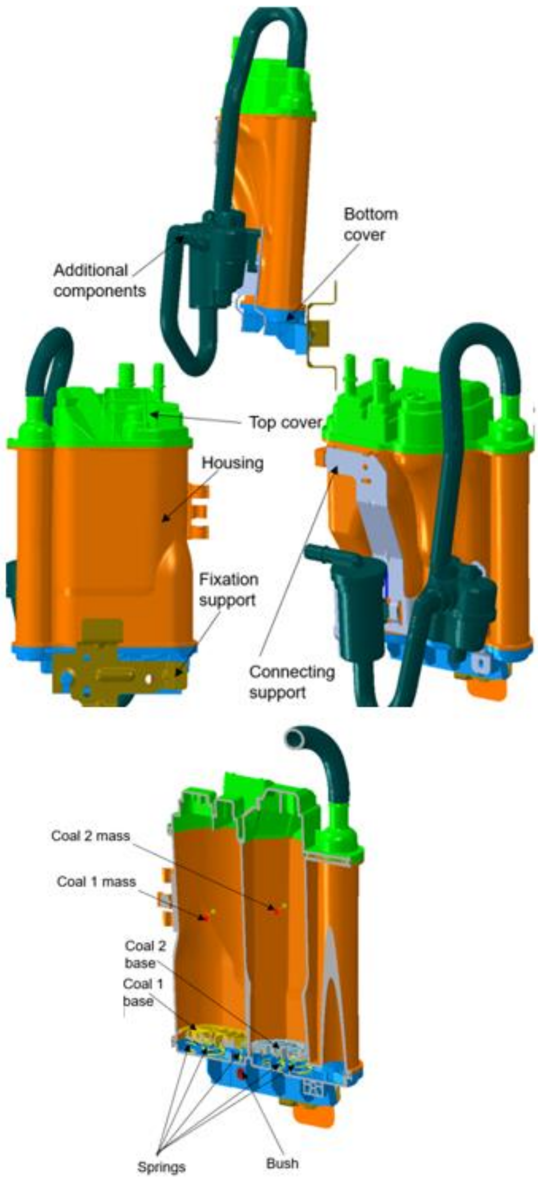

Figure 7. Carbon Canister FEA model.

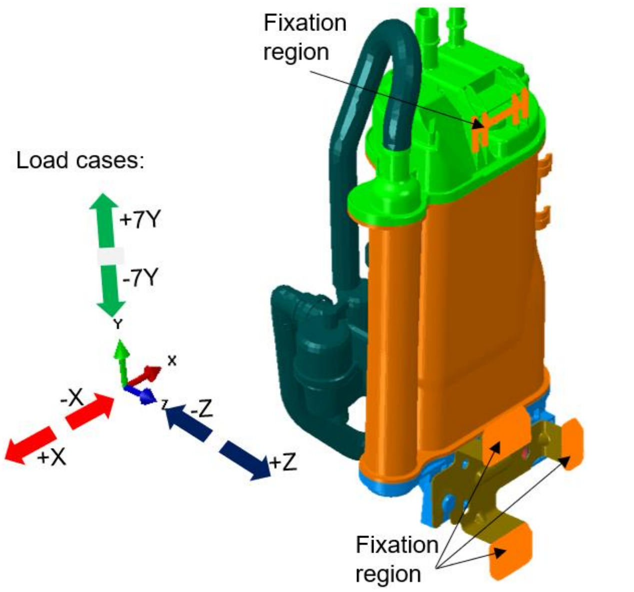

Figure 8. Carbon Canister – FEA boundary conditions

The criterion for the approval of the canister in this type of simulation is the rupture stress of the polymer in the plastic regions and of the steel in the fixation parts of this metal. In Figure 9 it is shown the deformed configuration of the canister assembly under the 6 cases of acceleration load

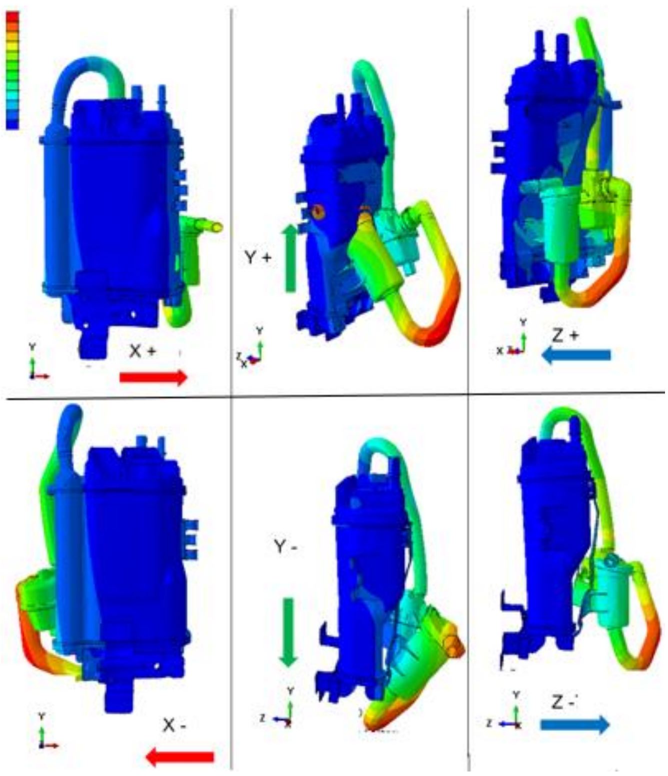

Figure 9. Deformation – 6 load cases (unit: mm – magnification scale 100x).

Figure 10 shows as an example the stresses on the fixation plate of the canister assembly that must be compared with the rupture limit of the material. The same comparison is made for the other pieces of the set.

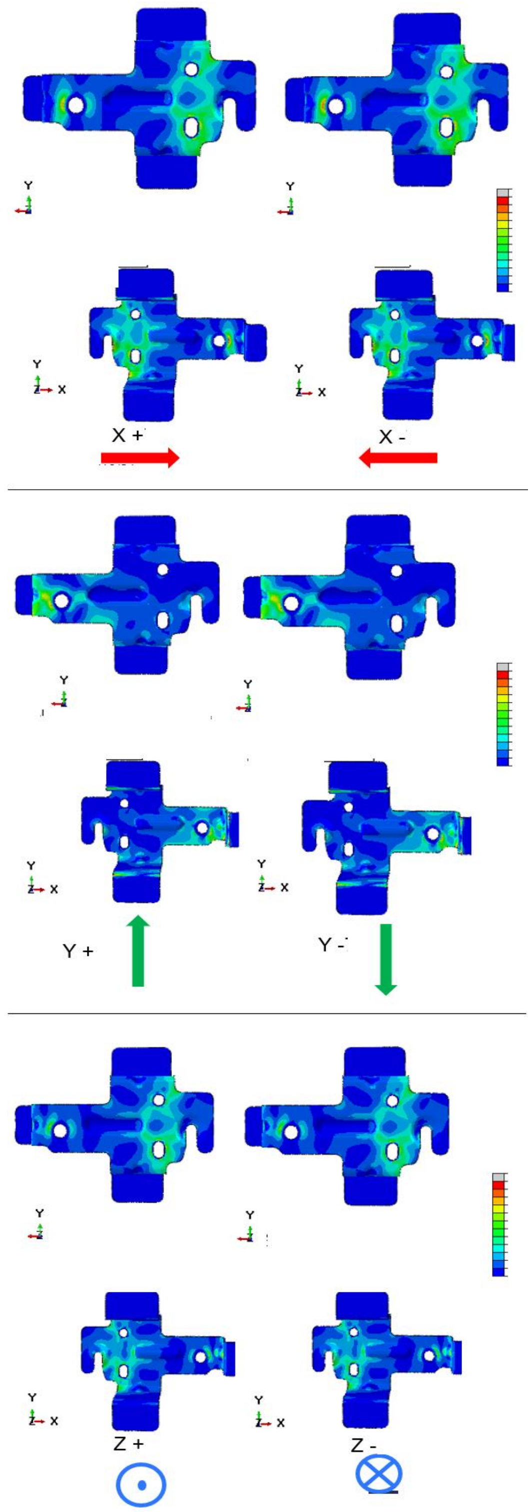

Figure 10. Stress results – 6 load cases (unit: MPa).

Checking the natural frequencies and vibration modes of the assembled canister assembly are also important to avoid potential resonance problems that can lead to structural failure and also noise problems. It is advisable to keep the lowest natural frequency higher than the maximum frequency of excitation to which the vehicle is subjected, considering a minimum safety coefficient. Figure 11 shows the first 3 modes of vibration of the canister used as an example in this work. By checking the regions of greatest deformation in the vibration modes it is possible to identify the regions that should be reinforced if the frequencies reached are undesirable.

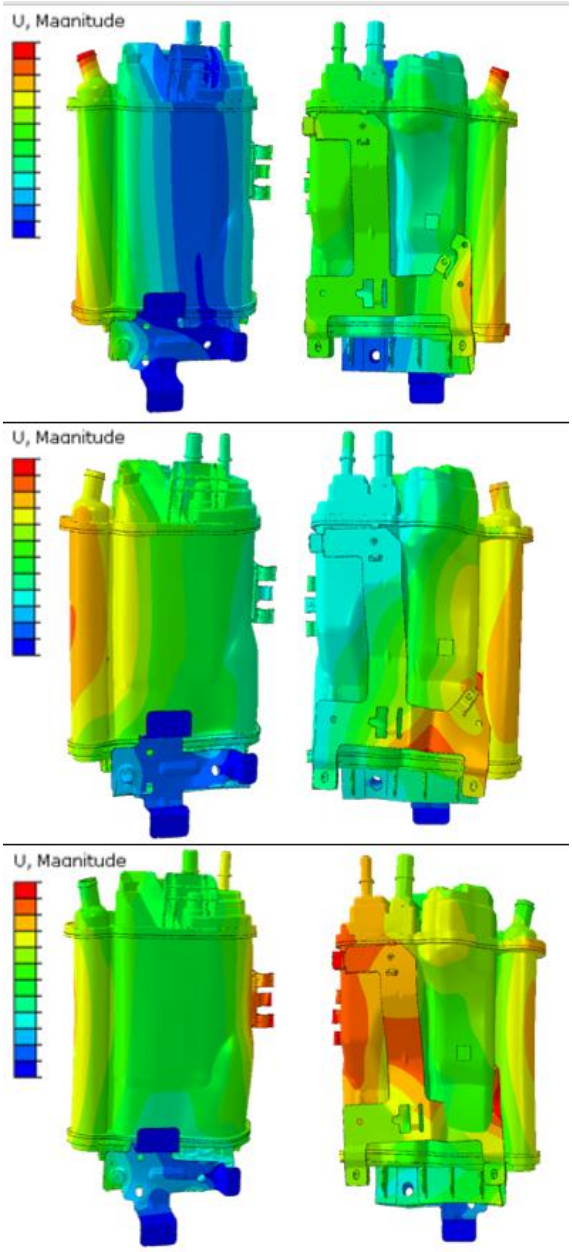

Figure 11. Vibration modes for 3 different natural frequencies.

Verification of canister performance is closely linked to the flow of gases through the chambers. Gas flow simulation can be performed using the computational fluid dynamics (CFD) technique [VERSTEEG, 2007]. The model consists of the chambers (internal volume) traversed by the gases from the entrance to the exit orifice, with coal being considered as a porous medium that must be characterized by its resistance to the passage of gas in relation to the flow. Figure 12 shows a CFD model of a canister for evaluating the performance of the passage of canister gases, indicating the sections where pressure losses are normally monitored. The porous medium constituted by coal is characterized by experimental head loss curves that are raised in experimental tests such as the curve illustrated in Figure 13.

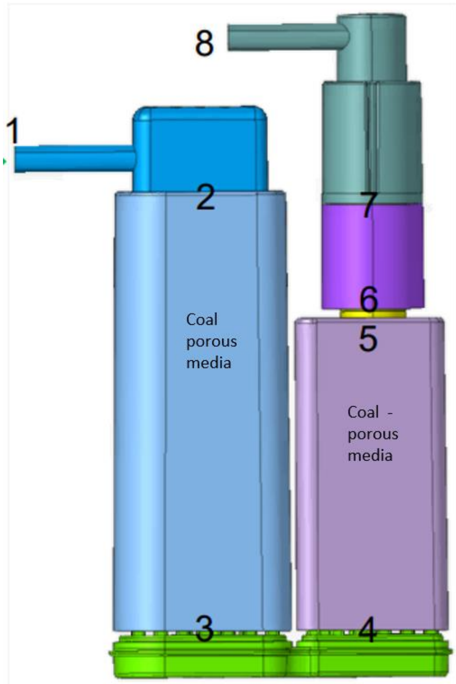

Figure 12. Exemplo de modelo CFD de cânister

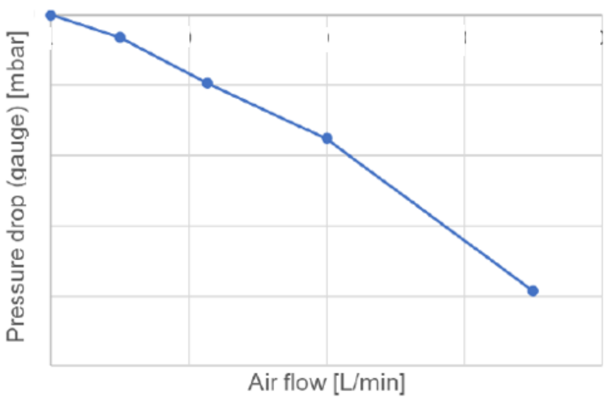

Figure 13. Exemplo de curva de perda no meio poroso

The flow distribution inside the chambers must be evaluated, as shown in Figure 14 and Figure 16 as well as the total pressure drop and the pressure drop in each passage section (Figure 15 and Figure 17), with the main focus being the minimization of the total pressure drop of the model.

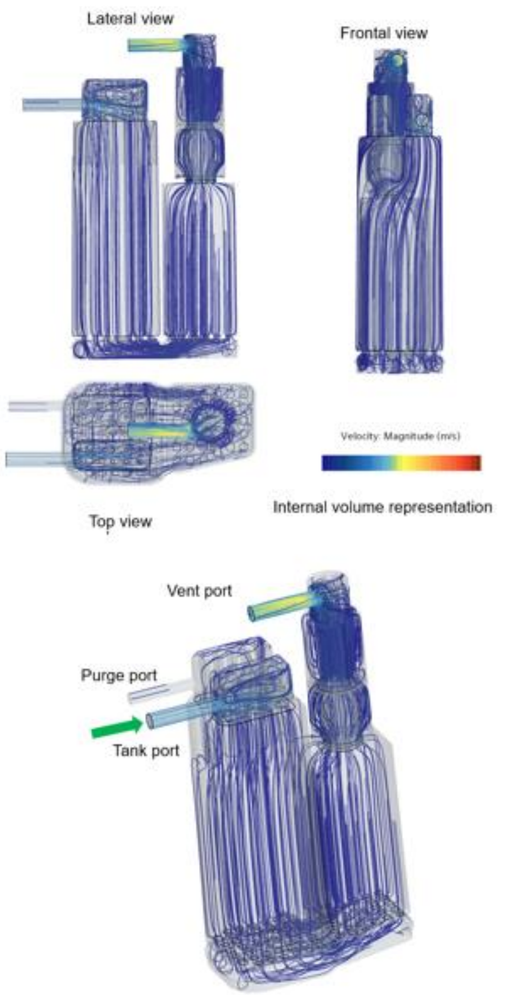

Figure 14. Flow velocity stream lines – tank port open, purge port closed

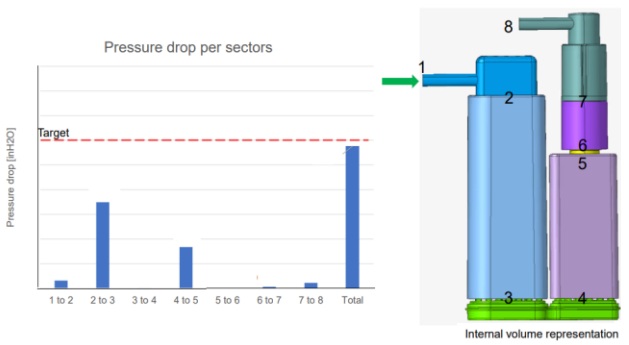

Figure 15. Pressure drop per sectors – tank port open, purge port closed

Based on the results of the gas flow simulations, it is possible to optimize the flow inside the coal chambers, seeking to maximize the volume occupied by the flow and consequently provide better conditions for the reaction of gases and within the volume of coal, as well as avoiding stagnation regions. The concern with pressure drop reduction is also fundamental to ensure that the gas flow within the approval requirements.

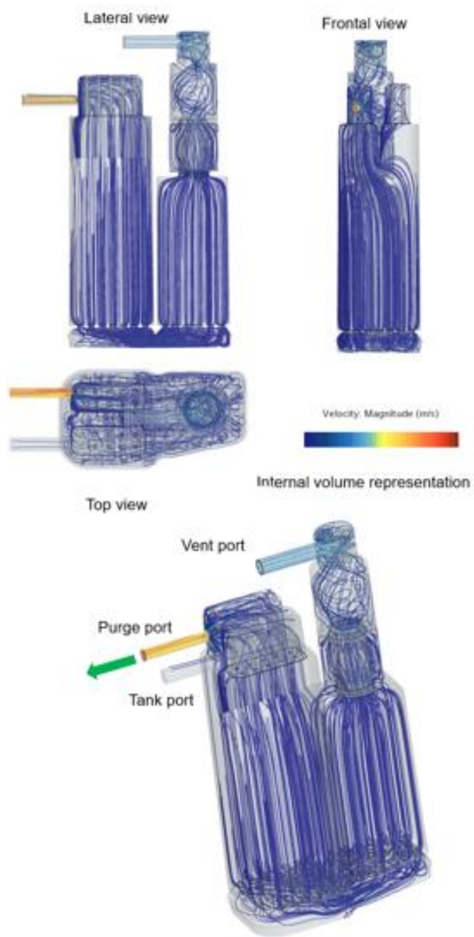

Figure 16. Flow velocity stream lines – Purge port open, tank port closed

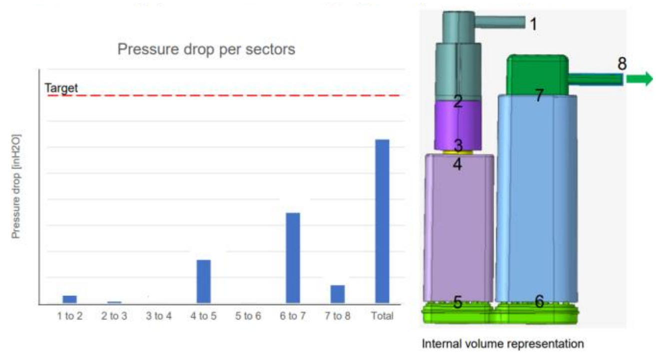

Figure 17. Pressure drop per sectors – Purge port open, tank port closed

CONCLUSIONS

The growing restrictions of legislation in relation to the control of emissions, has substantially increased the demand on the efficiency of components such as canisters due to their responsibility for filtering gases with toxins that are harmful to health and the environment. Within this context, it is essential to develop and to improve filtration technologies, as well as canister safety and durability.

In this work, an overview of the coal canister development process was given, comprising the design and validation stage. Although the final validation of the product through physical tests is essential, computational modeling is a design resource that brings greater precision, assertiveness in design improvement decisions and, mainly, greater agility in product development and consequently cost reduction of the product.

In a dynamic market with more and more requirements to be fulfilled and less time available to carry out product improvement loopings, it is essential to use technologies such as simulation to make it possible to meet project deadlines and costs.

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ABREVIATION

FEA: Finite element Analysis
CFD: Computational Fluid Dynamics